

Review Article

A Review of Animal Fat: A Great Source for Industrial Applications

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ABSTRACT

Animal fats have the potential to be a valuable resource in various fields due to their abundance and renewability. This review is aimed to highlight the potential of animal fats for industrial applications. Despite their versatility, the high levels of unsaturated fatty acids and instability have limited their usage. Chemical modification processes such as epoxidation, esterification, and acetylation are used to enhance stability and expand their applicability in various fields. These modified animal fats offer a sustainable alternative to petroleum-based products with a positive impact on the environment. The usage of animal fats in other industries provides more benefits, including reduced dependence on fossil fuels, savings in foreign currency, and an improved rural economy with increased job opportunities. In addition, the utilization of animal fats in the chemical industry can lead to the development of biodegradable products, which have a positive impact on the environment.



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1. Introduction

Business Wire, a Berkshire Hathaway Company reported on the topic “Animal and Marine Fats and Oils Market by Product Type, Source, Form and Application: Global Opportunity Analysis and Industry Forecast, 2021–2030”.

In 2020, the market size for animal and marine fats and oils was recorded as \$222,335.0 million, and it is projected to grow to \$516,759.3 million by 2030, representing a CAGR of 7.6% from 2021 to 2030. Due to the increase in animal fat production, it is concerning that the amount of waste from

animal fats is also increasing, which can lead to environmental pollution [1]. The use of waste animal fats in the production of various industries other than food industries can suppress the food versus product competition, which can contribute to reduce food prices and avoid food insecurity for vulnerable populations [2]. For example, animal fat, extracted and purified through the Coctio bone broth process, serves as a by-product derived from animal bones. It has versatile applications and can be supplied to the biodiesel industry as a non-edible component for fuel production. In addition, the refined animal fat finds utility in the food, cosmetics, and pharmaceutical sectors [3]. This article highlights the underutilized potential of animal fats, which are considered waste oils, in various industries such as food processing industries (vegetable oil refining residues, spent frying oils, and oil rich by-products) [4], agro-industries (agricultural crops such as oil seeds which generates oil-rich byproducts) [5], animal rendering industries (fat trimming and used cooling oil) [6], and pharmaceutical and cosmetic industries (residues from oil extracts) [7]. The review sheds light on the opportunities for future advancement and creativity in diverse domains, utilizing the results to discover new and innovative applications for raw materials that are considered waste. The article emphasizes the importance of interdisciplinary research in shaping various aspects of society and highlights the significance of animal fat sources, classifications, production cycles, chemistry, potential chemical reactions with fats, available fatty acids, and industrial applications in bringing out eco-friendly products.

Finally, industrial applications of animal fats are of great interest to bring out eco-friendly products which are reviewed with effort. The graphical abstract shown the production, reactions and their applications of the animal fats.

2. Classifying Oils- An Insight into Different Oil Varieties

Oils are mainly extracted from seeds (plants) and fats (animal) sources. Based on their origin, composition, and intended use, oils are

categorized into edible, non-edible, and animal fats [8]. (1) Edible oils, extracted from different plant-based sources, such as fruits, seeds, and nuts, contain essential fatty acids and provide many health benefits. Edible oils are suitable for human consumption. Examples of edible oils include canola oil, coconut oil, vegetable oil, and peanut oil. (2) Non-edible oils from plant sources are not suitable for human consumption as they have a bitter taste, a pungent smell, and are toxic. Examples of non-edible oils include jatropha, castor, and pongamia. (3) Animal fats are derived from animal sources such as tallow, beef, lard, pork, butter, and poultry and are used in baking and cooking.

It is significant to mention that some fats and oils can belong to multiple categories based on their specific application. For instance, lard can be used both as an edible fat for cooking and as a non-edible oil in the manufacture of soap and other products.

3. Livestock into Fat- An Enlightenment into the Animal Fat Production Cycle

The animal fat production process is a complex and multi-step process that is thoroughly explained in the below subsections [8].

3.1. Production of milk fats

Cream and non-fat milk layers are separated from milk using a centrifuge or gravity-based separator, and then cream is churned by hand or using a machine until it becomes solid. This creates friction through high agitation of the cream, which leads to the fat to separating from the buttermilk. The obtained melted fat is called butter fat [9-10].

3.2. Production of rendered oils

The process of rendering animal fats into greaves involves several key phases. Adipose tissues are subjected to the disintegration (shredding, grinding, or milling) process to break down the tissues into smaller pieces, making it easier to extract the oil. These tissues are allowed to melt to release the oil. This process involves heating the tissues to a high temperature, which separates the fat from the

solid materials by melting. Finally, centrifugation or filtration is to separate oil from the solid materials. Separated oil (tallow or lard) is then subjected to a clarification (de-waxing, de-gumming, and de-acidification) process to improve its quality. The leftover solid materials obtained are called Greaves meal. This byproduct can be used in animal feed as a protein source [11].

3.3. Production of fish oils

The production of fish oil from fish typically involves the following steps. The initial stage is to soften the flesh by cooking and remove any unwanted impurities or bacteria. This is often done by steaming or boiling the fish. The next stage is to separate the oil from the fish flesh. This is typically done by pressing the fish flesh to extract the oil or using solvents to dissolve the oil. Once the oil has been separated, it is usually subjected to a clarification process to remove any remaining impurities. This may involve filtering the oil through a series of filters or using centrifugation to separate the oil from any solid particles. The clarified oil is then ready for further processing, such as refinement and bottling [12].

4. Chemistry behind Animal Fats and Oils

The presence of fatty acids within fats and oils triggers various types of reactions. The most common reactions are hydrogenation, ozonolysis, transesterification, epoxidation, oxidation, hydrolysis, and saponification [13]. The detailed chemical reactions are

demonstrated in Figures 1-6. *Hydrogenation* involves the transfer of hydrogen atoms from the H_2 gas to the double bonds in the unsaturated fatty acids. This leads to the formation of single bonds, decreases the number of double bonds, and increases the saturation degree of the fatty acids. The result is a change in the physical and chemical properties of the fatty acids, which converts their phase from liquid oils into solid fats [14]. These hydrogenated fats are used in processed foods to increase the life span and also used instead of frying oil to withstand the heat and can be used longer [15]. Hydrogenated fats contribute to the texture and mouthfeel of processed foods. Trans fats produced during hydrogenation have been linked to increased cardiovascular risks [16]. As an alternative, it is used for the production of precursors in the production of biodiesel and bioplastics in recent years [17].

Ozonolysis is a chemical process that involves the reaction of ozone (O_3) with unsaturated compounds. This process is utilized for various industrial applications, leading to modifications in the chemical structure of compounds and generating value-added products and intermediates. The modifications resulting from ozonolysis have specific effects on the performance of fats, oils, or other compounds, and these effects can vary based on the nature of the starting material. Compared to many oxidation routes, ozone is produced on site eliminating problems related to storage and transportation of oxidation agents [18].

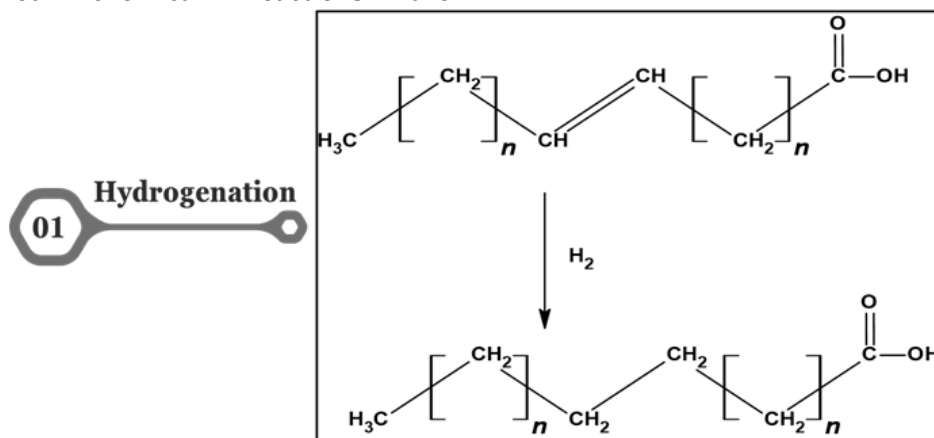


Figure 1. Hydrogenation

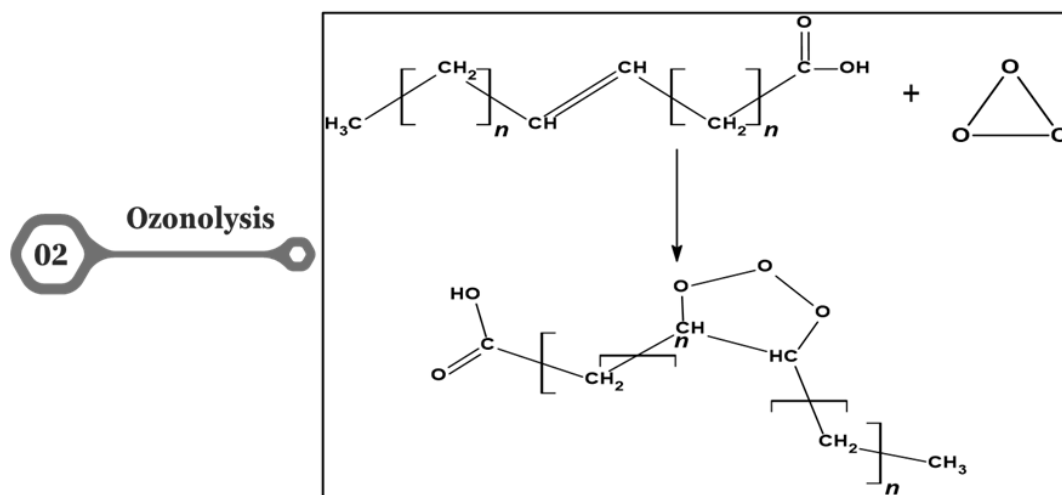


Figure 2. Ozonolysis

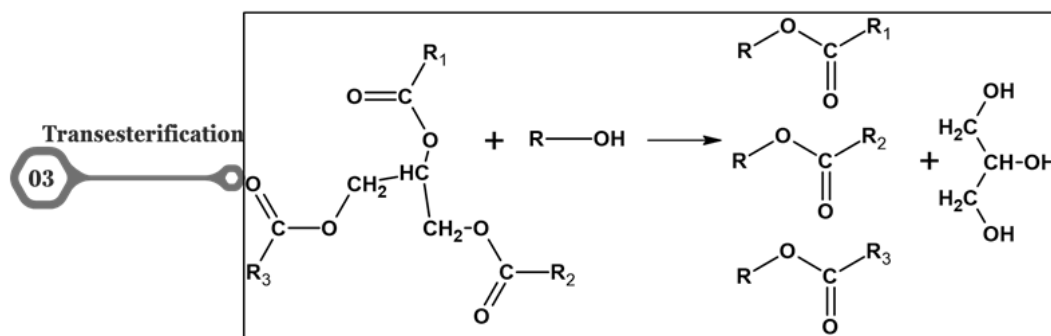


Figure 3. Transesterification

Transesterification is a process where the animal fats (triglycerides composed of fatty acids and glycerol) react with an alcohol (methanol or ethanol) to give fatty acid methyl or ethyl esters (biodiesel). This process is used to produce biodiesel from different feedstocks. The primary effect is the conversion of animal fats into biodiesel, a more environmentally friendly and sustainable fuel alternative. Biodiesel has lower viscosity compared to animal fats, improving its flow characteristics and ease of use [19].

The addition of an oxygen atom to the carbon-carbon double bond present in the fatty acid using reagents such as peroxy acids or peracids to form epoxide group is known as *epoxidation*. This reaction will modify the physical properties of the oil and fats and improve the oxidative stability. This modified oil and fats

can be used in the industries for the production of plasticizers, resins, and lubricants [20]. The *oxidation* of fatty acids in fats and oils takes place when they are exposed to air, light, or heat. They form a variety of by-products like aldehydes, carboxylic acids, peroxides, and ketones. These by-products have a negative impact on the quality or stability of the oil and leads to the formation of off-flavors, and rancidity. This can be minimized by treating it with antioxidants and recently encapsulation technologies [21]. *Hydrolysis/Saponification* occurs when fats or oils are exposed to water and base, the ester bonds between the fatty acids and glycerol are broken down. This reaction can result in the formation of sodium salts of the particular fatty acids (soap) and glycerol. The commercial application in this process is the production of soap [22].

04 **Epoxidation**

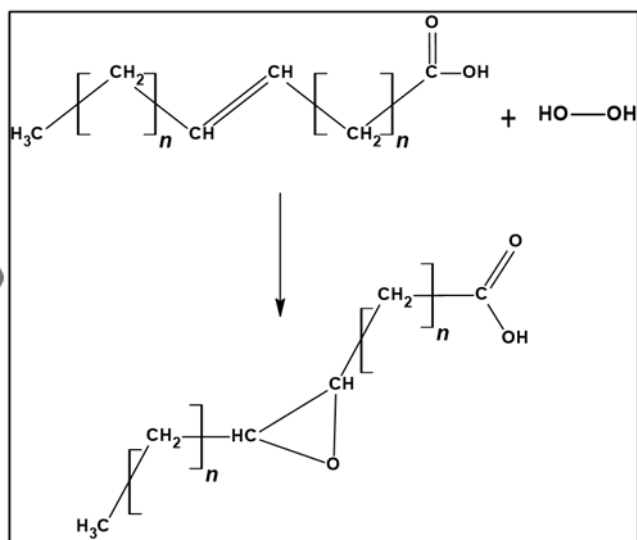


Figure 4. Epoxidation

05 **Oxidation**

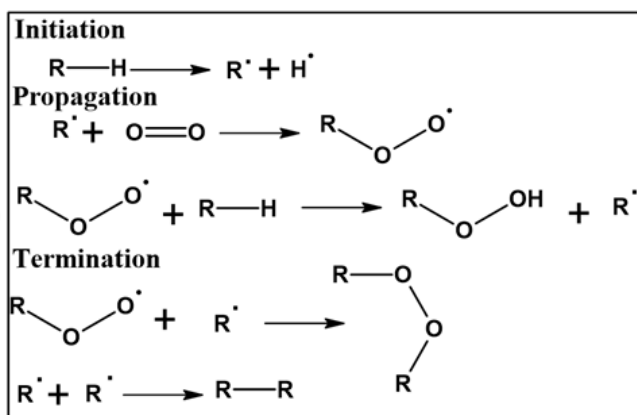


Figure 5. Oxidation

06 **Hydrolysis/
Saponification**

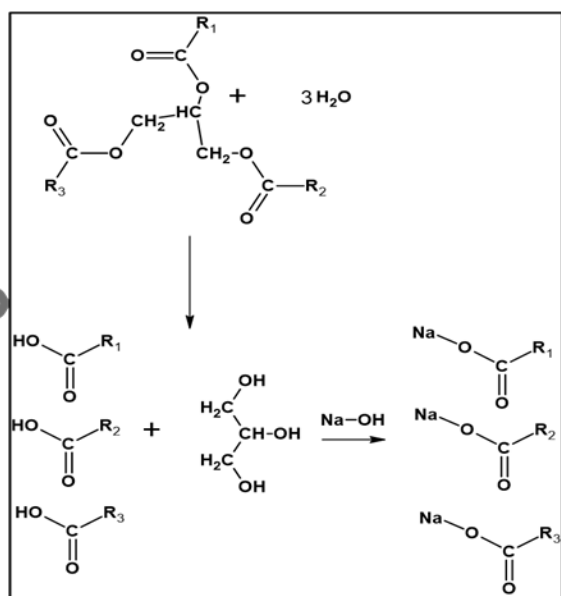


Figure 6. Hydrolysis/Saponification

4.1. Fatty acids in animal fats

Animal fats consist of lipids with a variety of fatty acids. Fatty acids serve as the foundational elements that differ in their saturation, structure, and length. Understanding the constituents of fatty acids is significant and provides a way to different applications namely caproic acid is one of the components in the vanilla and cheese and also used as an artificial flavor when it is changed into its ester form which can be used in food industries [23]. Caprylic acid is the saturated one which has the antimicrobial properties which is used as an antimicrobial agent in pharmaceutical industries [24]. Lauric acid which is used as a good antibacterial agent because it destroys the cell wall and the membrane of the bacteria [25].

Using more of myristic acid in the diet, immunomodulatory functions are exerted [26]. Palmitic acid has been used as the milk replacers for the young feeding animals. Palmitic and stearic acid has been used in the lactating cows to increase the nutritive value in its diet and enhance its milk production [27]. Oleic acid is mostly present in the animal fats which is used to treat the coronary heart diseases. Linolenic acid is used as a supplementary diet for the animals which itself cannot synthesize this fatty acid [28]. Types of fatty acids found in animal fats including information on their source, chemical name, molecular weight, chemical formula, number of double bonds, and structure are summarized from suitable research articles, as presented in Table 1 [29-37].

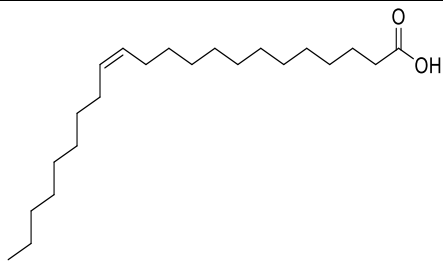
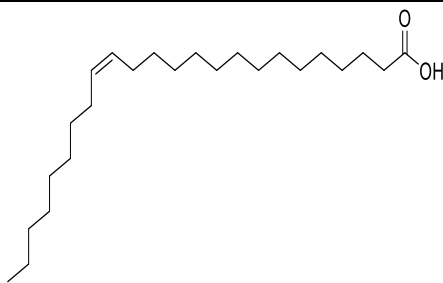
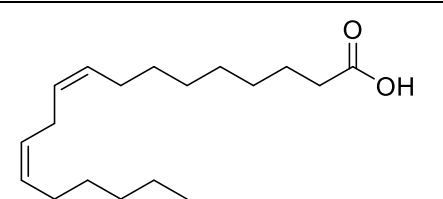
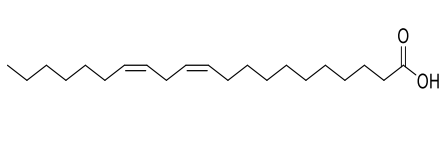
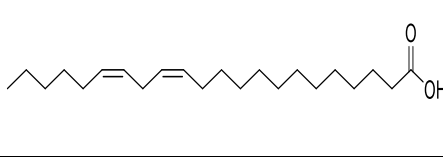
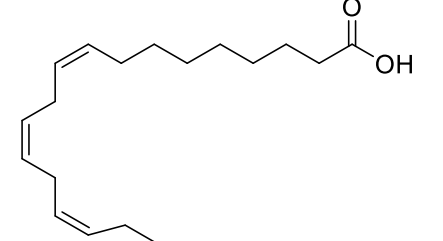
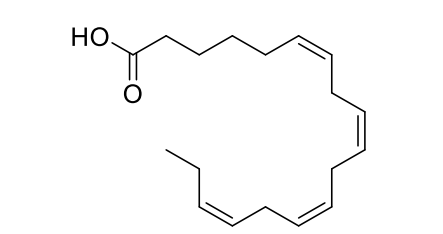
Table 1. Composition of animal fats: A comprehensive study of fatty acids and their characteristics [29-37]

Fatty acids	Sources	Chemical name	Molecular weight (g mol ⁻¹)	Chemical formula	No. of double bonds	Structure
Caproic acid	Milk fat	Hexanoic acid	116.160	C ₆ H ₁₂ O ₂	0	
Caprylic acid	Goat milk	Octanoic acid	144.214	C ₈ H ₁₆ O ₂	0	
Lauric acid	Cow and goat milk	Dodecanoic acid	200.322	C ₁₂ H ₂₄ O ₂	0	
Myristic acid	Bovine milk, butter fat	Tetradecanoic acid	228.376	C ₁₄ H ₂₈ O ₂	0	
Palmitic acid	Ruminant tallow	Hexadecanoic acid	256.430	C ₁₆ H ₃₂ O ₂	0	
Stearic acid	Pork, chicken, beef, fish	Octadecanoic acid	284.484	C ₁₈ H ₃₆ O ₂	0	
Margaric acid	Fat and milk fat of ruminants	Heptadecanoic acid	270.45	C ₁₇ H ₃₄ O ₂	0	
Arachidic acid	Fish oil	Icosanoic acid	316.6	C ₂₀ H ₄₀ O ₂	0	
Crotonic acid	Beef and dairy fat	(2E)-But-2-enoic acid	86.09	C ₄ H ₆ O ₂	1	

Table 1. Continued

Palmitoleic acid	Meat, butter, cheese, milk	(9Z)-Hexadec-9-enoic acid	254.41	C ₁₆ H ₃₀ O ₂	1	
Gondoic acid	Fish, beef, Dairy products	(11Z)-Icos-11-enoic acid	310.51	C ₂₀ H ₃₈ O ₂	1	
Myristoleic acid	Milk fat from ruminants	(9Z)-Tetradec-9-enoic acid	226.36	C ₁₄ H ₂₆ O ₂	1	
Oleic acid	Pig	(9Z)-Octadec-9-enoic acid	282.46	C ₁₈ H ₃₄ O ₂	1	
Elaidic acid	Dairy fat, Beef fat	(9E)-Octadec-9-enoic acid	282.46	C ₁₈ H ₃₄ O ₂	1	
Vaccenic acid	Animal fats and butter	(11E)-Octadec-11-enoic acid	282.46	C ₁₈ H ₃₄ O ₂	1	
Gadoleic acid	Cod liver oil	(9Z)-Icos-9-enoic acid	310.51	C ₂₀ H ₃₈ O ₂	1	
Eicosenoic acid	Herring fish, Eel, Sable fish, Salmon, Kielbasa	(11Z)-Icos-11-enoic acid	310.51	C ₂₀ H ₃₈ O ₂	1	

Table 1. Continued

Erucic acid	Geese, ducks, beef tallow, lard	(13Z)-Docos-13-enoic acid	338.57	C ₂₂ H ₄₂ O ₂	1	
Nervonic acid	Marine organisms	(15Z)-Tetracos-15-enoic acid	366.62	C ₂₄ H ₄₆ O ₂	1	
Linoleic acid	Meat and dairy products	(9Z,12Z)-Octadeca-9,12-dienoic acid	280.45 2	C ₂₀ H ₃₂ O ₂	2	
Eicosadienoic acid	Cat fish, turkey, chicken, egg	(11Z,14Z)-Icosa-11,14-dienoic acid	308.50	C ₂₀ H ₃₆ O ₂	2	
Docosadienoic acid	Fish	(13Z,16Z)-Docosa-13,16-dienoic acid	336.55	C ₂₂ H ₄₀ O ₂	2	
Linolenic acid	Meat and eggs from chicken	(9Z,12Z,15Z)-Octadeca-9,12,15-trienoic acid	278.4	C ₁₈ H ₃₀ O ₂	3	
Stearidonic acid	Fish oil	(6Z,9Z,12Z,15Z)-Octadeca-6,9,12,15-tetraenoic acid	276.42	C ₁₈ H ₂₈ O ₂	4	

4.2. Fatty acid profile analysis of animal fats

Animal fats contain a spectrum of fatty acids, including saturated, monounsaturated, and polyunsaturated types. Understanding the fatty acid composition in animal fats offers diverse practical applications across various domains. Ternary plot in Figure 7 illustrates the fatty acid composition of different animal fats [38]. The composition of fatty acids varies among animal fats, influencing their applications. The ternary plot provides a visual representation enabling a quick assessment of the overall fatty acid content.

5. Applications of Animal Fats

The modified animal fats produced from the various chemical process mentioned in Section 3 are more stable than the ordinary animal fats which can be used in various applications. The detailed explanation with recent literature survey has been discussed in the upcoming subsections.

5.1. Lubricant

Lubricants are crucial in all mechanical systems and reduce the wear and friction of moving parts between metal surfaces. Common industrial lubricants include metalworking fluids, engine oils, gearbox oils, compressor oils, and hydraulic oils. Nearly 50% of petroleum lubricants cause permanent damage to the environment. This has led to increased demand for biodegradable and renewable lubricant sources. A variety of oils are converted into biodegradable lubricants using methanol [39-40]. The process of producing biolubricants involves various reaction pathways, as shown in Figure 8. Properties such as friction and wear, oxidation stability, biodegradability, and environmental compatibility are important for effective performance as a lubricant. Animal fats have been found to have the potential to be used as biolubricants discussed in the next paragraph [41].

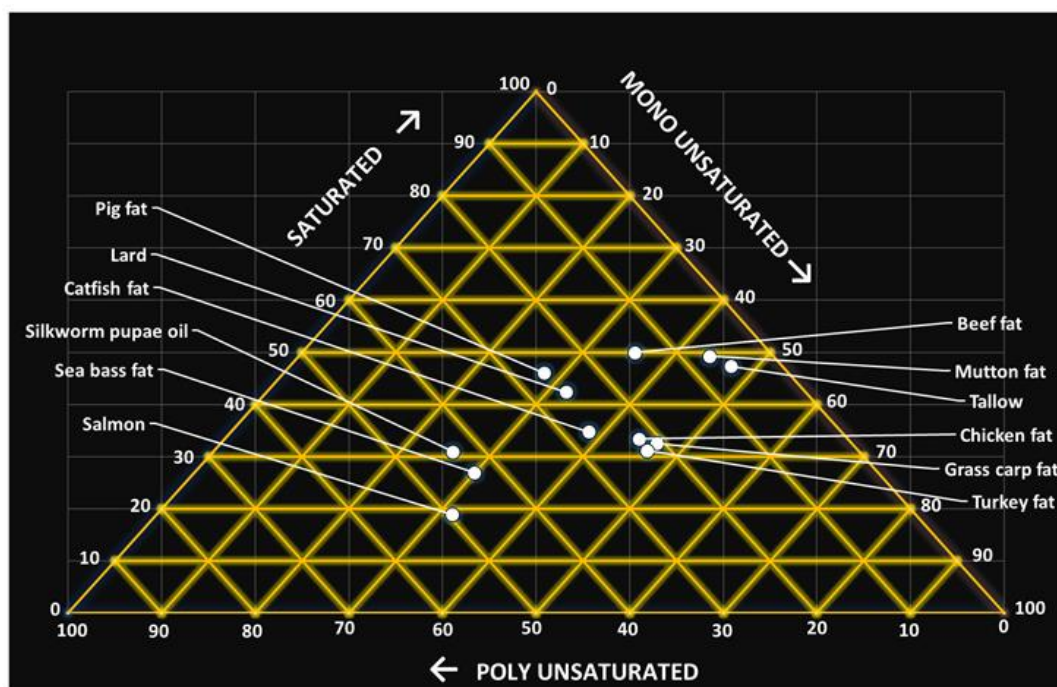


Figure 7. Ternary plot of the number of different types of fatty acids in animal fats

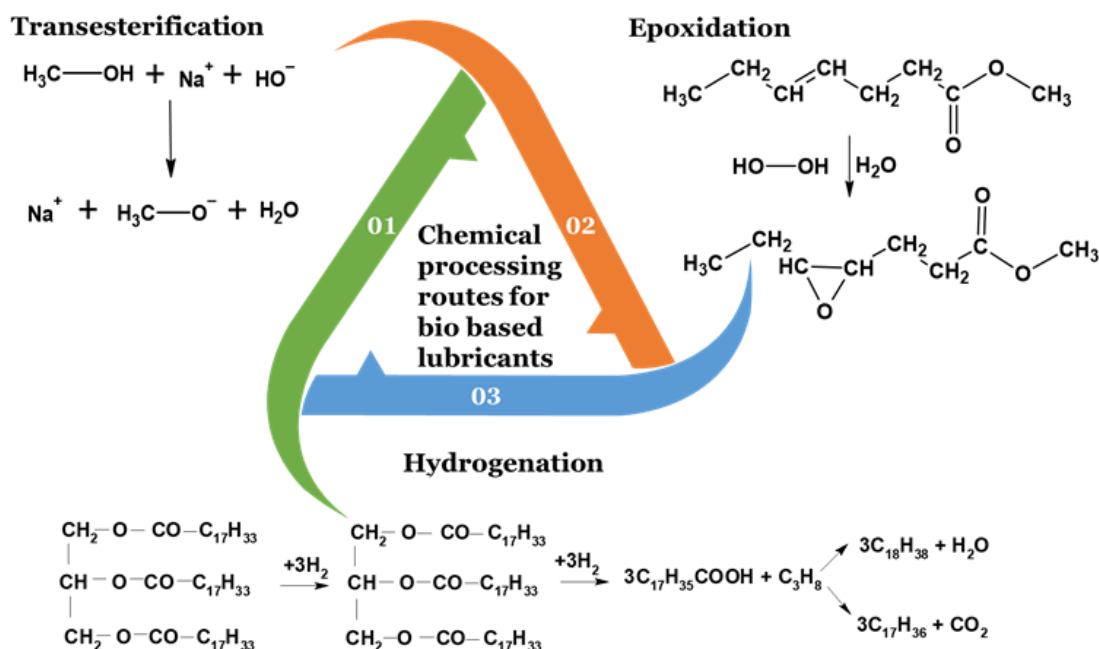


Figure 8. Reaction routes for the preparation of biolubricants

Lubricant from the chicken fat was obtained by physical refining process. 30-40% chicken fat was obtained from the poultry waste and converted into esters by the transesterification process. The esters viscosity is varied using oxidative stabilizers and viscosity modifiers such as ethyl vinyl acetate (EVA) and styrene butadiene styrene (SBS). The tribological properties of the samples (pure biodiesel, pure chicken fat, and various blends of biodiesel plus chicken fat with different compositions of SBS and EVA) were compared [42]. Omega-3 fatty acids were separated from the waste fish oil and used in many nutrition products. The remaining fatty acids are considered waste and used as lubricants, biofuel, and many other applications [43]. Fish oil obtained from Nile Tilapia is chemically modified by esterification, epoxidation, and ring opening reactions. This modified fish oil is compared with commercial lubricants and it showed high biodegradability and viscosity [44]. Duck fat biodiesel used as a biolubricant and compared with other vegetable oils such as, soybean, olive, coconut, palm, and canola [45].

5.2. Fuel

In response to the growing demand for oil, the Indian government [46] has passed an order to

promote the mixing of higher levels of ethanol and vegetable oil components with diesel and gasoline. Ethanol (10%) blended with gasoline has increased from 12% to 15%. For diesel, 20% of alkyl esters are from long-chain fatty acids of oils taken in the upcoming years. This move is aimed at reducing the country's dependence on fossil fuels and promoting eco-friendly alternatives [47] and strategies to blend is explained in this article [48]. Rudolph Diesel was the first person to use oils in diesel engines in 1911. The properties of raw oil are same as crude petroleum derived diesel and used in diesel engines without any blending. However, using the oils led to several drawbacks such as more carbon deposits, oil ring sticking, injector coking, high fuel viscosity, etc. Few of them can be solved, like reducing the viscosity by various methods (micro-emulsification, pyrolysis, dilution, and transesterification). Among these methods, transesterification is considered the best [49]. The biodiesel production by the transesterification process is elaborately explained in Figure 9 [50-51]. The research work from was 2020 to 2023 for the biofuel production from different animal fats were listed in Figure 10 [52-66]. It is evident from figure that utilization of animal fat acts as a key source for biodiesel production.

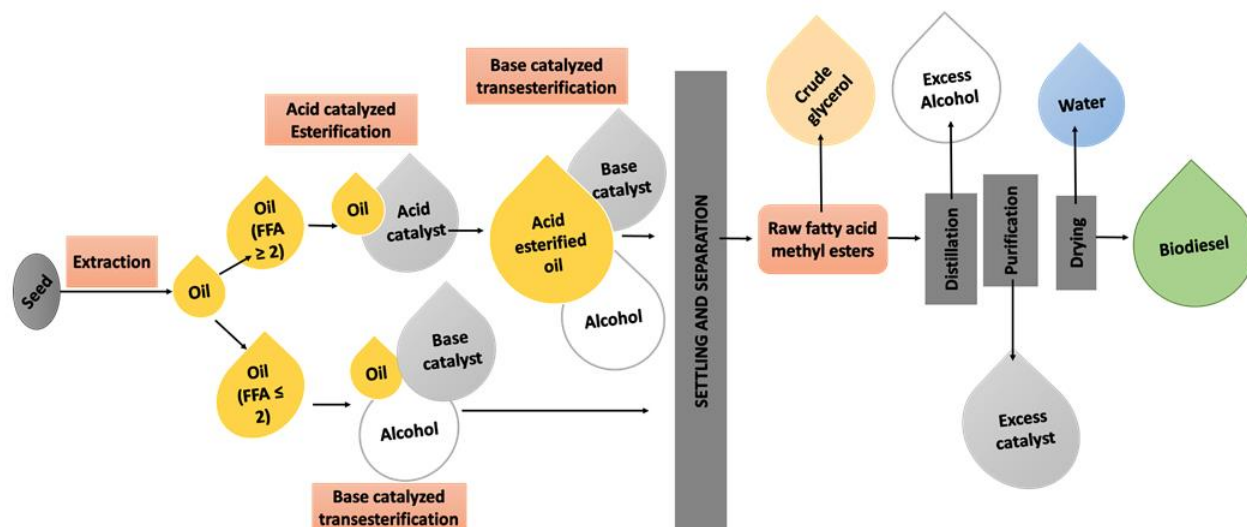


Figure 9. Transesterification process for biodiesel production

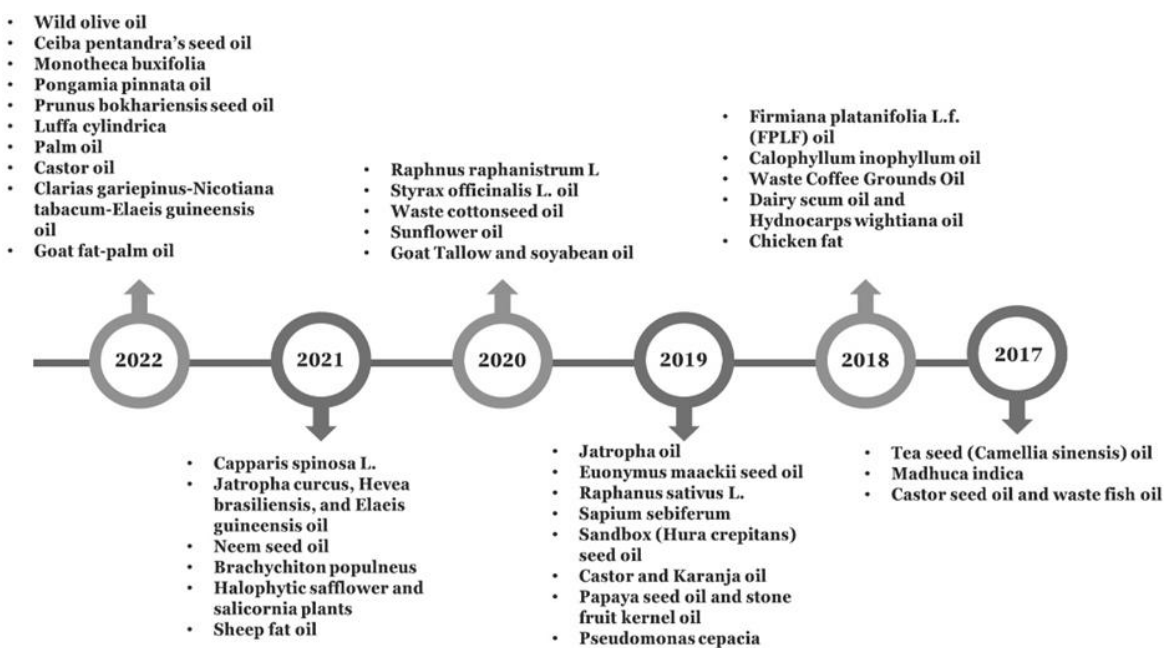


Figure 10. Review on animal fat sources for biodiesel synthesis from 2020-2023

5.3. Plasticizer in films

Plastics have entered in different ways into human lifestyle when standard of living gets modernized. But concerning the environmental account, it causes global pollution due to its non-biodegradable nature. If plastics usage goes on without limit, it will lead our world into a "plastic Earth" [67]. Therefore, there is a need to transition to biodegradable products. Biodegradable starch has been widely used in packaging industry due to its low cost and

abundance in nature, but it has poor hydrophilicity and low extensibility as its shortcomings. Other than starch, many biodegradable polymers have been used, such as chitosan [68], polylactic acid, polycaprolactone, etc. To meet the issues, plasticizers came into action. The plasticizers used were glycerol, esters, and sorbitol. Among these plasticizers, glycerol is toxic-free and cost-effective. The main criterion for the film to get onto the market is that it should be water

resistant. To make the film waterproof, oils have been used as an additive.

Several investigations have utilized plant oils in film preparation, including soybean oil [69], bamboo volatile oil [67], palm oil [70], cinnamon oil [71], olive oil [68], and buriti oil [72]. These studies employed the solution casting technique for the preparation. The basic steps involved in the formation of film by solution casting technique are pictorially demonstrated in Figure 11. Most of the films were done with the help of vegetable oil, but only few animal fats namely shellac resins from *Laccifer lacca* used as a coating on the surfaces of tomatoes [73] and green chilies [74].

5.4. Cutting fluid

The cutting process results in getting the desired shape and geometry of the specimen by using sharp machining tools. The energy required for such an operation is almost 66%, and major energy loss happens in the form of heat. The heat loss can be minimized by the use of metal cutting fluids (MCF) [75]. The MCF working is elucidated in Figure 12 [76]. Mineral

oils were used as MCF which severely reflects on the machine operator and the environment. The people and the environment exposed to the non-biodegradable metal cutting fluids suffer from cancer, lung and heart disease, DNA damage, skin irritation, and soil contamination due to disposal. The role of cutting fluid is to increase the life span of the tool by sluicing the chips from the cutting zone, reducing the thermal deformation of the workpiece, and improving the surface finish [77].

The reason for using mostly vegetable oils as metal cutting fluids is because that they stay in liquid form. The properties of the adsorption of oil facilitate the adsorption on the surface of the friction. This property provides a protective layer when undergoing machining operations. Not only is it good for lubrication, but it also has the properties of biodegradability and non-toxicity [78]. Animal fats modified by undergoing rendering, steaming, and extracting the oil, which is then used for the emulsification process. Tallow and lard were explored as potential MCF [79].

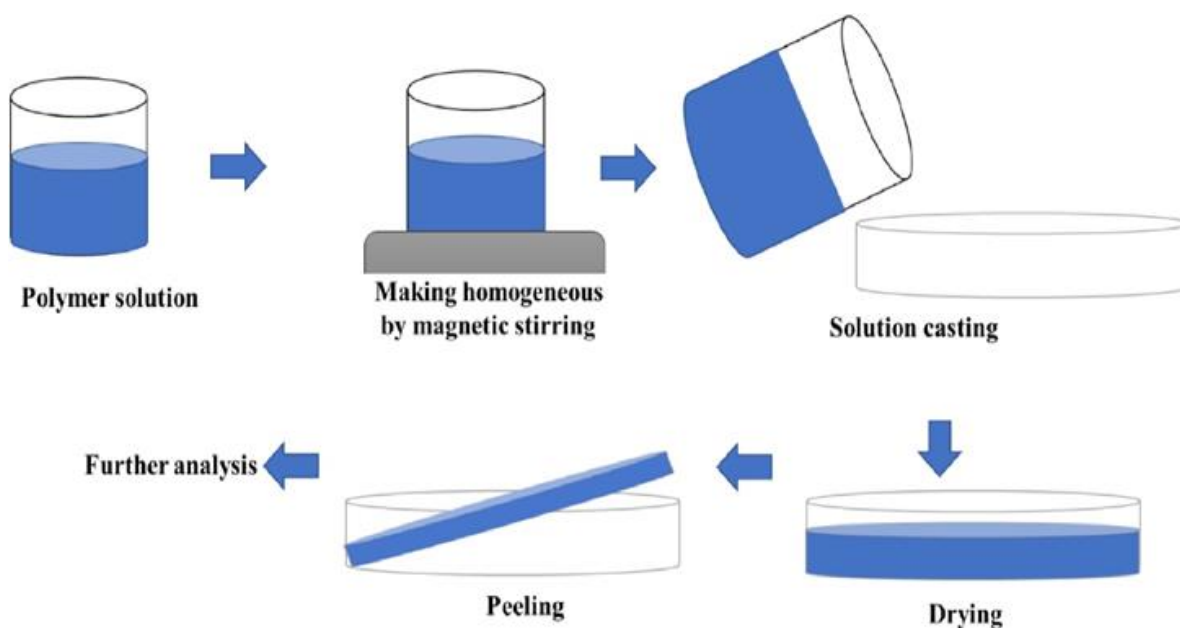


Figure 11. Schematic representation of solution casting technique for film preparation

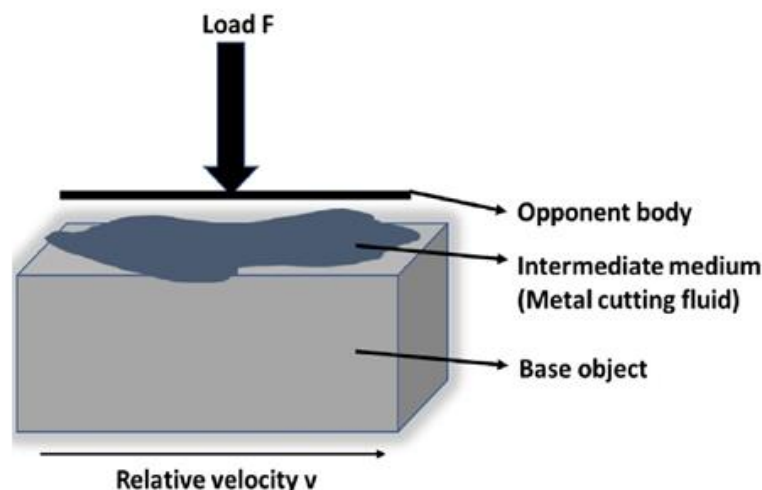


Figure 12. Working of metal cutting fluid (MCF)

5.5. Wound dressing

Infections delay the progress of wound healing and even cause sepsis. Antibacterial wound dressings are made to reduce or kill microbes during the healing time. The dressings were made to be biocompatible, provide moisture over the wounded tissues and protect the new tissues formed during the healing process from external trauma. To lessen the usage of fossil-based raw materials for polyurethane synthesis, bio-based feedstocks like plant oils were used [80-81]. Animal fats such as emu oil and badger oil themselves cannot be used as wound dressing components, so to provide support to the composites; they are blended with polyurethanes [82-83].

In addition, nanoparticles which have antimicrobial properties were loaded along with the composites [84]. Those mixtures were taken in the syringe to undergo the electrospinning process as shown in Figure 13 to form wound dressing material. Various essential oils were evaluated their antimicrobial properties for wound dressing application [85-86].

5.6. Paints

In ancient times, the practice of using oils as a binder for pigments was followed. The Egyptians around 2600 BCE used a mixture of oil and pigments to create a creamy paste for

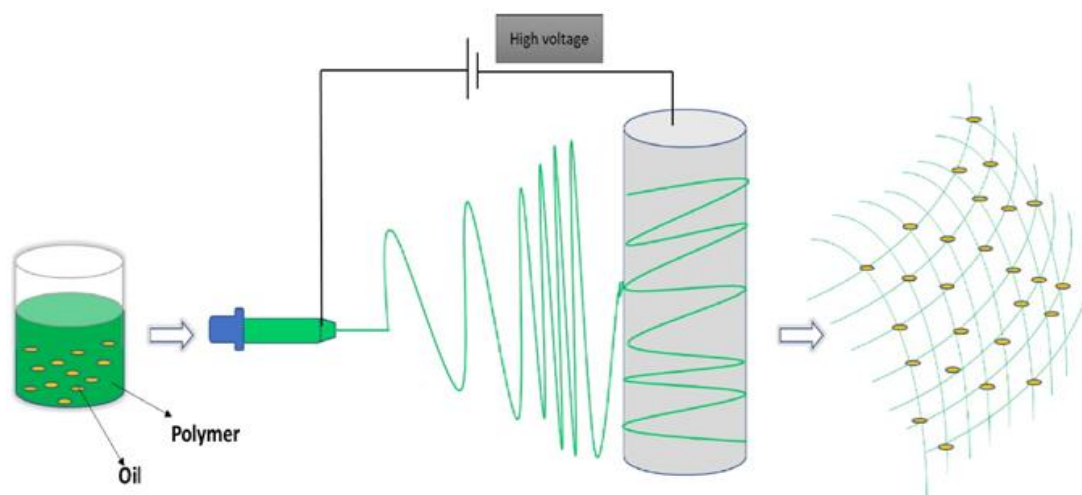


Figure 13. Pictorial representation of the electrospun process of wound dressing

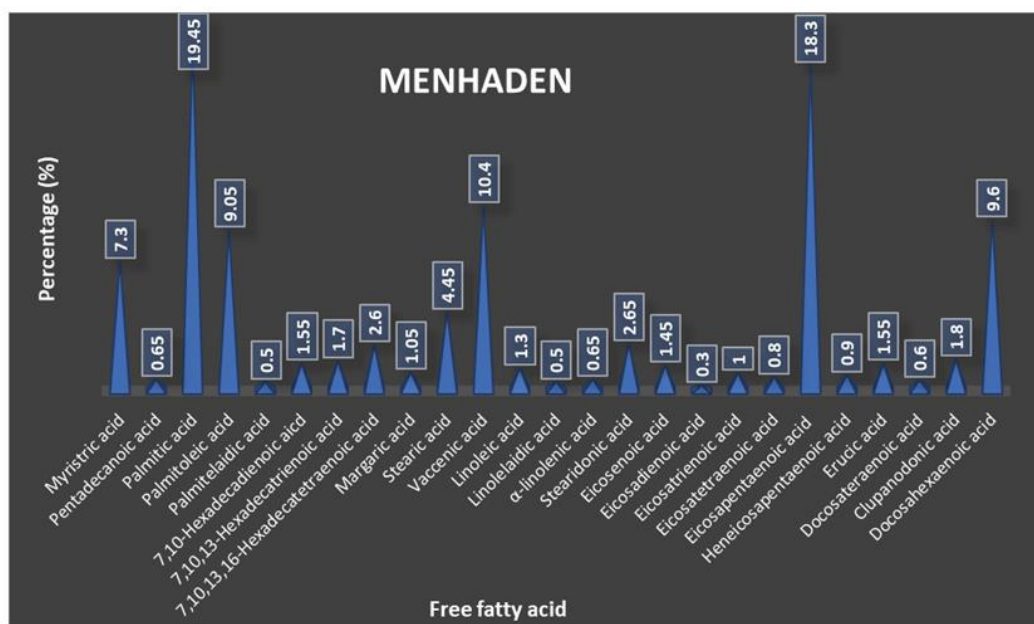


Figure 14. Free fatty acid percentage profile of menhaden (*Brevoortia sp.*)

inlay work [87]. Linseed oil was the most widely used medium for binding the paints in Europe, while poppy and walnut oil was more expensive options. Fish and marine mammals contain ample amounts of oil to utilize by coastal communities as paint binders or varnishes. However, whale oil has good commercial value, so it was used in a limited amount [88-89]. In the US, fish oils, particularly from menhaden (*Brevoortia spp.*), became

heavily exploited due to the abundance availability of this silvery fish along the Eastern and Atlantic seaboard [90]. Despite being considered unappetizing for human consumption, menhaden were utilized as bait or processed for their oil and used in various products such as margarine, soap, and paint [91]. The free fatty acid percentage profile of the fish menhaden is represented in Figure 14 [92].

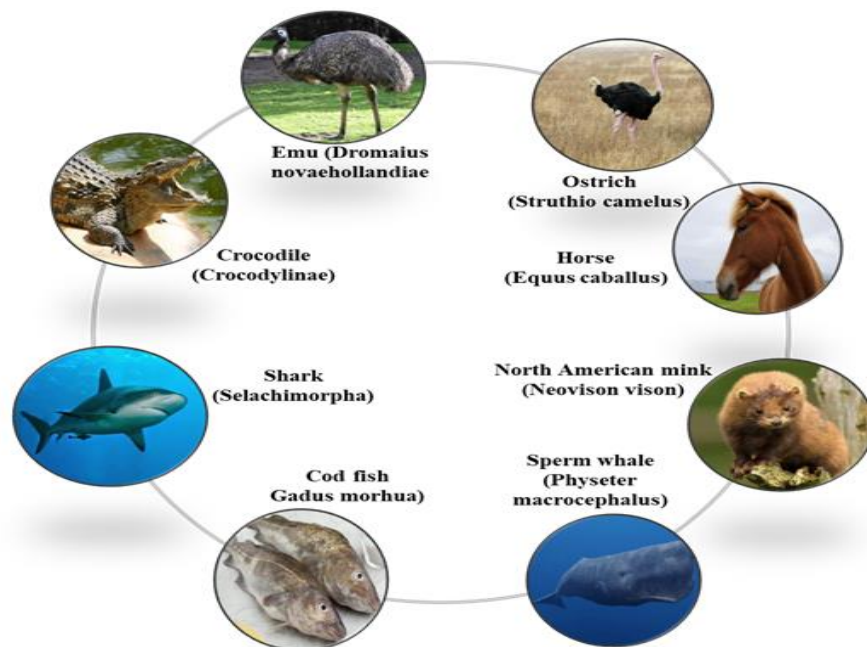


Figure 15. Applications of various animal fats in cosmetic industry

5.7. Cosmetics

In the cosmetic industry, rendered poultry fat, tallow, and lard are widely used. Lard is obtained from the rendering of swine adipose tissue, while tallow is obtained from the rendering of ruminant fat from farm animals such as sheep, buffalo, cattle, and goats. These rendered fats possess occlusive, emulsion-stabilizing, emollient, surfactant, and viscosity-increasing properties. Modern cosmetic products utilize fat from various animal species are illustrated in Figure 15 [93].

Animal fats such as emu oil and mink oil have penetrating power and easily get inside the dermal layers, stimulating hair and skin growth. These can be used in making lipsticks, hair sprays, moisturizers, body lotions, and skin cleansers [94]. Ostrich oil is used in antiaging cosmetics because it is rich in oleic acid, lauric acid, and palmitic acid [95]. Horse oil has skin moisturizing and skin barrier restoration properties and is used in making soap, shampoo, lotion, and face cream [96].

Ambergris wax is a constituent of perfumes that prolongs their scent. Sperm oil is used in beauty products as a moisturizer and as a vehicle for fragrances. Cod liver oil is used as an occlusive in skin care products. Shark liver oil is a triterpenoid organic compound that impressively mimics the skin's natural oils and is used in lip balm, hair dyes, facial moisturizers, sunscreen, and moisturizing creams. Crocodile oil is rich in oleic acid and Ω -3, 6 fatty acids. Due to its good healing property, it is used in skin care products [97].

6. Conclusion

Based on the overview elucidated, the animal fats pave a way for the search of inventing new products. This paper mainly focuses on ecofriendly and biodegradable things discovered recently. Edible oils that are suitable for consumption are not favored due to their higher cost. However, nonedible animal fats have been identified as potential sources for various applications. Animal fats have proven to be a versatile and indispensable resource in automobiles (lubricants, additives in fuels, and components in car care products), cosmetics

(production of soaps, creams, lotions, and other beauty and skincare products), food (production of margarine, shortening, cooking oils, and flavorings), paints (binders, solvents, or additives, providing improved performance and durability), and pharmaceutical industries (pharmaceutical ointments, capsules, and coatings for various medicinal products). By addressing these specific points, animal fats can be recognized as valuable and underutilized resources across industries, promoting their responsible usage and maximizing their economic and practical benefits.

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References

- [1]. D. Illakwahhi, B.B. Srivastava, Improving the efficacy of abamectin using Neem Oil in controlling tomato leafminers, Tuta absoluta (Meyrick), *Advanced Journal of Chemistry, Section A*, **2019**, 2, 216-224. [Crossref], [Google Scholar], [Publisher]
- [2]. I.B. Banković-Ilić, I.J. Stojković, O.S. Stamenković, V.B. Veljković, Y.-T. Hung, Waste animal fats as feedstocks for biodiesel production, *Renewable and Sustainable Energy Reviews*, **2014**, 32, 238-254. [Crossref], [Google Scholar], [Publisher]
- [3]. Z. Torabi, S. Saeida Ardekani, S.H. Hataminasab, New model of professional competence of managers of hotels, oil, gas and energy industries toward sustainable

development, *Advanced Journal of Chemistry, Section A*, **2021**, 4, 231-243. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[4]. I. Smeu, A.A. Dobre, E.M. Cucu, G. Mustătea, N. Belc, E.L. Ungureanu, Byproducts from the vegetable oil industry: The challenges of safety and sustainability, *Sustainability*, **2022**, 14, 2039. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[5]. L.M. Reguengo, M.K. Salgaço, K. Sivieri, M.R.M. Júnior, Agro-industrial by-products: Valuable sources of bioactive compounds, *Food Research International*, **2022**, 152, 110871. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[6]. D.L. Meeker, C. Hamilton, Essential rendering, *All about the animal by-products industry*, **2006**. [[Crossref](#)], [[Google Scholar](#)],

[7]. A. Ahmad, H. Ahsan, Lipid-based formulations in cosmeceuticals and biopharmaceuticals, *Biomedical Dermatology*, **2020**, 4, 1-10. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[8]. Animal fats and oils, *Fats and Oils Handbook*, Elsevier, **1998**, 121-173. [[Crossref](#)], [[Publisher](#)]

[9]. R.C. Chandan, Dairy processing and quality assurance: an overview, *Dairy Processing and Quality Assurance*, **2015**, 1-40. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[10]. P. Walstra, P. Walstra, J.T. Wouters, T.J. Geurts, Dairy science and technology, CRC Press, **2005**. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[11]. H. YH, W.R. Robert, A.Y. Owen, Meat science and applications, Marcel Dekker, Inc., **2001**. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[12]. H.D. Branion, Industrial fishery technology, *Poultry Science*, **1964**, 43, 1383. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[13]. N.P. Chauke, H.E. Mukaya, D.B. Nkazi, Chemical modifications of castor oil: A review, *Science Progress*, **2019**, 102, 199-217. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[14]. H. Patterson, Hydrogenation of oils and fats, *Recent Advances in Chemistry and Technology of Fats and Oils*, Springer, **1983**, 41-56. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[15]. D. Mozaffarian, M.B. Katan, A. Ascherio, M.J. Stampfer, W.C. Willett, Trans fatty acids and cardiovascular disease, *New England Journal of Medicine*, **2006**, 354, 1601-1613. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[16]. J.E. Hunter, J. Zhang, P.M. Kris-Etherton, Cardiovascular disease risk of dietary stearic acid compared with trans, other saturated, and unsaturated fatty acids: A systematic review, *The American Journal of Clinical Nutrition*, **2010**, 91, 46-63. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[17]. U.P. Laverdura, L. Rossi, F. Ferella, C. Courson, A. Zarli, R. Alhajjoussef, K. Gallucci, Selective catalytic hydrogenation of vegetable oils on lindlar catalyst, *ACS Omega*, **2020**, 5, 22901-22913. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[18]. D.K. Arriaga, A.A. Thomas, Capturing primary ozonides for a syn-dihydroxylation of olefins, *Nature Chemistry*, **2023**, 1-5. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[19]. G. Knothe, Dependence of biodiesel fuel properties on the structure of fatty acid alkyl esters, *Fuel Processing Technology*, **2005**, 86, 1059-1070. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[20]. a) V.M. Abbasov, F.A. Nasirov, N.S. Rzayeva, L.I. Nasirova, K.Z. Musayeva, Epoxidated vegetable oils: preparation, properties and application, *Ppor*, **2018**, 19, 427. [[Google Scholar](#)], [[Publisher](#)] b) F.I. Ahmadi, R. Fathollahi, D. Dastan, Phytochemical Constituents and biological properties of *Scutellaria Condensata* Subsp. *Pycnotricha*, *Journal of Applied Organometallic Chemistry*, **2022**, 2, 119-128. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[21]. M. Machado, L.M. Rodriguez-Alcala, A.M. Gomes, M. Pintado, Vegetable oils oxidation: mechanisms, consequences and protective strategies, *Food Reviews International*, **2023**,

- 39, 4180-4197. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [22]. R. Alenezi, M. Baig, J. Wang, R. Santos, G. Leeke, Continuous flow hydrolysis of sunflower oil for biodiesel, *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, **2010**, 32, 460-468. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [23]. S. Agnihotri, D.M. Yin, A. Mahboubi, T. Sapmaz, S. Varjani, W. Qiao, D.Y. Koseoglu-Imer, M.J. Taherzadeh, A glimpse of the world of volatile fatty acids production and application: A review, *Bioengineered*, **2022**, 13, 1249-1275. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [24]. Y. Li, The application of caprylic acid in downstream processing of monoclonal antibodies, *Protein Expression and Purification*, **2019**, 153, 92-96. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [25]. R. Barlina, K.T. Dewandari, I. Mulyawanti, T. Herawan, Chemistry and composition of coconut oil and its biological activities, *Multiple Biological Activities of Unconventional Seed Oils*, Elsevier, **2022**, 383-395. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [26]. S. Verruck, C.F. Balthazar, R.S. Rocha, R. Silva, E.A. Esmerino, T.C. Pimentel, M.Q. Freitas, M.C. Silva, A.G. da Cruz, E.S. Prudencio, Dairy foods and positive impact on the consumer's health, *Advances in Food and Nutrition Research*, **2019**, 89, 95-164. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [27]. J. Loftén, J. Linn, J. Drackley, T. Jenkins, C. Soderholm, A. Kertz, Invited review: Palmitic and stearic acid metabolism in lactating dairy cows, *Journal of Dairy Science*, **2014**, 97, 4661-4674. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [28]. Fatty acids, fat, volatile fatty acids, and energy, *Horse Feeding and Nutrition*, Elsevier, **1991**, 193-209. [[Crossref](#)], [[Publisher](#)]
- [29]. L. Lin, Z. Cunshan, S. Vittayapadung, S. Xiangqian, D. Mingdong, Opportunities and challenges for biodiesel fuel, *Applied Energy*, **2011**, 88, 1020-1031. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [30]. R. Misra, M. Murthy, Straight vegetable oils usage in a compression ignition engine—A review, *Renewable and Sustainable Energy Reviews*, **2010**, 14, 3005-3013. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [31]. S. Singh, D. Singh, Biodiesel production through the use of different sources and characterization of oils and their esters as the substitute of diesel: a review, *Renewable and sustainable energy reviews*, **2010**, 14, 200-216. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [32]. A. Srivastava, R. Prasad, Triglycerides-based diesel fuels, *Renewable and Sustainable Energy Reviews*, **2000**, 4, 111-133. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [33]. J.C. Juan, D.A. Kartika, T.Y. Wu, T.-Y.Y. Hin, Biodiesel production from jatropha oil by catalytic and non-catalytic approaches: an overview, *Bioresource Technology*, **2011**, 102, 452-460. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [34]. Y. Sharma, B. Singh, S. Upadhyay, Advancements in development and characterization of biodiesel: A review, *Fuel*, **2008**, 87, 2355-2373. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [35]. A.K. Agarwal, Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines, *Progress in Energy and Combustion Science*, **2007**, 33, 233-271. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [36]. P. Schinas, G. Karavalakis, C. Davaris, G. Anastopoulos, D. Karonis, F. Zannikos, S. Stournas, E. Lois, Pumpkin (*Cucurbita pepo* L.) seed oil as an alternative feedstock for the production of biodiesel in Greece, *Biomass and Bioenergy*, **2009**, 33, 44-49. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [37]. S. Jain, M. Sharma, Prospects of biodiesel from Jatropha in India: A review, *Renewable and Sustainable Energy Reviews*, **2010**, 14, 763-771. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [38]. S.L. Douvartzides, N.D. Charisiou, K.N. Papageridis, M.A. Goula, Green diesel: Biomass feedstocks, production technologies, catalytic research, fuel properties and performance in

compression ignition internal combustion engines, *Energies*, **2019**, *12*, 809. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[39]. S. Almasi, B. Ghobadian, G. Najafi, M.D. Soufi, A novel approach for bio-lubricant production from rapeseed oil-based biodiesel using ultrasound irradiation: multi-objective optimization, *Sustainable Energy Technologies and Assessments*, **2021**, *43*, 100960. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[40]. K. Adithyan, S. Edla, A.D. Thampi, S.A. Kumar, B. Sasidharan, M.M. Arif, S. Rani, Experimental investigation on the effects of clove oil as an anti-oxidant additive on the lubricant properties of transesterified rice bran oil, *Materials Today: Proceedings*, **2023**, *72*, 2892-2896. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[41]. P. Negi, Y. Singh, K. Tiwari, A review on the production and characterization methods of bio-based lubricants, *Materials Today: Proceedings*, **2021**, *46*, 10503-10506. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[42]. M. Hernández-Cruz, R. Meza-Gordillo, B. Torrestiana-Sánchez, A. Rosales-Quintero, L. Ventura-Canseco, J. Castañón-González, Chicken fat and biodiesel viscosity modification with additives for the formulation of biolubricants, *Fuel*, **2017**, *198*, 42-48. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[43]. B. Angulo, J.M. Fraile, L. Gil, C.I. Herrerías, Bio-lubricants production from fish oil residue by transesterification with trimethylolpropane, *Journal of Cleaner Production*, **2018**, *202*, 81-87. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[44]. C.P. do Valle, J.S. Rodrigues, L.M.U.D. Fachine, A.P. Cunha, J.Q. Malveira, F.M.T. Luna, N.M.P.S. Ricardo, Chemical modification of Tilapia oil for biolubricant applications, *Journal of Cleaner Production*, **2018**, *191*, 158-166. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[45]. S. Hamdan, W. Chong, J.H. Ng, M. Ghazali, R. Wood, Influence of fatty acid methyl ester composition on tribological properties of vegetable oils and duck fat derived biodiesel,

Tribology International, **2017**, *113*, 76-82. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[46]. U. Bello, C.M. Agu, D.A. Ajiya, A.A. Mahmoud, L. Udopia, N.M. Lawal, A.A. Abubakar, M. Muhammad, Biodiesel, In a quest for sustainable renewable energy: A review on its potentials and production strategies, *Journal of Chemical Reviews*, **2022**, *4*, 272-287. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[47]. A. Arumugam, V. Ponnusami, Biodiesel production from Calophyllum inophyllum oil a potential non-edible feedstock: An overview, *Renewable Energy*, **2019**, *131*, 459-471. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[48]. U. Bello, C.M. Agu, D.A. Ajiya, A.A. Mahmoud, L. Udopia, N.M. Lawal, A.A. Abdullahi, M. Muhammad, renewable energy: A review on its potentials and production strategies, *Journal of Chemical Reviews*, **2022**, *4*, 272-287. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[49]. S. Dawood, A.K. Koyande, M. Ahmad, M. Mubashir, S. Asif, J.J. Klemeš, A. Bokhari, S. Saqib, M. Lee, M.A. Qyyum, Synthesis of biodiesel from non-edible (*Brachychiton populneus*) oil in the presence of nickel oxide nanocatalyst: Parametric and optimisation studies, *Chemosphere*, **2021**, *278*, 130469. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[50]. M.K. Yesilyurt, C. Cesur, Biodiesel synthesis from *Styrax officinalis* L. seed oil as a novel and potential non-edible feedstock: A parametric optimization study through the Taguchi technique, *Fuel*, **2020**, *265*, 117025. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[51]. M. Halada Nandakrishnan, N. Dhanavel, M. CB, R. PG, M. VH, N. Reddy, Spent silkworm pupae as a renewable and sustainable source for biodiesel, *Biofuels, Bioproducts and Biorefining*, **2023**, *17*, 167-177. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[52]. N. Santhosh, A. Afzal, Ü. Ağbulut, A.A. Alahmadi, A.C. Gowda, M. Alwetaishi, S. Shaik, A.T. Hoang, Poultry fat biodiesel as a fuel substitute in diesel-ethanol blends for DI-CI engine: Experimental, modeling and

- optimization, *Energy*, **2023**, 270, 126826. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [53]. K. Mohan, P. Sathishkumar, D.K. Rajan, J. Rajarajeswaran, A.R. Ganesan, Black soldier fly (*Hermetia illucens*) larvae as potential feedstock for the biodiesel production: Recent advances and challenges, *Science of The Total Environment*, **2023**, 859, 160235. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [54]. I.Y. Dharmegowda, L.M. Muniyappa, A.B. Suresh, M.P.G. Chandrashekarappa, N. Pradeep, Optimization for waste coconut and fish oil derived biodiesel with MgO nanoparticle blend: Grey relational analysis, grey wolf optimization, driving training based optimization and election based optimization algorithm, *Fuel*, **2023**, 338, 127249. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [55]. L. Yi-Chia, M. Sekar, A. Chinnathambi, O. Nasif, B. Gavurová, G. Jhanani, K. Brindhadevi, N.T.L. Chi, Role of chicken fat waste and hydrogen energy ratio as the potential alternate fuel with nano-additives: Insights into resources and atmospheric remediation process, *Environmental Research*, **2023**, 216, 114742. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [56]. A.C. Kumoro, M.T.M. Saeed, Ultrasound-assisted transesterification of tropical goat fat-Palm oil blend for biodiesel synthesis, *Energy Conversion and Management: X*, **2022**, 14, 100213. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [57]. D.J. Lee, M. Kim, S. Jung, Y.K. Park, Y. Jang, Y.F. Tsang, H. Kim, K.H. Park, E.E. Kwon, Direct conversion of yellow mealworm larvae into biodiesel via a non-catalytic transesterification platform, *Chemical Engineering Journal*, **2022**, 427, 131782. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [58]. E. Canh Pham, T.V.T. Le, K.C.T. Le, D. Van Nguyen, Optimization of microwave-assisted biodiesel production from waste catfish using response surface methodology, *Available at SSRN* 3978735. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [59]. A.H. Mahmoud, M.Y. Hussein, H.M. Ibrahim, M.H. Hanafy, S.M. Salah, G.M. El-Bassiony, E.A. Abdelfattah, Mixed microalgae-food waste cake for feeding of *Hermetia illucens* larvae in characterizing the produced biodiesel, *Biomass and Bioenergy*, **2022**, 165, 106586. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [60]. N. Hasan, M.V. Ratnam, Biodiesel production from waste animal fat by transesterification using H_2SO_4 and KOH catalysts: A study of physiochemical properties, *International Journal of Chemical Engineering*, **2022**, 2022. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [61]. M. Gad, A.I. EL-Seesy, H.M.A. Hashish, Z. He, W. Alshaer, Combustion and emissions aspects of a diesel engine working with sheep fat oil biodiesel-diesel blends, *Case Studies in Thermal Engineering*, **2021**, 26, 101162. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [62]. a) R. Kumarasubramanian, P. Karthikeyan, S. Yuvaraja, G.S. Prasath, V. Praveenkumar, Performance and emission characteristics of nano emulsion biodiesel by using pork fat oil, *Materials Today: Proceedings*, **2021**, 44, 3707-3711. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)] b) S. Ismail, Botanical insecticides and mineral oils synergize toxicity of imidacloprid against *Bemisia tabaci* (Hemiptera: Aleyrodidae), *Progress in Chemical and Biochemical Research*, **2021**, 4, 295-304. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [63]. V. Telgane, S. Godiganur, H. Srikanth, S. Patil, Performance and emission characteristics of a CI engine fueled with milk scum biodiesel, *Materials Today: Proceedings*, **2021**, 45, 284-289. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [64]. S. Erdoğan, M.K. Balki, S. Aydın, C. Sayın, Performance, emission and combustion characteristic assessment of biodiesels derived from beef bone marrow in a diesel generator, *Energy*, **2020**, 207, 118300. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [65]. C. He, Y. Mei, Y. Zhang, L. Liu, P. Li, Z. Zhang, Y. Jing, G. Li, Y. Jiao, Enhanced biodiesel production from diseased swine fat by ultrasound-assisted two-step catalyzed process,

Bioresource Technology, **2020**, *304*, 123017. [Crossref], [Google Scholar], [Publisher]

[66]. A.P.S. Dias, M. Ramos, M. Catarino, M.F.C. Pereira, Biodiesel by co-processing animal fat/vegetable oil mixtures over basic heterogeneous Ca catalyst, *Cleaner Engineering and Technology*, **2020**, *1*, 100012. [Crossref], [Google Scholar], [Publisher]

[67]. B. Wang, S. Yan, W. Gao, X. Kang, B. Yu, P. Liu, L. Guo, B. Cui, A. Abd El-Aty, Antibacterial activity, optical, and functional properties of corn starch-based films impregnated with bamboo leaf volatile oil, *Food Chemistry*, **2021**, *357*, 129743. [Crossref], [Google Scholar], [Publisher]

[68]. M. Hasan, R. Rusman, I. Khaldun, L. Ardana, M. Mudatsir, H. Fansuri, Active edible sugar palm starch-chitosan films carrying extra virgin olive oil: Barrier, thermo-mechanical, antioxidant, and antimicrobial properties, *International Journal of Biological Macromolecules*, **2020**, *163*, 766-775. [Crossref], [Google Scholar], [Publisher]

[69]. C. Hood, S.M. Ghazani, A.G. Marangoni, E. Pensini, Flexible polymeric biomaterials from epoxidized soybean oil, epoxidized oleic acid, and citric acid as both a hardener and acid catalyst, *Journal of Applied Polymer Science*, **2022**, *139*, e53011. [Crossref], [Google Scholar], [Publisher]

[70]. a) J. Yang, Y.C. Ching, S. Julai J, C.H. Chuah, D.H. Nguyen, P.C. Lin, Comparative study on the properties of starch-based bioplastics incorporated with palm oil and epoxidized palm oil, *Polymers and Polymer Composites*, **2022**, *30*, 09673911221087595. [Crossref], [Google Scholar], [Publisher] b) Z. Abbasi, M. Ahmadi, Process optimization photo-esterification of free fatty acids in waste cooking oils under UV irradiation via the RSM method, *Chemical Methodologies*, **2023**, *7*, 799-824. [Crossref], [Publisher]

[71]. R.M.O. Syafiq, S.M. Sapuan, M.Y.M. Zuhri, S.H. Othman, R.A. Ilyas, Effect of plasticizers on the properties of sugar palm nanocellulose/cinnamon essential oil reinforced starch bionanocomposite films,

Nanotechnology Reviews, **2022**, *11*, 423-437. [Crossref], [Google Scholar], [Publisher]

[72]. D.S.d. Costa, K.P. Takeuchi, R.M.d. Silva, J.G.d. Oliveira Filho, M.R.V. Bertolo, C.M. Belisário, M.B. Egea, G.R. Plácido, Cassava-starch-based films incorporated with buriti (*Mauritia flexuosa* L.) oil: a new active and bioactive material for food packaging applications, *Polysaccharides*, **2022**, *3*, 121-135. [Crossref], [Google Scholar], [Publisher]

[73]. O. Chauhan, C. Nanjappa, N. Ashok, N. Ravi, N. Roopa, P. Raju, Shellac and Aloe vera gel based surface coating for shelf life extension of tomatoes, *Journal of Food Science and Technology*, **2015**, *52*, 1200-1205. [Crossref], [Google Scholar], [Publisher]

[74]. K. Chitravathi, O. Chauhan, P. Raju, Postharvest shelf-life extension of green chillies (*Capsicum annum* L.) using shellac-based edible surface coatings, *Postharvest Biology and Technology*, **2014**, *92*, 146-148. [Crossref], [Google Scholar], [Publisher]

[75]. T.G. Gutowski, The carbon and energy intensity of manufacturing, *40th Seminar of CIRP, Keynote Address, Liverpool University, Liverpool, UK*, **2007**. [Google Scholar], [Publisher]

[76]. E. Brinksmeier, D. Meyer, A. Huesmann-Cordes, C. Herrmann, Metalworking fluids—Mechanisms and performance, *CIRP Annals*, **2015**, *64*, 605-628. [Crossref], [Google Scholar], [Publisher]

[77]. S. Anton, S. Andreas, B. Friedrich, Heat dissipation in turning operations by means of internal cooling, *Procedia Engineering*, **2015**, *100*, 1116-1123. [Crossref], [Google Scholar], [Publisher]

[78]. M. Mahadi, I. Choudhury, M. Azuddin, Y. Nukman, Use of boric acid powder aided vegetable oil lubricant in turning AISI 431 steel, *Procedia Engineering*, **2017**, *184*, 128-136. [Crossref], [Google Scholar], [Publisher]

[79]. B.U. Anyanwu, D. Fadare, O.S. Issac Fayomi, P.O. Aiyedun, Exploring the potential of animal fats and vegetable oils as potential metal cutting fluids., *International Journal of*

Mechanical and Production Engineering Research and Development, **2020**, *10*, 1139–1146. [[Google Scholar](#)], [[Publisher](#)]

[80]. V.L. Mucci, M.E.V. Hormaiztegui, M.I. Aranguren, Plant oil-based waterborne polyurethanes: A brief review, *Journal of Renewable Materials*, **2020**, *8*, 579–601. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[81]. I. Singh, S.K. Samal, S. Mohanty, S.K. Nayak, Recent advancement in plant oil derived polyol-based polyurethane foam for future perspective: A review, *European Journal of Lipid Science and Technology*, **2020**, *122*, 1900225. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[82]. a) A.R. Unnithan, P.T. Pichiah, G. Gnanasekaran, K. Seenivasan, N.A. Barakat, Y.S. Cha, C.H. Jung, A. Shanmugam, H.Y. Kim, Emu oil-based electrospun nanofibrous scaffolds for wound skin tissue engineering, *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, **2012**, *415*, 454–460. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)] b) H. Jabbari, N. Noroozi Pesyan, Production of biodiesel from jatropha curcas oil using solid heterogeneous acid catalyst, *Asian Journal of Green Chemistry*, **2017**, *1*, 16–23. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[83]. J.H. Kim, A.R. Unnithan, H.J. Kim, A.P. Tiwari, C.H. Park, C.S. Kim, Electrospun badger (*Meles meles*) oil/Ag nanoparticle based antibacterial mats for biomedical applications, *Journal of Industrial and Engineering Chemistry*, **2015**, *30*, 254–260. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[84]. T. Amna, M.S. Hassan, J. Yang, M.S. Khil, K.D. Song, J. D. Oh, I. Hwang, Virgin olive oil blended polyurethane micro/nanofibers ornamented with copper oxide nanocrystals for biomedical applications, *International Journal of Nanomedicine*, **2014**, 891–898. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[85]. a) A. Rezaei, H. Ehtesabi, S. Ebrahimi, Incorporation of Saez essential oil into polyvinyl alcohol/chitosan bilayer hydrogel as a potent wound dressing material, *International Journal of Biological Macromolecules*, **2023**, *226*, 383–396. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)] b) J. Mejri, A. Aydi, M. Abderrabba, M. Mejri, Emerging extraction processes of essential oils: A review, *Asian Journal of Green*

Chemistry, **2018**, *2*, 246–267. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[86]. H. Mahmood, M. Asif, S.H. Khalid, I.U. Khan, Z. Chauhdary, F.A. Razzaq, S. Asghar, Design of a multifunctional carrageenan-tannic acid wound dressing co-loaded with simvastatin and geranium oil, *Journal of Drug Delivery Science and Technology*, **2023**, *79*, 104080. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[87]. R. Stacey, J. Taylor, Writing that cannot be erased: investigations of a box of pigmented inlays from the tomb chapel of an Old Kingdom noble, British Museum technical research bulletin, **2007**, *1*, 49–51. [[Google Scholar](#)]

[88]. D.G. Jarvis, T.M. Barrett, The Historical Use of Ochre Pigments in Newfoundland and Labrador, *Heritage NL Fieldnote Series*, **2019**, *3*, 18. [[Google Scholar](#)], [[Publisher](#)]

[89]. K.J. Van den Berg, I. Bonaduce, A. Burnstock, B. Ormsby, M. Scharff, L. Carlyle, G. Heydenreich, K. Keune, Conservation of modern oil paintings, Springer, **2019**. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[90]. I. W. Lane and H. H. Kriegel, The story of menhaden fish oil. The leading marine oil produced in the United States, *Journal of the American Oil Chemists' Society*, **2018**, *40*, a4–a7. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[91]. H. Fineberg, A.G. Johanson, Industrial use of fish oils, *US Bureau of Commercial Fisheries*, **1967**. [[Google Scholar](#)], [[Publisher](#)]

[92]. R. Ackman, Fish oils, *Bailey's Industrial Oil and Fat Products*, **2005**. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[93]. F.R. CK, T. Farooq, K. Sharun, S. Talukder, R.R. Kumar, Rendered animal fat: A boon to the cosmetic industry, *Indian Vet. J.*, **2022**, *99*, 20–26. [[Crossref](#)], [[Google Scholar](#)]

[94]. B. Mishra, M. Akhila, A. Thomas, B. Benny, H. Assainar, Formulated therapeutic products of animal fats and oils: Future prospects of zootherapy, *International Journal of Pharmaceutical Investigation*, **2020**, *10*. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[95]. S.M. Alshahrani, Preparation, characterization and in vivo anti-inflammatory studies of ostrich oil based nanoemulsion, *Journal of Oleo Science*, **2019**, *68*, 203–208. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[96]. C. Lee, Y.A. Eom, H. Yang, M. Jang, S.U. Jung, Y.O. Park, S.E. Lee, H. Jung, Skin barrier restoration and moisturization using horse oil-loaded dissolving microneedle patches, *Skin Pharmacology and Physiology*, **2018**, *31*, 163-171. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[97]. I.A. Abdalsamed, I.A. Amar, F.A. Altohami, F.A. Salih, M.S. Mazek, M.A. Ali, A.A. Sharif, Corrosion strategy in oil field system, *Journal of Chemical Reviews*, **2020**, *2*, 28-39. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]