

Applications of Various Plasticizers in the Plastic Industry - Review

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Abstract

Poly (vinyl chloride), PVC has extensive applications due to the incorporation of plasticizers on it. Plasticizers are known to make PVC polymers flexible, malleable, and easy to process. The paper addresses a general overview of plasticizers which encompasses the definition, types, examples and sources of it. Petroleum based plasticizers are known to be toxic in nature and can be detrimental to human's health. For this reason, bioplasticizers have been introduced to the plastic industry due to its low toxicity, leachability, enhanced thermal and mechanical properties and its high compatibility with PVC. The paper also listed the properties of plasticizers, its various applications, and a brief summary of research works that applied plasticizers to PVC.

Keywords: *Plasticizer, Phthalate, leachability polymers, bioplasticizer*

INTRODUCTION

Over the years, plasticizers have played a major role in the plastic industry as it is used as additives in polymers such as poly (vinyl chloride). Generally, unplasticized PVC has limited applications like pipes, window profiles and siding. This is due to its hard and brittle nature caused by the presence of the Cl-Cl bond. To improve the mechanical and thermal properties of PVC, plasticizers are introduced into the polymer (Unar *et al.*, 2010). Furthermore, the plasticizers also provide sufficient elasticity, flexibility, and malleability to the final products. Plasticizers simply refers to low molecular weight compounds added to polymers to lower glass temperature and increase processability, workability and ductility (Wei *et al.*, 2019).

However, owing to environmental and health issues, the plastic industry is gradually shifting its research focus from the traditional phthalate-based plasticizers to bio-based plasticizers (Mekonnen *et al.*, 2013). Additionally, the limited amount of petroleum resources to which the phthalates can be produced, has resulted in many researches to be directed towards using bioplasticizers. The bio-based plasticizers are renewable in nature and prevent their leaching. Moreover, it's less toxic and ecofriendly (Tong and Hai, 2018; Lee *et al.*, 2018). Some researchers have synthesized and applied bioplasticizers with PVC. For instance glycerol esters, succinate esters, isosorbide, fatty acids, castor oil derivative, plant oils, lactic acid, and citrate esters (Lavorgna *et al.*,

2010; Stuart *et al.*, 2010; Yin and Hakkareinen, 2011; Jia *et al.*, 2015; Jia *et al.*, 2016; Fernandez *et al.*, 2015; Chavan and Gogate, 2015; Gil *et al.*, 2006).

This paper gives an overview of plasticizers, its types, properties and applications. It also enumerates the sources of bioplasticizers and provides a brief review of research works that applied plasticizers.

WHAT ARE PLASTICIZERS?

Plasticizers are chemical substances used in the plastic industries to modify (or enhance) the mechanical properties of plastic products. They usually are low in molecular weight and exist in liquid (rubbery) form (Wypych, 2004). Thus, when plasticizers are added to a polymer (poly vinyl chloride, PVC) it makes the polymer softer and can be used for other purposes. This is made possible as the glass temperature (T_g) of the polymer is reduced by the plasticizer (Kumar, 2019).

TYPES OF PLASTICIZERS

Currently, we have 500 plasticizers of which phthalates and adipates are the most widely used plasticizers (Stedile *et al.*, 2015). Plasticizers can be grouped into two classes – namely the petroleum based and the bio based plasticizers. The petroleum-based plasticizers include; dioctyl phthalate (DOP), dioctyl terephthalate (DOTP), diallyl phthalate (DAP), buytlbenzene phthalate (BBP), diethyl phthalate (DEP), etc.

Table 1 gives the list of some common phthalates used in the plastic industry and Figure 1 gives the chemical structure of some petroleum based plasticizers.

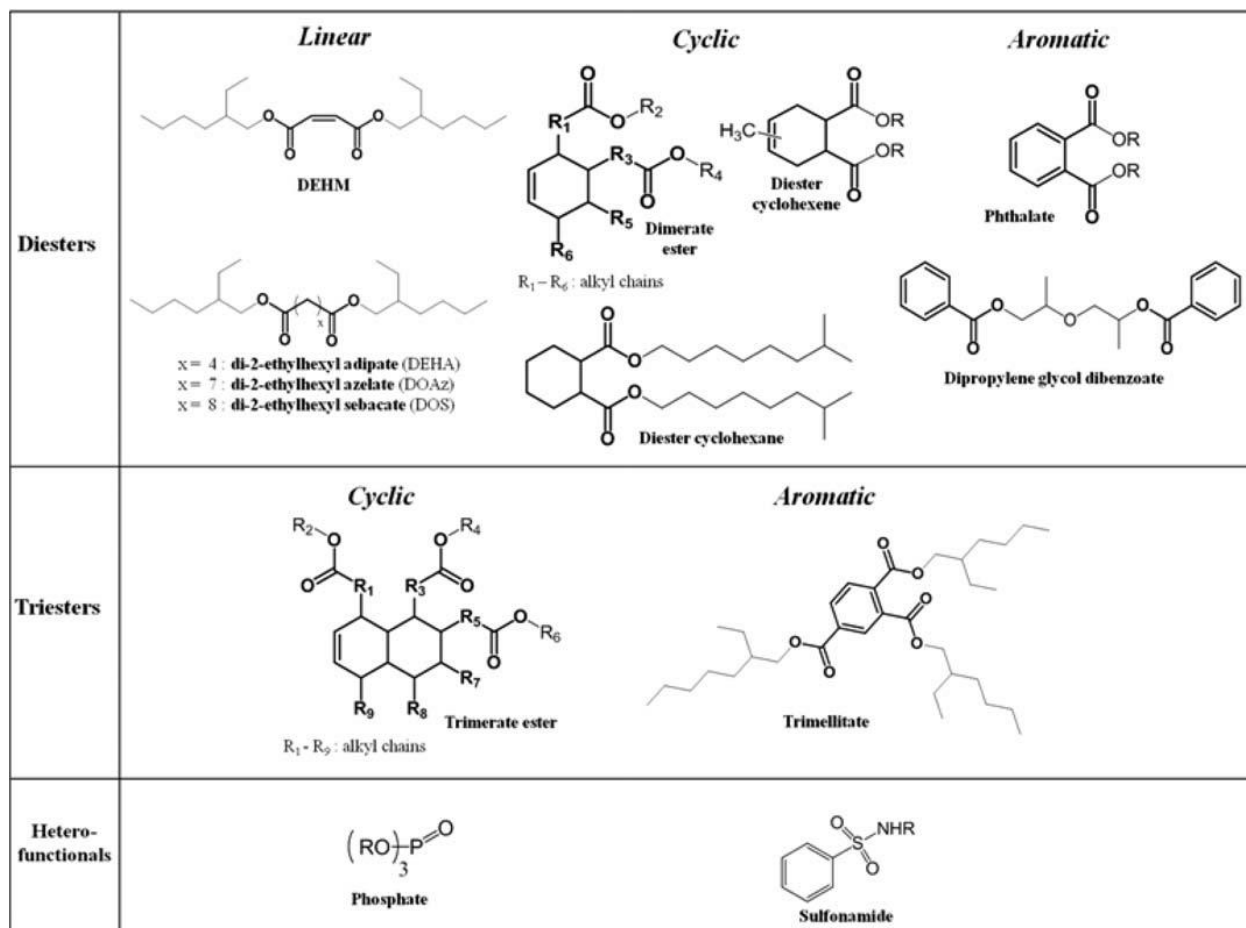


Figure 1: Chemical structures of some major petroleum based plasticizers (Bocque *et al.*, 2015)

These phthalates are not strongly bonded to the polymer and as such they are easily released into the environment via evaporation, leaching and volatilization. This can be risky to human health. For this reason, PVC plasticized with phthalate plasticizers has limited applications in flooring, toys, cosmetics, and furnitures (Peters, 2003; Pors and Fuhlendorff, 2001; Bui *et al.*, 2016). Several phthalate plasticizers have been revealed to cause harmful effects to the health of animals (Foster *et al.*, 2001; Higuchi *et al.*, 2003; Li *et al.*, 1998). Also many authors have been studying the toxic effect of the phthalate plasticizers on humans. For instance, antiandrogenic effects have been linked to internal phthalate concentration due to its wide volume of use as stated by Bustamante-Montes *et al.*, 2013 and Huang *et al.*, 2009. Fatty foods such as butter, milk, and meats are the major sources of DEHP plasticizers and another phthalate in human society (Erythropel *et al.*, 2014). Phthalate is suspected of disrupting human hormones (endocrine system) and causing numerous chronic diseases in children such as allergies and asthma (Wang and Qian, 2021). Phthalates such as (benzyl butyl phthalate (BBP) metabolite) have also been found to be

present in the urine of infants that live with floors made from PVC. All of these had led to some countries like Canada and US to give restrictions on the use of phthalate plasticizers (diethylhexyl phthalate, DEHP, diisononyl phthalate DINP, and diisodecyl phthalate, DIDP) in low concentration in children items (Carlstedt *et al.*, 2013).

TABLE 1: SOME COMMON PHTHALATES

Plasticizers	Common Abbreviation	Application	Another name
Dibutyl phthalate	DBP	Nail polishers; plasticizer; an additive to adhesives or printing inks	Di-n-butyl phthalate, DnBP, DNBP
Diethyl phthalate	DEP	Toothbrushes; automobile parts; tools; toys; food packaging; cosmetics; insecticides; aspirin	Ethyl phthalate; Di-n-ethyl phthalate
Di-isononyl phthalate	DiNP	Plasticizer	Bis(7-methyloctyl) phthalate DINP
Di-iso-decyl phthalate	DiDP	Plasticizer	Di(i-decyl) phthalate; diisodecyl phthalate DIDP
Butyl benzyl phthalate	BBP	Plasticizer	Benzyl n-butyl phthalate; n-Butyl benzyl phthalate
Di-isobutyl phthalate	DiBP	Plasticizer; adhesive	Di(i-butyl)phthalate; Isobutyl phthalate; di-l-butyl phthalate; DIBP
Dioctyl phthalate	DnOP	Household items and building products; food applications	Di-n-octyl phthalate; DNOP
Mono-(2-ethylhexyl) phthalate	MEHP	Vinyl tiles; food conveyor belts; carpet tile; artificial leather	tert-Butyldimethylsilyl 2-ethylhexyl phthalate

BIOPLASTICIZERS

Bioplasticizers are substances with low molar mass and incorporated into a polymer (mostly PVC) to enhance the fluidity, processability and serviceability of the polymer. These plasticizers are bio-based or derived from plant products such as vegetable oils, sugar cane, or starch containing plants. However, due to the toxic nature of some petroleum based plasticizers (phthalates, adipates, etc.), it becomes a necessity to use environmentally friendly plasticizer, that is the ones that are easily biodegraded by microbial agents (Federico *et al.*, 2014). Bioplasticizers sometimes called epoxy esters are derived from epoxidized plant oils (like soybean oil, linseed oil and tall oils), citrates. Other bioplasticizers include aliphatic esters (derived from adipic, azelaic, and sebacic acids), trimellitate esters, polymeric plasticizers, and phosphate esters (Charles, 2000).

BASIC SOURCES OF BIOPLASTICIZERS

Biobased plasticizers are renewable and are made from vegetable raw materials. These bioplasticizers could be obtained from plant oils such as soybean oil, palm oil, castor oil, coconut oil, rubber seed oil, citrate esters, stearic acid, lactic acid (Burgos *et al.*, 2014); glycerol esters (Lavorgna *et al.*, 2010); succinate esters (Stuart *et al.*, 2010); isosorbide (Yin and Hakkarainen, 2011) fatty acids, cardanol, citric acid, camphor, curcumin, glycidyl glycerol, rosin acid, tartaric acid and starch (Kumar, 2019).

APPLICATIONS OF PLASTICIZERS

It is because of its ability to enhance the flexibility and processability of polymer plastics, plasticizers have been used in making a variety of products, which include:

- **Wire & cable insulation:** They are used in making building wire as well as other wire and cables.
- **Construction:** It is used in making hoses, roofing, swimming pool liners, wall paper, pond liners, oil tank liners, urethane sealants and more products.
- **Flooring & carpets:** Vinyl tiles, carpets and resilient flooring are made from it.
- **Automotive:** It can be used to make the mats in a car, artificial leather, wiring systems in a car, and other automobile parts.
- **Household & miscellaneous:** It can be used to make furniture, table cloths, foot wears, toys, shower curtains, floor mats, food wraps, garden hoses, raincoats, belts, etc.
- **Medical:** It is used to make blood bags, tubes and hoses used in hospitals and nutrition. (Zhang *et al.*, 2019; Hassan *et al.*, 2018; Ramakrishnan *et al.*, 2016; Orr and patel, 2015)

Figure 2 gives the percentage application of plasticizers in various fields and consumer goods seen to have the lowest percentage while others took the highest percentages.

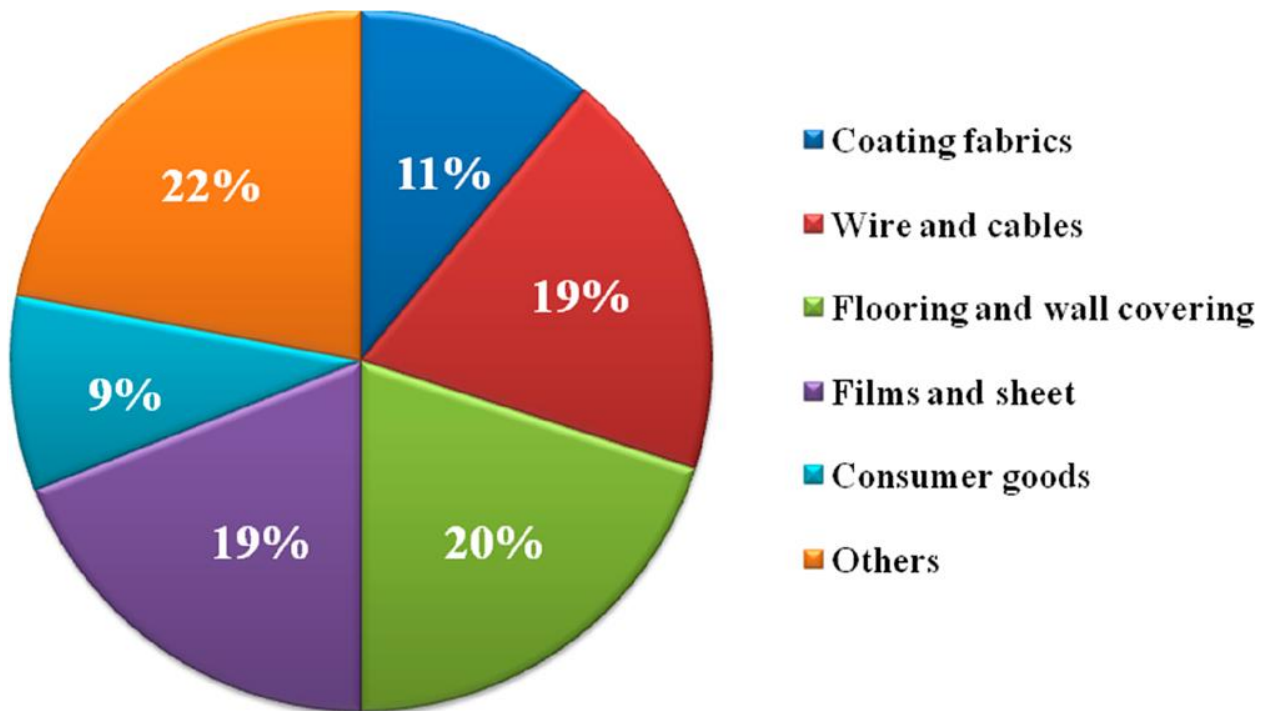


Figure 2: Application of plasticizers in several products (Kumar, 2019)

A brief review of research works that plasticizers were applied is presented in Table 2.

BASIC PROPERTIES OF A PLASTICIZER

When selecting a plasticizer, one must consider the following properties- volatility, flammability, toxicity, ease of compounding, solubility, heat and light stability, low temperature brittleness, migratory properties and efficiency (softening effect). Brief explanation of each property is outlined below:

- **Volatility:** It has to do with plasticizer molecules escaping from a polymer to the atmosphere. This loss could occur either through diffusion or evaporation processes (Wilson, 1995). The rate at which the molecule of the plasticizer diffuses is usually influenced by the structure of the plasticizer (i.e. molecular weight and its linearity) as well as how permeable the PVC geomembrane is. Thus highly plasticized PVC has a higher rate of diffusion whereas that of low plasticized PVC possess lower rate of diffusion. Studies have

shown trimellitates and polyesters (or polymeric) plasticizers to have low volatility properties due to the presence of more carbon atoms in the alkyl group as well as less branching systems. Therefore, plasticizer will be less volatile if it has a linear structure as well as high apolar/ polar functionality due to high molecular weight (Charles, 2000).

- **Flammability:** Plasticizers are added to PVC to raise the flammability level of PVC since the presence of chloride in PVC possesses good flame resistant properties. Phosphate plasticizers and halogenated/brominated phthalates have good flame resistant properties. The highest fire retardant is tricresyl phosphate (TCP) even though it gives out much smoke under fire situations; whereas trialkyl phosphates (such as TOF) have low fire resistance properties. To have commercial plasticizers with combined properties like fire reduction, volatility and efficiency, plasticizers (especially phosphate plasticizers) are combined with other materials. For instance, the jacketing of cables and the proper insulation of it is obtained when phosphate plasticizer is blended with antimony trioxide, and zinc borate to form a high grade of flame retardants (Charles, 2000).
- **Toxicity:** The toxicity of plasticizers used in polymer plastics depends upon their chemical composition. For instance, organic phosphates have a higher toxicity than citrates or adipates. For example, among the phosphoric esters, propyl glycol phosphate and 2-ethyl diphenyl phosphate are considered to be non-toxic and are allowed to be used in the United States for food wrapping purposes. Whereas tricresyl phosphate (TCP) is known to be the most toxic among phosphoric esters, and also among plasticizers. The phthalic esters are also considered toxic in nature as they are not used in food wraps and pharmaceuticals. However, citric esters are non-toxic, succinates and epoxy esters obtained from natural sources (vegetable oil) are found also to be non-toxic in nature (Wexter, 1971).
- **Ease of Compounding:** The physical and chemical properties and the way the polymer act on mixing with a plasticizer are what accounts for the ease at which the plasticizers are blended with PVC polymers. At higher temperatures of 160 °C to 170 °C, PVC are easily mixed, fused, shaped and form a flux for plasticizer to be added to it. With the incorporation of plasticizer the hard-like PVC becomes rubber-like or gel-like in nature and becomes easily processed into several products (Wikes *et al.*, 2005).
- **Solubility:** The structure of the plasticizers affects its solubility or miscibility in PVC. That is it can be polar or apolar. The PVC polymer easily binds with the polar part of the plasticizer molecules, thereby making PVC to be more flexible and soft. Whereas the interaction between the molecules of PVC and that of the plasticizer are controlled by the non-polar nature of the plasticizer molecule so that it does not lose its crystallinity. The polar components are the carbonyl group of carboxylic esters and the aromaticity ring; while the non-polar component is the aliphatic side chain of an ester. Thus, for there to be increase in the solubility and compatibility between the plasticizers molecules to that of polymer, the polar

and non-polar portions of the molecules must be an equilibrium (i.e too much polarity damages the crystallinity of PVC and too much non-polarity leads to poor compatibility). The solubility parameter is increased as polarity and/or aromaticity is increased. Examples of plasticizers with strong solvation power are benzoates esters, sulfonates, tricresyl phosphate (TCP), dihexyl phthalates (DHP), butyl octyl phthalates (BOP), and butyl benzyl phthalates (BBP) (Wikes *et al.*, 2005).

- **Heat and Light Stability:** The UV stability as well as the thermal properties of PVC is improved when epoxidized plasticizers are employed. They serve as plasticizers and stabilizers in PVC. As plasticizers, they form epoxides (which are thermally stable) and as stabilizers, the epoxies react with HCl. The PVC polymer is grafted chemically at the chlorine labile site and mixed with metal stabilizers. The epoxides or oxirane compounds formed have increased stabilizing effect and are not easily attacked by fungi (Charles, 2000).
- **Low Temperature Brittleness:** The low temperature property is as a result of the linear alkyl structures. Thus, the less-branched the alkyl groups are the lower the temperature features will the plasticizers possess and of course the less brittle it will be and the lower will be the plasticizer volatility. Examples of low temperature plasticizers are Di-2-ethylhexyl adipate (DOA), Di-2-ethylhexyl azelate (DOZ), Di-2-ethylhexyl sebacate (DOS), and diisononyl adipate (DINA) (Wikes *et al.*, 2005).
- **Migratory Properties:** Plasticizer migration is a process of plasticizer escaping a polymer to a solid, liquid or gas phase i.e it can be liquid migration (leaching) or air migration (volatility or evaporation). The reason for this migration is due to the exposure of the polymer-plasticizer blend to high processing temperature; also, since there is no chemical bonding (reaction) between the plasticizer and the polymer, they become easily detached from the polymer resin.
- **Efficiency (Softening Effect):** This is the amount of plasticizer needed to reduce the stiffness of the polymer material to a desired level. Factors that contribute to plasticizer efficiency are the molar mass, size, and the rate of diffusion of the plasticizer in the polymer matrix. Thus, the higher the rate of diffusion, the greater the efficiency of the plasticizer compound. However, high diffusion rates lead to high volatility loss and this occurs usually with small size molecules (Koleske and Wartman, 1995).

TABLE 2: BRIEF REVIEW OF RESEARCHES THAT APPLIED PLASTICIZERS

Author (s)	Plasticizer (s)	Results
Chen <i>et al.</i> (2015a)	cardanol and epoxide cardanol glycidyl ether (ECGE), dioctyl phthalate (DOP)	The tensile strength (TS) of the PVC matrix was enhanced by the increase of the ECGE content. Also, when compared to dioctyl phthalate (DOP), ECGE plasticized film gave a better tensile strength and elongation properties but lowered modulus.
Stuart <i>et al.</i> (2013)	diethylhexyl succinate, didecyl succinate, and didodecyl succinate,	On adding the third succinate diesters to the other two diesters, the resulted product was more effective as a plasticizer than when each plasticizer was used singly in PVC.
Chen <i>et al.</i> (2017)	soybean oil-based epoxidized glycidyl ester of fatty acids (EGESOFa) and tung oil based tung-maleic triglycidyl esters (TMTE) plasticizers,	The results proved that the soybean oil-based plasticizers improved the mechanical and thermal properties of PVC blends as compared to DOP. Further, EGESOFa could provide PVC with well-balanced properties of hardness, strength, and flexibility. Thus, soybean oil (SO) based plasticizers displayed better potential properties compared to the traditional plasticizers (i.e., DOP).
Wang <i>et al.</i> (2018)	tung-oil based ester such as GEHTMA_1, GEHTMA_2, GEHTMA_3, and GEHTMA_4 (glycidyl ester hydroxyl congaing tung-maleic anhydride), dioctyl terephthalate (DOTP)	The bioplasticizer (GEHTMA_3) blended with PVC provided good mechanical properties. However, a combination of GEHTMA_3 plasticizers into the DOTP (PVC-DOTP-GEHTMA_3), the plasticized PVC gave an improved mechanical and thermal stability, and the migration resistance properties contrasted to that of the PVC-DOTP networks. Likewise the formulation (PVC-28DOTP-12GEHTMA_3) showed a higher tensile strength (TS) and elongation from 32.19 MPa to 345.20%, respectively, and higher thermal stability. This is as a result of the molecular interaction of GEHTMA_3, DOTP, and PVC.
Yin and Hakkarainen (2011)	oligo(isosorbide adipate (OSA), suberate	The 40 wt % SDH plasticized PVC films revealed comparable tensile strain as to that of the traditional plasticizers (DIOP) based PVC film,

	oligo(isosorbide succinate (OSS), and isosorbide dihexanoate (SDH).	whereas the other isosorbide plasticizers exhibited lower tensile strain. The PVC plasticized by 20 wt % DIOP and three different types of isosorbide plasticizers revealed a comparable tensile strain. The 40 wt % OSA and OSS plasticized PVC demonstrated lower Tg, lower tensile strain, and higher tensile stress than an SDH or DIOP plasticized PVC film. the OSS revealed lower Tg but higher tensile strain. Further, the OSA and OSS plasticized PVC demonstrated higher thermal stability compared to the bio SDH and traditional plasticizers (DIOP).
Jia <i>et al.</i> (2017)	triethyl citrate and DOP	The modulus, elongation at break (%), and thermal stability was improved compared to that of the DOP plasticized materials.
Saltos <i>et al.</i> (2014)	curcumin and stearic acid, dibutyl phthalate (DBP)	The combined plasticizers presented lower cytotoxicity and better leaching resistance as compared to the traditional dibutyl phthalate (DBP) plasticizers
Howell and Sun (2018)	tartaric acid	The result showed the plasticizer to be much compatible with PVC, low migration, good plasticization effect, and no effect on the thermal stability of the polymer. Hence, these enhanced properties make it better substitutes for phthalate plasticizers.
Chen <i>et al.</i> (2015b)	cardanol glycidyl ether (CEG), diisononyl phthalate (DINP) and bis(2-ethylhexyl) benzene-1,4-dicarboxylate (DOTP)	The analyses of SEM and DMA indicated that the CEG plasticizer is compatible with PVC. The thermal analysis on the CEG/PVC system gave higher thermal stability, easy processability, higher exudation resistance, and better elongation properties in contrast to the DINP/PVC and DOTP/PVC systems. Therefore, CEG has great potential to reduce the dependence on petroleum based plasticizers.
Raju <i>et al.</i> (2007)	Coconut oil and Naphthenic oil	The results showed the coconut oil to have better mechanical properties than the Naphthenic oil. The thermal studies using differential scanning calorimetry (DSC) showed the temperature of initiation of degradation of the coconut mix increased by 10 °C and the peak rate of degradation also increased by 7 °C.
Melissa <i>et al.</i> (2014)	esterified rice fatty acids with polyols and di-octyl adipate, DOA	The results showed that both the natural and commercial plasticizers had the same properties except for colour variation. An increase of (371.2%)

		elongation was obtained with PVC films having the natural plasticizer than that of the pure PVC film.
Federico <i>et al.</i> (2014)	epoxy methyl soyate	A better bioplasticizer was gotten (with an epoxide or oxirane number of 5) using the first method, I.e distilling the biodiesel before epoxidation reaction.
Pawan <i>et al.</i> (2011)	epoxidized wild safflower oil (WSO)	This was achieved by using a peroxy acid. The effects of temperature, stirring speed, catalyst loading and molar reactant ratios on the epoxide yield were examined. The study showed a comparative change to epoxide ring to be 85% with molar reactant ratio of 1: 0.5: 1.5 (for ethylenic unsaturated, acetic acid, H ₂ O ₂) at a temperature of 60 °C and stirring speed of 2000 rpm.
Liew <i>et al.</i> (2015)	<i>Jatropha Curcas</i> oil	The optimum results obtained were reaction temperature of 45 °C, reaction time of 2 hours, formic acid to ethylenic unsaturated mole ratio of 2.0, hydrogen peroxide to ethylenic unsaturated mole ratio of 12, the relative oxirane conversion of 80.4%, iodine value was 94.7% and yield was 70%. Characterization of the epoxidized linolenic acid was done using Fourier transform infrared (FTIR) spectroscopy and nuclear magnetic resonance (NMR) analysis. It was also observed that low amount of H ₂ O ₂ formed an epoxide and oxirane ring cleavage at the same time.
Darfizzi and Jumat (2010)	Palm olein	The results showed a yield of oxygen oxirane content (OOC) value of 3.61% and total conversion of 96.5%. The optimum results were a temperature of 45 °C, stirring speed of 350 rpm, reaction time was 150 minutes, and the mole ratio of (PO _o : HCOOH: H ₂ O ₂) was 1:5:2. Other physical properties obtained were density of 0.886 gmL ⁻¹ , dynamic and kinematic viscosities of 358.1 centistokes and 317.3 centipoise respectively.
Tayde <i>et al.</i> (2012)	cottonseed oil	The optimal results were temperature (60 °C), hydrogen peroxide to ethylenic unsaturated ratio (2:1), acetic acid to ethylenic unsaturated ratio (0.5:1) and the sulphuric acid used was 2% by weight of the total weight of peroxide and acetic acid while the stirring speed was 850 rpm.

Raffie-Moghaddam <i>et al.</i> (2014)	Jatropha Curcas seed oil	The optimal result were – theoretical maximum OOC of 6.13%, and experimental OOC of the epoxidized Jatropha oil was 5.67% and a percentage comparative transformation to oxirane (RCO) was 93.64%. Other optimum conditions included temperature (50 °C), 7% enzyme load with respect to the weightiness of Jatropha oil, mole ratio of H ₂ O ₂ : C=C bonds was 3.5:1 and lauric acid loading was 23% (with respect to the weight of Jatropha oil), and reaction time was 7.5 hours.
Bashar <i>et al.</i> (2011)	linoleic acid of immobilized candida antartica (Novozym 435®)	The yield obtained at these conditions was 82.14%, iodine value of 66.65 mg/g, and 4.91% of OOC. The epoxy product was characterized by FTIR.
Gil <i>et al.</i> (2006)	esters of aconitic, citric and phthalic acids	PVC mixed with di-isononyl phthalate plasticizers had high performance compared to others. However, tri-butyl aconitate (TBA) had the overall best thermal stability and mechanical properties and can be used to replace the toxic DINP.
Yin <i>et al.</i> (2014)	Glucose esters	The results showed that glucose esters was highly miscible with PVC and the maximum elongation at break was attained at 40 wt % glucose ester.
Ferrer <i>et al.</i> (2010)	Epoxidized soybean oil (ESO)	The results showed that on formulating different dosages (30 to 50 wt %) of ESO to PVC, it improved thermal stability and enhanced compatibility.
Benaniba <i>et al.</i> (2001)	Epoxidized sunflower oil (ESO)	The result showed that the thermal degradation of PVC was improved by ESO.
Zhao <i>et al.</i> (2011)	Epoxidized soybean oil (ESO)	Elongation at break was greatly improved on adding ESO to polybutylene succinate (PBS) as depicted by high value of elongation at break for 5 wt% of PBS, which is 15 times more than pure PBS.
Xu and Qu (2009)	Epoxidized soybean oil (ESO)	The results showed that 9 wt % ESO increased the elongation at break of poly (lactic acid) (PLA) by about 63%.
Park <i>et al.</i> (2004)	Epoxidized soybean oil (ESO)	The thermal stability and the glass transition temperature, T _g was reduced on applying ESO on epoxy resins. Additionally, the flexural strength and stress intensity factor was improved.

Silverajah <i>et al.</i> (2012)	Epoxidized palm oil (EPO)	They observed that 1 wt% of EPO increased the flexural and impact properties, strength, and flexibility of poly (lactic acid), PLA.
Jusoh <i>et al.</i> (2012)	Crude palm oil (CPO)	The tensile strength, elongation at break, impact strength and tear strength were all increased on blending different dosages (1%, 3%, and 5%) of CPO with polypropylene (PP).

FUTURE PERSPECTIVES

The applications of bio-based plasticizer have outweighed that of petroleum-based plasticizer. In fact, the bioplasticizer has more potential to replace or even limit the use of traditional plasticizers and has a major role in the current market. However, the demand for the applications of biobased plasticizers is growing rapidly. Hence, the need for more research to be directed towards exploring more bioplasticizers and to have a deeper understanding of their chemistry. The plasticization mechanism of plasticizers should further be researched especially with regards to its toxicity and degradability. From the review, a lot of researches have been tailored towards the effect of applying bioplasticizers on the thermal and mechanical properties of polymers as well as the migration stability and plasticizing efficiency. However, this is not the case for biological effect or toxicity on humans and animals as literatures for this purpose is limited. Hence, more research should be channeled to investigating the relationship between biological toxicity and chemical structure of bioplasticizers. Further studies should include an in-depth knowledge of the interactions of plasticizers and polymers and their basic physicochemical and biochemical properties to aid in the design and production of desirable and competitive materials using compatible plasticizers.

CONCLUSION

The petroleum based plasticizers (phthalates) have high leachability properties since they do not strongly bond to the polymer. This has posed high risk on human health and to the environment. For these reasons, bio based plasticizers are introduced due to less leachability, volatility, toxicity, and good compatibility with PVC. Additionally, the thermal and mechanical properties of the PVC polymer are enhanced. From the paper review, research works have shown the comparative effect of applying petroleum plasticizers and bioplasticizers on PVC to enhance the mechanical and thermal properties of the PVC polymer. Hence, there is need for further researches on other bioplasticizers not yet applied since there is greater demand for it in the plastic industry.

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