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Review Article

A Short Review: The Use and Application of Matrix Resins Formed with Some Plant-Based Oils in Bio-Composite Materials

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ABSTRACT

Increasing environmental problems, waste recycling problems, and non-biodegradable resources have led researchers to different searches for composite materials in recent years. In these studies, interest in bio-composite materials known as green composites has increased significantly due to their potential to replace traditional materials in material production. The creation of biocomposite materials from natural fibers or natural resins instead of synthetic fibers and synthetic resins has made natural resources the focus of researchers. Among these natural resin formations, the use of vegetable-based oils in various applications has started to be seen frequently due to their low cost, biodegradability, and availability. In addition to being recyclable, vegetable-based oils are an important alternative in many sectors, especially in the chemical industry, both environmentally and economically, with a wide variety of chemical conversion possibilities. The desire to explore the versatility of vegetable oil components formed by the complex multi-component mixtures of fatty acids and glycerol ester accelerates the studies in this field even more. In this study, the chemical compositions of vegetable oils hybridized with different resins, the chemical structures of pure vegetable oils, the different varieties among these vegetable oils, and various types of biocomposites produced using vegetable oil-based resins were investigated. In addition, the latest trends in other applications of these bio-composites, especially in automotive, were examined.

Keywords: *Composites, Bio-composites, Matrix, Vegetable oils*

Kısa Bir İnceleme: Biyo-Kompozit Malzemelerde Bazı Bitki Bazlı Yağlarla Oluşturulan Matris Reçinelerin Kullanımı ve Uygulaması

ÖZ

Artan çevre sorunları, atık geri dönüşüm sorunu ve biyolojik olarak parçalanamayan kaynaklar son yıllarda araştırmacıları farklı kompozit malzeme arayışlarına yöneltmiştir. Bu çalışmalarda, malzeme üretiminde geleneksel malzemelerin yerini alma potansiyeli nedeniyle yeşil kompozitler olarak bilinen biyo-kompozit malzemelere olan ilgi önemli ölçüde artmıştır. Sentetik lifler ve sentetik reçineler yerine doğal liflerden veya doğal reçinelerden biyokompozit malzemelerin oluşturulması, doğal kaynakları araştırmacıların odak noktası haline getirmiştir. Bu doğal reçine oluşumları arasında bitkisel bazlı yağların düşük maliyeti, biyolojik olarak parçalanabilirliği ve bulunabilirliği nedeniyle çeşitli uygulamalarda kullanımı sık görülmeye başlanmıştır. Bitkisel bazlı yağlar geri dönüştürülebilir olmasının yanı sıra çok çeşitli kimyasal dönüşüm olanakları ile başta kimya sektörü olmak üzere birçok sektörde hem çevresel hem de ekonomik olarak önemli bir alternatiftir. Yağ asitleri ve gliserol esterin karmaşık çok bileşenli karışımlarından oluşan bitkisel yağ bileşenlerinin çok yönlülüğünü keşfetme isteği bu alandaki çalışmaları daha da hızlandırmaktadır. Bu çalışmada farklı reçinelerle bitkisel yağların kimyasal bileşimleri, bitkisel yağların kimyasal yapıları, bu bitkisel yağlar arasında hangi

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çeşitlerin ön planda olduğu ve bitkisel yağ bazlı reçineler kullanılarak üretilen çeşitli biyokompozit türleri incelenmiştir. Ayrıca bu biyokompozitlerin başta otomotiv olmak üzere diğer uygulamalardaki son trendlerin neler olduğu incelenmiştir.

Anahtar Kelimeler: *Kompozitler, Biyokompozitler, Matris, Bitkisel yağlar*

I. INTRODUCTION

Efforts to ensure proper fuel economy, emissions requirements, and reduce dependence on unnatural energy sources are key drivers in improving vehicle efficiency in the automobile industry. Keyways to improve efficiency are through powertrain improvement and mass reduction by using lighter materials. In an industry where material properties are important, such as the automotive industry, researchers have turned to many different areas to reveal safe, light, and inexpensive materials. In these researches, bio-based composites are one of the prominent areas for future applications in the automotive industry. However, the increased awareness of environmental protection in the world encourages manufacturers and researchers to innovate in the field of composite and bio-composite materials [1],[2]. Composites are heterogeneous material combinations consisting of a load-bearing reinforcing element and a matrix material that holds these elements together. Especially in the automotive, construction, aviation, defense industry, and food sector, it has found an important commercial use area and has recently covered more and more space in the material sector. Estimates in the global composites industry indicate that a product market of 113.2 billion dollars will be formed by 2022 [3]–[5]. Characteristics of polymers in these areas are modified to meet high strength/high modulus requirements through fillers and fibers. Fiber-reinforced polymers emerge as materials that show significant advantages in comparison to other conventional materials in certain properties [6], [7]. Natural fibers are the most preferred for reinforcement elements in composite materials because they are easy to process, light, non-abrasive, cost-effective, and biodegradable. In addition, natural fiber usage as a reinforcement in polymer materials provides appropriate strength and hardness values, as well as weight reduction. These materials, which have significantly superior properties to traditional materials, increase the tendency towards natural fibers in various sectors such as construction, space and aerospace, the defense industry, and automotive [8]–[12]. Commonly used natural fiber types comprise jute, hemp, flax, ramie, kenaf, abaca, sisal, cotton, and kapok. Matrix structure is the main factor in determining the overall durability, shape, environmental tolerance, and surface appearance of composites. In general, matrix structures are also used in polymer materials such as petrochemical-based thermosets and thermoplastics, and bio-based resins [13]-[15]. Although thermoplastics are the most widely used matrix materials with natural fiber polymer composites, unlike thermosets, their re-mouldability features reveal the possibility of using raw materials effectively in the recycling of materials. Thermosets are a type of polymer that irreversibly transforms from a liquid solution to a solid material after curing by an external effect such as heating or ultraviolet radiation. Examples of thermoplastics are polyethylene, polyvinyl chloride, polypropylene, and polystyrene, while thermosets are polyester, epoxy, vinylester, and polyurethane [16]-[18]. Among the thermosets, epoxy resins are known for their excellent modulus and strength, good chemical resistance, and high dimensional stability, while various green approaches are also being studied to minimize the brittleness of the epoxy, significantly reduce the viscosity and increase the workability [19], [20]. Biocomposites formed by synthetic or natural polymer matrices and natural fibers come to the fore with their cost-effectiveness, not harming the environment, and having characteristics that can compete with synthetic composites Although biocomposite materials do not currently provide the same performance as synthetic composites, it is stated that they will become more common as new materials and production technologies develop [21]-[23]. The development of partially green composites in which the matrix and reinforcing elements are biodegradable, and wholly green composites, where obtained from renewable resources and encompass reinforcement and matrix materials are biodegradable, are also ongoing [24]. The danger of risk of petroleum sources, the increase in recognition for environmental protection, and the increasing concern for non-biodegradable wastes have accelerated the emergence of bioresins, which are called green resins instead of thermosets and thermoplastics and have begun to popularize their use. Although bioresin is a resin that depends on vegetable oil and other natural components, it also has the potential to be seen as an important resin for use in various applications, sensitive to the atmosphere, and with minimized toxic effects [25]–[27]. Vegetable oils are an important auxiliary element for polymers, which have emerged as an important alternative to petroleum-based polymers at this point, on the way to becoming renewable materials [28]–[30]. Vegetable oils have increasingly become a focus in both academia and industry, with low environmental impact and sustainability. In addition to its use in foods since the past, vegetable oils have taken their place in many areas such as paint solvents, polishes, and lubricants [31]–[33]. In Figure 1, the life cycle of vegetable oil-based polymers is given.

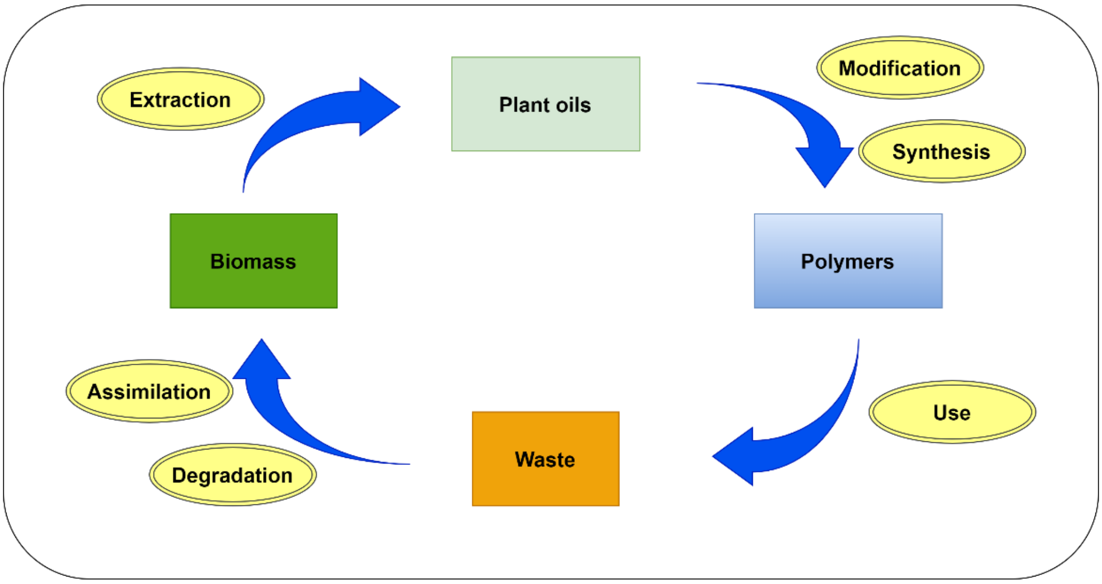

Figure 1. *Life-cycle of vegetable oil-based polymers [34]*

Natural oils, which are known as the most important group in renewable resources, can be obtained from plants found in nature such as flaxseed, cotton, and sunflower. While 20% share in fat production and global oil is from animal sources, approximately 80% belongs to vegetable oil. Soybean is the leading vegetable oil with 25%, followed by palm oil, rapeseed, and sunflower oil [34], [35]. The composition of vegetable oils from unsaturated triglycerides indicates a promising potential for forming cross-linkable bioresins. The use of chemically modified fatty acids and vegetable oils as sustainable polymer formation and reactive modifiers is increasing. Saturated and unsaturated fatty acids form the main component in triglyceride vegetable oils. Chemical modification and back-polymerization, direct polymerization of double bonds, and polymerization of monomers synthesized using vegetable oil-derived chemicals are preferred in converting vegetable oils into polymeric materials [36]–[38]. While natural triglyceride oils are used for composite materials, polymers, and adhesives, epoxidized triglyceride oil also has the ability to react with an amine or anhydride hardener to produce an epoxy matrix resin [39]. When it comes to epoxy resins, epoxidized vegetable oils are the focus of research as resin components of renewable origin in composite matrices formed by epoxidation of various bio-based oils [40]. Epoxidation is an important and useful exchange modification using double bonds in unsaturated fatty compounds [41]. Epoxidation can be performed especially when the product is used in other chemical transformations, to achieve maximum transformation or to obtain a product in the most economical way [42]. The bond angles between the molecules are approximately 60°, causing the ring to become highly tense and reactive. The presence of these high-energy rings of fatty acid chains leads to crosslinking during the curing of the epoxy resin, and the high amount of epoxy rings opened can cause the cross-linking to be at the same rate and the quality of the obtained material increases at that rate [43]. There are many studies in which the epoxidation of unsaturated fatty acid derivatives such as long chain olefins, soybean oil, and other vegetable oils has been applied in the industrial field [44]. Parada Hernandez et al. [45] investigated the epoxidation process of castor oil using different reagents and aimed to create a green system by freeing the catalyst system from heavy metals and poisoning effects. The outcomes of the research indicate that the use of epoxidized castor oil can provide a significant increase in the efficiency of the system and that the catalyst system can be used in different areas with an environmentally friendly approach. Esen et al. [46] aimed to create a new thermoset polymer material from renewable resources by reacting epoxidized soybean oil with a different catalyst. They showed that the new polymer they created revealed a new type of liquid resin potential with superior physical properties. Akesson et al. [47] tried to create a composite structure with different fibers without adding a reactive comonomer to acrylate epoxidized soybean oil. As a result of the different mechanical tests of the composite structure they produced, they concluded that a product with superior properties could be fabricated without the addition of reactive comonomers such as styrene. Liu et al. [48] combined four diverse bio-based thermoset resins and two distinct fibers to specify the mechanical and physical characteristics of their composites. The results of the study stated that in addition to maintaining the high bio-based content in the bio-composites they produce, they show superior properties as compared to their traditional bio-based or petroleum-based counterparts. Can et al. [49] aimed to produce rigid thermosetting resins such as vinylester and polyester from soybean oil monoglyceride maleates with styrene. As the mechanical properties and swelling behavior of the obtained materials were examined, an environmentally friendly, cost-effective material whose mechanical characteristics are close to polyesters and vinylester was obtained. The effect of bioresins on the mechanical and thermomechanical features of the composites prepared in the search [50], in which two bioresins such as epoxy methyl soybean and epoxidized soybean oil and sisal fiber used, were investigated. While the tensile and flexural properties of bioresin-modified epoxy composites gave better results than petroleum-based epoxy composites due to cellulosic fiber-matrix interaction. The morphological results showed that strong interface adhesion provided improved mechanical characteristics in bioresin-modified epoxy composites. Sahoo et al. [51] examined to prepare an environmentally friendly composite material by combining sisal fibers and petroleum-based epoxy with epoxidized linseed and castor oils. Mechanical, morphological, thermal, and dynamic mechanical tests have revealed that a sustainable bio-composite with approximately 60% biological origin content has been developed for automotive and structural applications with a significant shock absorbing ability. Park et al. [52] prepared and thermally tested novel types of epoxy resins using epoxidized castor oil and epoxidized soybean oil. It was seen in the results that epoxidized castor oil resin added to N-benzylpyrazinium hexafluoroantimonate had a lower coefficient of thermal expansion and higher glass transition temperature than epoxidized soybean oil resin. In their study, Tan and Chow [53] examined the cure rate, crosslink density, water absorption capacity, flat strain fracture toughness, and degree of transformation in the resin formed by adding three different curing agents to epoxidized palm oil. They found that as the amount of epoxidized palm oil in the resin increased, higher fracture toughness, more water absorption capacity, and lower crosslink density were observed. Jin and Park [54] compared the thermal and thermomechanical properties of homogeneous resin and the resin they prepared by introducing bioresin from epoxidized castor oil and epoxidized soybean oil and diglycidyl ether of bisphenol A materials. In the analyses, the coefficient of thermal expansion increased linearly with increasing epoxidized vegetable oil-based content, while the thermal stability decreased due to the lower crosslinking density with increasing epoxidized vegetable oil-based content. In the study of [55] on bioresin, epoxidized hemp oil-based bioresin and epoxidized soybean bioresins reinforced with jute fiber were prepared. The biocomposites were compared mechanically, thermally, and physically, both as two different bioresins and with biocomposites formed with synthetic epoxy resin. The mechanical characteristics of both epoxidized hemp oil biocomposites and epoxidized soybean oil biocomposites were adversely affected with bioresin content exceeding 30%. Miyagawa et al. [56], [57] applied thermal, mechanical, and dynamic tests to the new biobased resins they created by treating biobased epoxies including epoxidized linseed oil with anhydride and amine hardener. While there is a decrease in dynamic mechanical properties and glass transition temperature due to the increase in the amount of epoxidized linseed oil, no phase separation was detected because of morphological analysis. This article focuses on the chemical structure, epoxidation, production methods, availability, mechanical and chemical properties, and areas of use of vegetable-based oils most commonly used in the literature in biocomposites. Moreover, it includes the latest studies on products produced for use in different sectors related to biocomposites formed by vegetable oil-based matrices.

II. PLANT OILS

In general, while there are different types of vegetable oil such as soybean oil, cottonseed oil, canola oil, olive oil, palm oil, corn oil, linseed oil, and rapeseed oil, it has been determined that the four most important vegetable oil types on a global scale are sunflower oil, palm oil, soybean oil, and rapeseed oil. It has been determined that these four oil types cover more than 80% of the sector. Oil production has been increasing year by year in the world since the 1980s, with the increase of mechanization, better farming methods, science, and technological advances. Palm oil production in Malaysia or soybean production in Brazil is of great importance due to the palm tree's adaptation to growing conditions and mechanized agriculture [58], [59]. Vegetable oils are triglyceride structures consisting of three fatty acids linked to glycerol by ester bonds as in Figure 2. The combination of fatty acids shifts depending on growing states and oil source. The diversity of the fatty acids in the triglyceride and their chemical structures have differentiated the usage area of each triglyceride. For instance, because linseed oil contains reactive unsaturated fatty acids, its unsaturated bonds enter a curing reaction with atmospheric oxygen and are preferred as a paint binder. In current studies, three-dimensional networks formed by vegetable oils, defined linear structures, and the use of matrices in biocomposites and hybrid materials are examined [60], [61]. Figure 3 indicates the chain structure of the commonly used fatty acid in polymers.

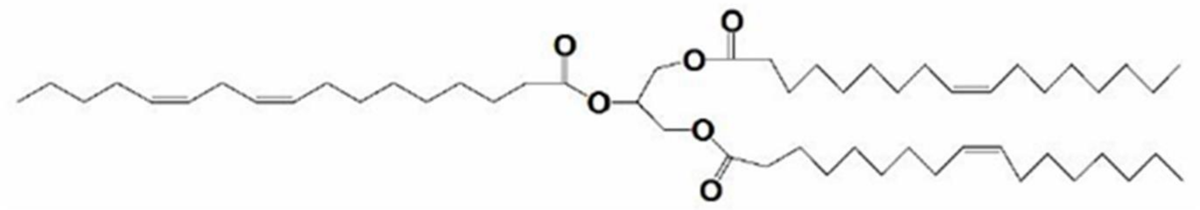

Figure 2. *Triglyceride molecule structure[60]*

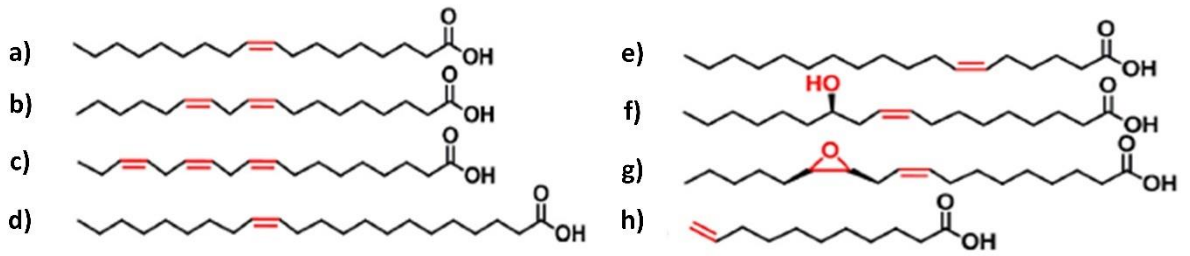

Figure 3. *Commonly used fatty acids in polymers; (a) oleic acid, (b) linoleic acid, (c) linolenic acid, (d) erucic acid, (e) petroselinic acid, (f) ricinoleic acid, (g) vernolic acid, (h) 10-undecenoic acid [62]*

A. SOYBEAN OIL

Soybean oil is known to be the most attractive type of vegetable oil because it is very affordable and available in ample supply. Soybean oil is distinguished from other vegetable oils due to its different composition as indicated in Table 1 and an effective reactive diluent or hardener after epoxidation treatment. Resins and plastics are also major classes in industrial soybean oil use. Soybean oil is basically a kind of oil constitute of triglyceride molecules derived from unsaturated acids. While unsaturated acids are required to be functionalized by adding epoxy, carboxyl, or hydroxyl groups for use in the formation of polymeric materials, they have double bonds that are reactive sites for paints and coatings [63]–[65]. By changing the triglyceride structure from soybean oil by epoxidization and acrylation process, acrylated epoxidized soybean oil (AESO) is obtained as in Figure 4.

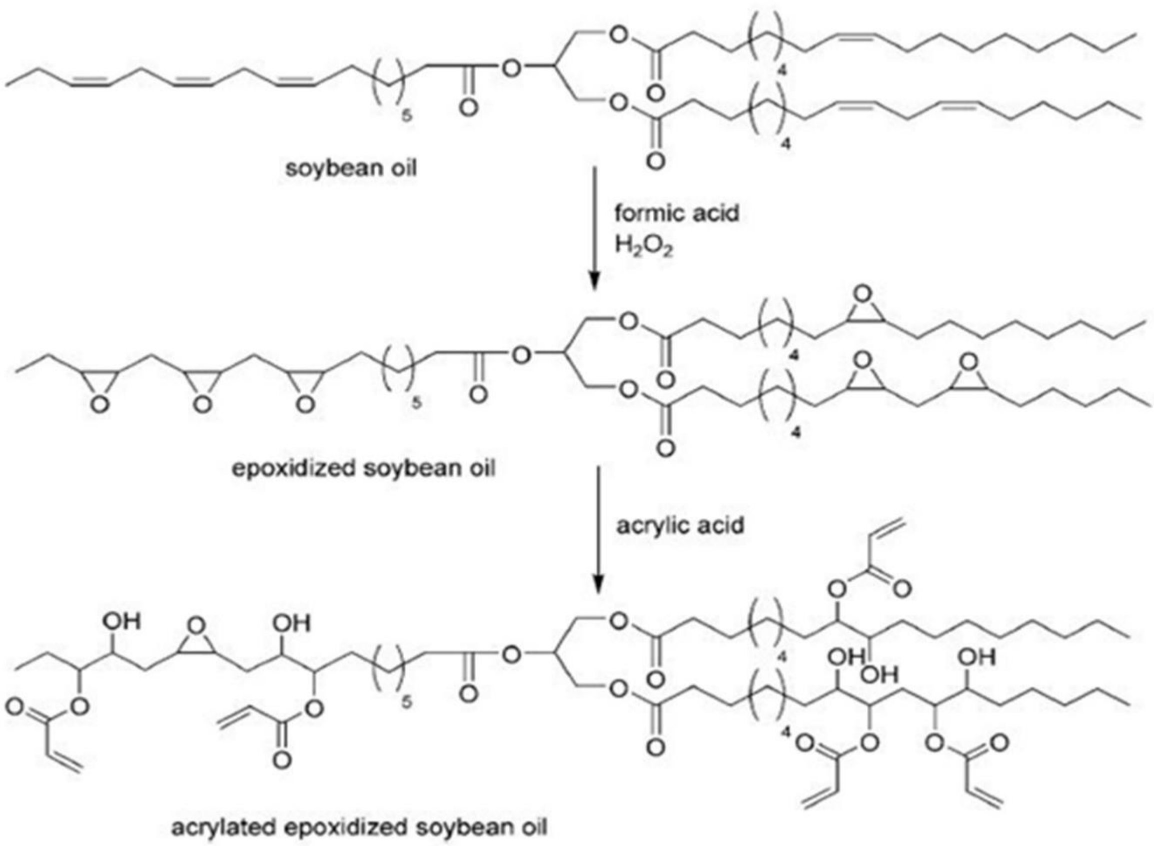

__Figure 4.__ Demonstration of acrylated epoxidized soybean oil synthesis [66]

Thus, soybean oil can be turned into a green composite matrix. Epoxidized soybean oil (ESO) is utilized as a plasticizer in polyvinyl chloride. Mechanical strength in cured ESO can be improved by the addition of fiber reinforcement or nano-reinforcements. However, its low glass transition temperature limits the use of the resin in practical applications. The acrylate epoxidized soybean oil, known for its non-volatile and non-toxic properties, is obtained by the epoxidation process of soybean oil and its reaction with acrylic acid. The low degree of unsaturation and long aliphatic chains cause low crosslinking capacity in acrylate epoxidized soybean oil, while at the same time, this oil is known to be highly viscous at room temperature [67]–[69]. By mixing AESO with some reactive diluents, its workability is improved and thermosets and composites suitable for structural applications can be produced. This situation creates the opportunity to use biopolymers in different properties and applications, making it an important option to use instead of petroleum-based polymers [70]. With alterations that can simplify the polymerization of soybean oil, solid films, and composite materials that can be used in automotive, aviation, military, marine, infrastructure, sports, and industrial areas are revealed [71].

__Table 1.__ Compositions of certain plant-based oils [9], [72]

Natural oils	**Fatty acids (%)**						
	Oleic	**Palmitic**	**Stearic**	**Linoleic**	**Linolenic**	**Arachidic**	**Gadoleic**
Soybean oil	23.4	11.0	4.0	53.3	7.8	0.5	0.37
Palm oil	40.5	42.8	4.2	10.1	-	-	-
Rapeseed oil	56.0	4.0	4.2	26.0	10.0	-	-
Cottonseed oil	18.6	21.6	2.6	54.4	0.7	0.21	0.12
Linseed oil	19.1	5.5	3.5	15.3	56.6	0.5	0.12
Canola oil	64.0	4.3	2.0	18.4	7.2	0.6	1.1

B. RAPESEED OIL

In vegetable oil-based polyols, seed oils consisting of rapeseed, sunflower, and flowering plants of the Camelina sativa type are the subject of research as sustainable sources [59]. The formation of rapeseed oil consists of chemically saturated and unsaturated fatty acid triglycerides. Unsaturated C=C bonds cause poor oxidative stability as well as polyunsaturated compounds such as linolenic and linoleic acids [73]. It is stated that the conversion efficiency of unsaturated triglycerides in rapeseed oil is 95% and can be epoxidized enzymatically [74]. For use in industrial applications, rapeseed oil is most abundant in Europe and palm oil in Asian countries, while soybean oil is the most abundant oil in the United States and South America. Classification of vegetable oils according to their iodine values. The iodine value (IV) for oils is known as the amount of iodine (mg) reacting with the double bonds in 100 grams of oil and is the critical point in understanding the degree of unsaturation of vegetable oil. Those with IV>130 are defined as drying oils, those with 100<IV<130 as semi-drying oils, and those with IV<100 as non-drying oils. Soybean and rapeseed oils are known as semi-drying oils, and fish oils and linseed are drying oils [66], [75]. Fatty acid esters of rapeseed oil may find use as a solvent for printing ink, replacing conventional organic solvents, or in some detergent applications such as car shampoos. It is also stated that epoxidized rapeseed can be used as a biodegradable lubricant by tribo-polymerization on the friction surface, revealing a polyether material [59], [76].

C. CANOLA OIL

In canola oil, Canada appears to be the second largest oil producer and largest exporter country in the world. The fact that canola oil consists of approximately 60% oleic acid makes it the most important choice for epoxidation. In terms of the amount of oleic acid it has, canola oil differs in terms of fatty acid profile compared to the polyunsaturated linoleic acid content (53%) in soybean oil. Another notable distinction between these oils is that canola oil (6%) has a lower content of saturated fatty acids than soybean oil (15%). Therefore, the general characteristic in canola oil-based resins is attributed to both unsaturation and saturation levels. This fatty acid form of canola oil explains why it is a suitable choice for epoxy resins, as saturated fatty acids cannot be epoxidized and therefore cannot accompany the formation of polymers. It is stated that epoxidized canola oil (ECO) can be used as a raw material for the chemical industry and also as a promising source of biological lubricating oil [77]–[79]. While maleinized acrylate epoxidized canola oil and acrylated epoxidized canola oil-based resins are synthesized with various resins in the industry, the acrylated epoxidized canola oil-based resin shows a superior character in resin impregnation ratio [59].

D. PALM OIL

Palm oil is of particular importance in the Asia-Pacific region, with Malaysia and Indonesia being the main producers. In addition to these countries, Thailand can also produce large amounts of palm oil for both domestic consumption and export. However, palm trees provide an economic advantage at affordable costs, with the highest vegetable oil yield compared to other sources such as castor oil and coconut, with 3.8 tons per hectare per year [80], [81]. Figure 5 demonstrates the processing steps of crude palm oil. Palm oil biomass has come to the fore recently, as it is readily available in some tropical countries and attracts great interest in the composite industries [82]. Palm oil can be used as a good reinforcement in polyester resins due to its porous surface morphology, toughness, and hardness, and better mechanical bonding in composite production [59]. In addition to the non-food sector, the usage area of palm oil products is increasing in the fabrication of pharmaceutical products, soap and detergent production, and cosmetic products. Palm oil holds promising potential as a renewable raw material that can be used as a substitute for industrial chemicals. It is stated that most of the palm oil-based products in coatings that can be cured with ultraviolet rays are obtained from epoxidized palm oil [83], [84].

Figure 5. *Palm oil production steps [59]*

E. LINSEED OIL

Natural oils from products obtained from agricultural sources can form useful raw materials for polymer synthesis. Generally, unsaturated fatty acids such as linseed oil are preferred in covering and printing inks, and epoxidized oils are preferred as supplements in thermoplastics to enhance flexibility and stability [85], [86]. Its unique structure in non-edible oils makes flaxseed oil stand out in applications such as reducing the natural fragility effect of epoxy. Linseed oil is known as drying oil with its high iodine values. It indicates that the higher the iodine value in the oil, the more double bonds it has in the oil. Thus, flaxseed oil has a good chemical reaction with its many double C bonds. This, in turn, leads researchers to explore higher performance bio-based or sustainable polymers with highly unsaturated or reactive regions [87]–[89]. In addition, many researchers have examined the drying properties of linseed oil in commercial applications such as varnishes, oil-based paints, linoleum, paste, and so on [90]. Epoxidized linseed oil is also widely chosen as a plasticizer in epoxy resins, Polyvinyl chlorides for flexibility, and coatings and adhesive applications [91].

F. COTTONSEED OIL

Cotton seeds are not only preferred as animal feed but are also used as edible oil and lubricant. India, which has the second largest share in cotton seed production in the world, is also known for being an agricultural country. When the situation of cottonseed oil in India is examined in this way, it is a cost-effective and useful oil type during resin production in surface coating applications [92], [93]. The rate of unsaturated (65-75%) fatty acids to saturated (26-35%) fatty acids in cottonseed oil is 2:1. Unsaturated fatty acids contain 18-24% monounsaturated and 42-52% polyunsaturated fats. In addition, the existence of double bonds and ester bonds makes cottonseed oil a potential crude material for the manufacturing of vegetable oil-based resins. This high degree of unsaturation of cottonseed oil creates different solutions in terms of chemical conversion in producing polyurethanes with various characteristics [94], [95]. Although cotton crops are primarily cultivated for cotton fiber production, they are also the sixth largest source of vegetable oil in the world. A small amount of the oil produced is used in the formulation of cosmetics and other industrial uses, in the production of pesticides, explosives, and rubber [96]. Cottonseed oil emerges as a by-product of high cotton plant production in the cotton industry and is also used for some applications in the food industry. However, new additional uses are being developed for the production of high-volume cottonseed oil [82].

III. APPLICATIONS OF PLANT OILS IN DIFFERENT INDUSTRIES

Researchers have turned to biodegradable biomaterial applications consisting of bioderived components, with low energy consumption, due to the expensiveness of the materials that make up most traditional composite material systems, and the low probability of the materials that make up the synthetic composites dissolving and decomposing again. Bio-composites can be used with or replace petroleum-based composite materials in a variety of applications, thus opening beneficial possibilities for production and consumer as well as environmental and agricultural aspects. As the number of raw materials obtained from renewable resources increases, the possibility of integrating bio-composites into the natural cycle increases. Environmental awareness on a global basis, laws, and agreements put forward by governments will lead to more environmentally friendly bio-based materials, especially in the automotive sector [97], [98]. In the automotive industry, it is aimed to use of biocomposites in order to provide better insulation against sound and heat in the door panel, ceiling panel, and panels separating the engine and passenger compartments, to reduce costs and to ensure sustainability, and biocomposite integrated studies are tried [99]. In addition, the good damping characteristics found in soybean oil biopolymers make them widely used in automobile, aircraft, and machinery industries as damping materials to reduce unwanted noise, and prevent vibration fatigue [100]. In a research conducted by Ford Motor, composites were developed using natural fibers, soy resin, sisal, and hemp in the production of exterior body panels, and other automotive companies such as Toyota, Mercedes Benz, and General Motors have been developing bio-based composites in recent years [101]. Moreover, it is also stated that with the development of bio-based resins such as bio-based polyols and biodegradable polyesters for automotive designers, completely bio-based composite options will emerge [102]. Oztemur et al. [103] aimed to design shock absorbing panels using denim waste and bio resin. It was revealed that as the amount of AESO mixture in the epoxy resin they used with the reinforcement material increased, the composite material showed a more ductile feature and the impact absorption capacity of the composite material increased. Considering the results, it has been observed that both environmental and especially AESO-added samples can serve as shock absorbing panels in different usage areas such as automotive and construction, due to their impact resistance features, with the contribution of the material with bio-resin content to solid waste management. Flanigan et al. [104] used hemp fiber as natural fiber and soy-based vinyl ester and vinyl ester resin as resin in their study. They concluded that by using soy polyol, flexible, polyurethane foams with soy content can be created fulfilling the material requirements for automotive interior applications. The foam compositions created meet the required norms of indoor applications, such as flammability, density, and odor. Pin et al. [105] searched the use of biobased materials depending on epoxidized linseed oil in electronic applications by improving the mechanical properties. The side reaction of the polymerization was strengthened by selecting the appropriate hardener with the cross-linking carried out. In the results of the study, improved mechanical characteristics were found in the materials with crosslinking. Thus, a very high glass transition temperature was obtained and the possibility of using them in industrial applications was revealed. Haq et al. [21] aimed to produce biocomposites with unsaturated polyester and epoxidized soybean oil, which are both environmentally friendly and with enhanced mechanical features. However, they found that hygro-thermal and hardness characteristics worsened compared to materials formed with the polyester resin used without epoxidized soybean oil. They tried to achieve optimum resin and fiber compatibility by reinforcing this deficiency with nano clays at a certain rate. As a result of the study, it has been stated that sustainable bio-based materials with improved versatile characteristics can be used in structural application areas such as transportation and housing. In research on bio-epoxies, it was found that remarkable tensile and impact strengths could be obtained with composites containing four-layer denim fabric with bio-epoxy and AESO content. The products produced as a result of the study are automotive interiors, construction, entertainment, furniture, etc. has the opportunity to be used in application areas [106]. The use of bio-based polyurethane foams in automotive applications is given in Table 2.

Table 2. *Applications of bio-based materials in the automotive industry [107]*

Materials	Type	Applications
Soybean oil	Flexible foams	Seatbacks and seat-cushion, soy-foam headliner, arm and headrest
	Flexible and rigid foams	Instrument panels, impact-absorbing foams, headliners, arm and headrests, noise, vibration, and harshness/under carpet foams, consoles and door panels and automobile seats, bumper ribbon, and body panels
Castor oil	Flexible and rigid foams	Arm and headrests and automobile seats
Sunflower oil or castor oil	Flexible and rigid foams	Automobile seats
	Flexible foams	Feasible for automobile seats

Developed oil-based plastics have been widely used in applications such as railway infrastructure, bridges and highway components, offshore equipment, pipes in marine structures, chipboard in the construction industry, ceilings, and processed timber, apart from the automotive field [108]. In their study, Hong and Wool used keratin fibers as a reinforcing element compatible with AESO resin. They stated that the biocomposites they created using keratin and AESO are low-k dielectric materials that can be applied in modern high-speed microelectronics [109]. Miao et al. created epoxidized soybean oil-based paper composites using poly-epoxidized soybean oil. They stated that with this biocomposite material they created, vegetable oil-based water-resistant composites can be used in the packaging material sector [110]. In their study, Kumar et al. examined the use of AESO resin in paper coating applications. They presented that the AESO resin coatings they created have high thermal stability, that their mechanical properties give better results than uncoated papers, and that they will have wide application possibilities in food and industrial packaging materials with their high transparency characteristics [111]. O'Donnell et al. [112] create re-composite products based on vegetable oil using natural fiber supplements of hemp, flax, cellulose, and pulp. It has been understood that composites, which have become cost-effective with the use of natural fiber and plant-based resin, have the necessary mechanical durability and characteristics that can be used in automotive parts, construction materials, and furniture applications. In the field of agricultural machinery, there are studies of agricultural machinery using a new bioresin-based side panel. There are studies to develop high-strength composite panels and cabin roofs with soybean and corn-based polymer content. With the improvements, it is stated that corn/soybean-containing composites provide flexibility, durability, and corrosion resistance to the panels together with 25% lightness compared to the standard used steel [113]. In the study of a company producing composite materials, a bio-based prepreg train seat arm support production study was carried out as seen in Figure 6. The seat support is manufactured using 100% biological polyfurfuryl alcohol resin with high-strength carbon fiber reinforcement. Owing to these newly designed seat supports, easier cleaning and increased space in the luggage compartment, reduced energy consumption, and lower axle loads can be achieved with the composite structure with reduced weight [114].

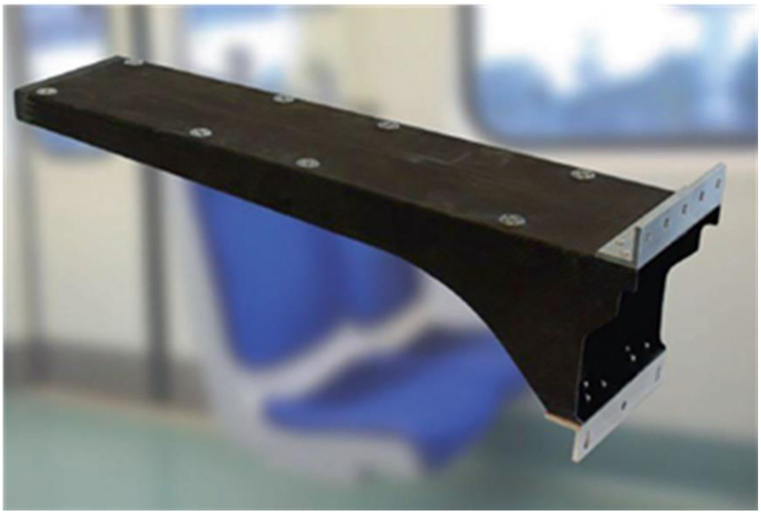

Figure 6. *Train passenger seat support made of fire resistant bio-resin prepreg [114]*

In the study of Jiang et al. [115], they added Mycelium, the vegetable part of a mushroom, to biocomposite materials, allowing it to act as a natural adhesive. They aimed to create an advantage over traditional synthetic composites with affordable cost, biodegradability, low density, and reduced energy consumption in the biocomposites they created using natural fibers such as flax and jute. As a result of the study, they stated that the open sandals they made could be made with different natural fibers and bioresins, and the design diversity would increase by changing the shape of the mold. In another study, in which mycelium was used to create biocomposites, jute fabrics were cut according to the shoe mold, and different production methods were compared. It was concluded that die cutting method, dip and soak coating, curtain coating, microwave drying, and match mold forming is the optimal choice for the manufacturing line [116]. In another study, Dweib et al. [117] wanted to fabricate a bio-based composite roof panel using cellulose fiber and acrylate epoxidized soybean oil. The outcomes of the search indicate that composite products with good mechanical performance, suitable for use in roof structures with appropriate operational and material costs, can be produced. It is seen that the applications of vegetable oil-based polymeric materials are not limited to industrial areas, but also find wide use in various biomedical applications such as pharmacological patches, drug carrier scaffolds for tissue engineering, surgical sealants, and adhesives, wound healing devices. Renewable oils have also been proposed as composite matrices since the innovative studies started in the last years of the 20th century and it is stated that this trend continues as a developing trend with promising results [62].

IV. CONCLUSION

This article contains a brief review of the research on the chemical structures of plant oils in the matrix structure of biocomposites formed based on vegetable oil and the applications of these vegetable oils in different sectors. In the study, it has been seen that vegetable oil-based biocomposites will have an increasing use rate in future applications in many industrial sectors, including the automotive sector, which has a leading role in technological and industrial developments. Considering the environmental and energy problems in the world, it will be inevitable to change many traditional production materials as potential materials of plant-based composite products, which can be obtained from nature, can blend harmoniously with many materials, and contribute to the environmental cycle. The use of plant-based biocomposites will reduce the dependence on petroleum-based resins and reduce costs in many sectors, as well as increase the sustainability and productivity of these industries and provide added value. Considering that vegetable oil-based polymers were created in the recent past to partially replace synthetic polymers in providing green materials to industries, the trend towards green composites under the current circumstances will increase even more in the coming years, with good compatibility and overall performance in composite manufacturing.

V. REFERENCES

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