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The Role of Bio-based Plasticizers in Mitigating Polymer Membranes Fragility and Brittleness

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Abstract: The review article focuses on the potential of bio-based plasticizers to enhance the mechanical properties of polymer membranes, addressing the critical issues of fragility and brittleness. It highlights the environmental and health risks associated with traditional plasticizers like phthalates and also advocates for the adoption of sustainable and non-toxic bio-based alternatives. In doing so, it emphasizes the significant advancements in bio-based plasticizer research, aiming to stimulate further scientific inquiry into their application in membrane synthesis. By advocating for the adoption of green polymers, the article underscores the critical necessity for the development of environmentally benign and mechanically robust membrane technologies. These advancements hold considerable promise for a wide array of applications, notably within biomedical domains and separation processes, heralding a new era of sustainability and functionality in membrane technology.

Keywords: Bio-based plasticizer; Embrittlement; Flexibility; Random scission, Tensile test

Introduction

Polymer membranes are essential in applications such as gas separation, water treatment, and biomedical devices. Petroleum-based polymers, including polyethersulfone (PES), polysulfone (PS), and polyvinylidene fluoride (PVDF), are extensively utilized in the production of membranes for several applications (Dong et al., 2021). These polymers are not considered sustainable and environmentally friendly due to their resistance to microbial degradation (Sadeghi et al., 2021). In contrast, biodegradable polymers like polylactide (PLA), chitosan, and polyacrylonitrile/starch blends offer a more sustainable alternative (Q. Liu et al., 2015).

However, the polymer membranes can be brittle and fragile due to the rigid nature of their polymer chains (Farah et al., 2016). To overcome these challenges, incorporating plasticizers into polymer membranes has emerged as a promising solution. Plasticizers increase the flexibility of polymer chains, reducing brittleness and fragility (Farah et al., 2016)

Although phthalates have been commonly used as plasticizers, their environmental and health risks have led to a search for safer alternatives. Bio-based plasticizers, derived from renewable sources, have gained attention as sustainable substitutes for traditional plasticizers. These bio-based options not only offer improved environmental safety but also possess biodegradable and non-toxic properties, making them suitable for applications where environmental and human health are critical considerations (Farah et al., 2016).

The use of bio-based plasticizers offers an opportunity to enhance the mechanical properties of polymer membranes, addressing issues related to fragility and brittleness. Researchers are exploring advancements in bio-based plasticizers to revolutionize the polymer industry, to address the raised concerns about the common plasticizers, especially the phthalates (Bocqué et al., 2016).

Therefore, incorporating bio-based plasticizers into polymer membranes is a significant advancement in improving their mechanical properties and ensuring

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durability in demanding applications. By transitioning to sustainable and environmentally friendly alternatives like bio-based plasticizers, the polymer membrane industry can tackle performance limitations associated with traditional materials, leading to enhanced functionality and broader utility across different fields.

The objective of this review is to garner the attention of the scientific community towards the imperative of dedicating efforts to foster the utilization of bio-based plasticizers in membrane synthesis. This initiative is poised to facilitate the integration of green polymers into membrane technology, thereby promoting environmental sustainability.

Method

The methodological framework involves a comprehensive review of the literature surrounding the significance of polymer membranes across various applications. This is followed by delving into the concerns related to sustainability and environmental friendliness of plasticizers. The subsequent sections delve into the potential of biobased plasticizers for membrane fabrication, discussing the benefits and challenges associated with their application, specifically addressing the critical issue of membrane embrittlement and the innovative use of biobased plasticizers to mitigate this challenge.

The data collection process involved an exhaustive search of peer-reviewed articles, conference proceedings, books, and book sections. The search criteria were formulated to include a broad range of keywords such as polymer membranes, sustainability in polymer production, embrittlement, plasticizers in membrane technology, and bio-based plasticizers. This approach ensured the capture of a wide array of studies relevant to the scope of this review.

The analysis of collected literature was structured to first highlight the critical role of polymer membranes in various applications, gradually transitioning into the discussion on the embrittlement of fragile polymeric membranes and the causes of membrane embrittlement. The review provides an in-depth examination of the role of plasticizers in enhancing the flexibility and durability of polymer membranes.

Each selected study was critically evaluated for its relevance, scientific rigor, and contribution to the field of polymer membrane technology. The writing of the literature was conducted in a manner that ensures a logical progression of ideas, from the establishment of context regarding the significance and sustainability concerns of polymer membranes to the detailed examination of solutions addressing these concerns, specifically through the use of biobased plasticizers.

Result and Discussion

Membrane brittleness

Membrane brittleness refers to the tendency of a membrane to fracture or break under stress without significant deformation. When membranes exhibit high brittleness, they become vulnerable to failure, compromising their effectiveness in water purification. A polymeric membrane is prone to fracture when it constitutes precursor(s) with rigid crosslinking, high bulk density, reduced free volume, and entanglement within the membrane. These lead to the critical molar mass (M_c) of the polymer material exceeding its molar mass (M) (H. J. Lim et al., 2023), (Koyama et al., 2023), exhibiting higher glass transition temperature (T_g) (Guo et al., 2013). This situation renders the membrane vulnerable to random polymer chains.

The random scission of the chains is the fragmentation of chains in the polymer (H. J. Lim et al., 2023), (Koyama et al., 2023). This diminished entanglement in the polymer renders the membrane prone to cracking and fracture. Chain scission in polymers is a complex phenomenon that can be linked to a multitude of factors. Applied stress can result in the rupture of covalent bonds, leading to chain breakage (Galán, 2020). Another causative factor for chain scission in polymers is UV light irradiation, which leads to the excitation of the polymer and the formation of radicals (Karim et al., 2022), resulting in the photochemical scission of covalent bonds and the subsequent collapse of the chains (Pantuso et al., 2019). Moreover, exposure to solvents, particularly polar ones, serves as another reason for chain scission in dendronized polymers (DPs) (Messmer et al., 2019). The scission in the degree of polymerization (DPs) depends on the presence of highly polar solvent and rightful dendritic generation, g. Dendritic generation depends on the polymerization category of the DPs, (Arkas et al., 2023). In fuel cell membranes, the generation of radicals tends to unzip side chains, subsequently inducing chain scission (Khattra et al., 2020). Figure 1 schematically shows an example of random chain scission.

Embrittlement emanates from membranes' stiffness, low flexibility, and minimal elongation at break (Akbarzadeh et al., 2021). As a result of the weak mechanical strength, membranes performance and durability suffer (Cao et al., 2017). This poses a significant limitation in respect of their potential applications. The limitation arises from concerns regarding the integrity of the membranes, which is prone to cracking, breaking, and the emergence of pinholes during processing and operation. Over time, brittle membranes tend to lose their initial structure and performance due to attrition (Wang et al., 2020). The high vulnerability of brittle membranes to cracking and

breakage is a major issue in maintaining the intended application, as it necessitates frequent replacement, causes operational downtime, and additional costs.

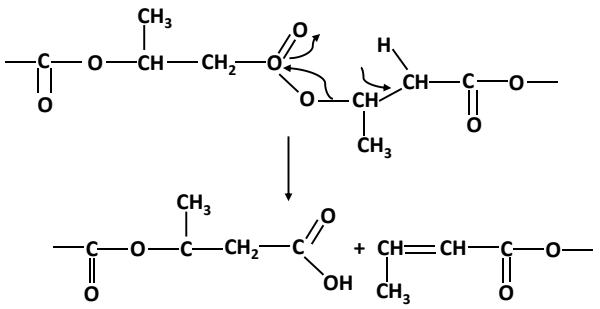

Figure 1. Diagrammatic Depiction of Chain Scission in Polyhydroxybutyrate

The brittleness of membranes is a common characteristic observed in biopolymers, stemming from their inherent weakness in mechanical properties. These biodegradable membranes include cellulose acetate (Rehman et al., 2022; Akbarzadeh et al., 2021, (Cindradewi et al., 2021), (Mansor et al., 2020), polysterene (Achari et al., 2020), polyvinyl alcohol (Karim et al., 2022), polylactic acid (Bandehali et al., 2021), carrageenan (Okolišan et al., 2022), and more. For instance, the β-D-glucose rings in the main chain of cellulose acetate (CA) is the main contributing factor for the rigidity and embrittlement of CA membrane (Teixeira et al., 2021).

In addition to the inherent nature of the polymers with which the membranes are made from, ageing of membranes contribute immensely to embrittlement. The mechanical strength of the membrane is prone to deterioration over time, resulting in a decrease in plasticization and an increase in stiffness. It has been found that polymers, such as PLA, become more brittle with time (Cui et al., 2020). Abdelaal et al., (2014) reported the embrittlement of a high-density polyethylene geomembrane due to long-term stress. According to Anadão et al. (Anadão et al., 2018) with the passage of time, all membranes exhibit brittleness. However, this effect is often noticeable in the composite membranes because of the formation of defects within them. The combined effect of deformation and reduced mechanical strength with time leads to membrane embrittlement (Feng, 2017). Membrane ageing leading to brittleness is widely reported in the literature. However, most of the ageing-triggered embrittlement are associated with exposure to chemicals and influence of heat (Li et al., 2021; Kadirkhan et al., 2022; Arhant et al., 2022). Therefore, the nature of the degradation is often peculiar to the characteristics of the chemical with which the membranes are exposed to.

Plasticizers for membrane flexibility

The stiffness and toughness of membranes, which result in embrittlement, are typically addressed by adding plasticizers. Plasticizers can be categorized as external and internal. External plasticizers are added at elevated temperatures to polymers without forming bonds between them (Tyagi & Bhattacharya, 2019), (Jamarani et al., 2018). They only interact to provide the necessary flexibility by avoiding or limiting friction between the polymer chains. On the other hand, internal plasticizers are additives that become part of the polymers through grafting or copolymerization, thereby creating free space for chains to move and resulting in flexibility (Tyagi & Bhattacharya, 2019). They are a group of non-volatile, low-molecular-weight additives used in polymer processing to enhance softness and flexibility by reducing the glass transition temperature (T_g) (Cindradewi et al., 2021; Mansor et al., 2020). Furthermore, they are monomers co-opted into the polymer chains and hence offer less freedom to chain flexibility due to created bonds (Jamarani et al., 2018). Depending on their compatibility with the polymer plasticizers are further classified into primary and secondary. A plasticizer is categorized as a primary plasticizer when it can dissolve in a plasticizer at high concentrations within the usual processing temperature range. Conversely, secondary plasticizers exhibit less compatibility with the polymers (Tyagi & Bhattacharya, 2019).

The use of plasticizers to improve the pliability of membranes is widely used to address embrittlement in polymeric membranes and films (Kaczorowska, 2022; Cindradewi et al., 2021; Salahuddin et al., 2018). The application of plasticizer in polymeric membranes promotes polymer chain mobility and flexibility, thereby lowering the propensity for embrittlement (Mansor et al., 2020). This achieved by reducing the intermolecular forces between the chains by increasing the space between them.

Unlike Jamarani and colleagues, the likes of Mancilla-Rico and others (Mancilla-Rico et al., 2021) opined that plasticizers interact with the host polymer and neutralize the polar groups of the polymer with their own polar groups. Although the nature of polar group neutralization is not stated here, it suggests that some sort of bond formation is possible between the plasticizers and the polymers. Achari et al. (Achari et al., 2020) described the application of dibutyl phthalate (DBP) to solve the brittleness of the polystyrene sulfonic co-maleic acid/Sodium alginate (PSSAMA/NaAlg) membrane. The authors reported the formation of strong interactions between the hydroxyl groups of NaAlg and the carboxyl-oxygen groups of DBP forming hydrogen bond and minimizing the intermolecular forces between the polymer chains.

Plasticizers are known to enhance the flexibility of polymeric membranes, and their mechanism can be attributed to three classical theories proposed by renowned researchers. One of these theories is the lubricity theory, which was introduced by Kirkpatrick. According to this theory, generally, certain segments of the plasticizer interact with specific parts of the polymer, while the remaining unbound portions of the plasticizer serve to lubricate the connections between the polymer molecules (Kirkpatrick, 1940). The theory implies that an effective plasticizer should have a suitable structure and possesses mutually attractive groups between the plasticizer and the polymer and positioned appropriately. The second theory was proposed by Aiken et al. (Aiken et al., 1947), and it suggests that the attractive groups present in both the plasticizer and the polymer interact, leading to the formation of dipoles along the polymer chains. Meanwhile, the non-polar tails of the plasticizer tend to cluster together, resulting into a concentration of unpaired polar chains on the polymer surface, forming a viscous gel (Marcilla & Beltrán, 2012). The gel formed, plays a crucial role in providing the material with flexibility. Although the study that led to the emergence of this theory was conducted using PVC, it is believed that this principle may apply to other petroleum-based polymers as well. Accordingly, the gel theory suggests that plasticizers with straight aliphatic chains contribute more to polymer plasticization compared to those with cyclic aromatic groups (Sinisi et al., 2021). The third theory, known as the free volume theory, resulted from the efforts of various authors, including Fox and Flory (Fox & Flory, 1950), who postulated it years after the lubricity and gel theories (Marcilla & Beltrán, 2012). The theory suggests that only free volume exists between atoms and molecules, and nothing else. This free volume represents the volume of space between atoms and molecules, termed "holes." An increase in the free volume of these holes permits improved motion of polymer molecules, which arises from the movement of chain ends, side chains, and the main chain (Platzer, 1982). Thus, according to (Marcilla & Beltrán, 2012), the incorporation of a lower molecular weight compound leads to the creation of more end groups, an increased length of side chains, and consequent motion of the main chain in addition to lowering the glass transition temperature. This brief elucidation explains the mechanism of combating embrittlement in polymer membranes using plasticizer.

Traditional plasticizers commonly employed to address embrittlement are phthalates, adipates and other synthetic compounds having potential health and environmental hazards. (Achari et al., 2020), (Zuber et al., 2019). As a result, several countries have made policies against their use in areas such as food packaging, healthcare devices, and toys . Moreso, they are not sustainable because they are derived from petroleum resources. Hence, there is a need for naturally based plasticizers that are both non-toxic and sustainable (Zhu et al., 2021). Bio-based plasticizers can be derived from agricultural resources, including vegetable oils and agro-industrial wastes (Righetti et al., 2023), (Cai et al., 2020), tartaric acid (Zhu et al., 2021), (Howell & Sun, 2018), glycerol and citric acid (Kudahettige-Nilsson et al., 2018) and so on.

Bio-based plasticizers

Bio-based plasticizers are eco-friendly, inexpensive, and sustainable additives for combating the embrittlement of polymeric membranes. When blended with polymers, they interact to increase the inter-chain space and enable chain mobility, thereby enhancing membrane flexibility and subduing embrittlement. Bio-based plasticizers used to reduce membrane and thin films embrittlement include glycerol (Okolišan et al., 2022), polyethylene glycol (PEG) (Naser et al., 2021), triacetin (TA), and triethyl citrate (TC) (Cindradewi et al., 2021) to mention only few.

In addition to eco-friendliness, cost-effectiveness, and sustainability, bio-based plasticizers are usually endowed with straight chains, unsaturated double bonds, polar groups, and hydroxyl groups (Zhang et al., 2021). These properties enable them to participate in macromolecular interactions between plasticizers and polymers during blending. Therefore, the selection of the plasticizer in relation to the polymer should be guided by the presence of matching groups in the polymer, longer chains, as well as the intended purpose of the polymeric material.

Glycerol can occupy intermolecular space between polymer chains and interfere with the strong hydrogen bonds between the adjacent molecules. This action induces chains mobility and flexibility in membranes (Ab Rahman et al., 2023). For example, glycerol can be absorbed within the pectin chains, resulting in interactions that occur in different ways. These interactions include the formation of hydrogen bonds and covalent linkages through reactions such as hydroxyl-hydroxyl or hydroxyl-carbonyl condensation (Costanza et al., 2019). The interactions aid the mobility of the chains to combat brittleness in polymeric membranes, films, or skin tissues. It is convincing to assert that glycerol is a suitable plasticizer for biopolymers containing hydroxyl and/or carbonyl groups. The compatibility of glycerol with biopolymers is evident in its application to enhance flexibility in carrageenan membrane (Okolišan et al., 2022), chitosan membrane (Gupta et al., 2023), chitosan film (Lau et al., 2021), chitosan skin tissue (Faikrua et al., 2009),

cellulose-based film (Rahman et al., 2023), (Syafiq et al., 2022), cellulose acetate film (Cindradewi et al., 2021), and many more. On the issue of plasticizer stability, the hydrogen bonds formed between glycerol and the polymers, which arise from interference with the polymer inter-chain hydrogen bonds. The formation of the glycerol-polymer hydrogen bond acts as a water shield that prevents the leaching of the glycerol (Tarique et al., 2021). Citrate ester-based plasticizers play a crucial role in preventing membrane embrittlement. This group of plasticizers includes acetyl triethyl citrate (ATEC), triethyl citrate (TEC), acetyl tributyl citrate (ATBC), and tributyl citrate (TBC). They are used to efficiently enhance the flexibility of cellulose ester polymers membranes due to the interaction between the plasticizer and polymer ester groups (Teixeira et al., 2021). Zuber et al. (Zuber et al., 2019) reported the application of TEC to plasticized polyvinyl alcohol (PVA) film using the solution casting method. In this method, distilled water was used to dissolve the PVA, which was then stirred at 80°C for 2 hours. Afterwards, triethyl citrate was added and stirred for 1 hour at the same temperature. The resulting mixture was then cast into a container and dried under vacuum conditions at 60°C. Chaos et al. (Chaos et al., 2019) investigated the effect of TBC on improving the properties of polyhydroxybutyrate and polylactide food packaging membranes using the solvent casting method. Briefly, solvent casting involves the uses solvent to dissolve the polymer instead of distilled water, poured into a flat bottom glass Petri dish. The solvent is then allowed to evaporate after which the film is carefully peeled off the bottom of the Petri dish. The authors reported sufficient mechanical strength and barrier properties for both membranes when using the plasticizers. Liu et al. (J. Liu et al., 2023) studied the plasticization effect of the some common citrate plasticizers, namely ATEC, TEC, ATBC, and TBC, on PVC film. Their findings revealed an enhancement in the flexibility of the film, with ATEC and ATBC having greater plasticization impact than TEC and TBC. Additionally, they noted a decrease in the thermal stability of the resin plasticized with the non-acetylated citrates due to the interruption of the strong van der Waals force between chlorine (Cl) atoms in the polymer chains by the citrates, despite their non-participation in any reactions. Triacetin is another bio-based plasticizer that is effective in imparting flexibility to stiff membranes. The application of triacetin to prevent brittleness in polymeric films, such as PVA (Zuber et al., 2019) film and cellulose acetate film (Dreux et al., 2019), has demonstrated its effectiveness in addressing embrittlement. Dreux et al. used both solvent and melt processing methods. In the melt processing technique, the authors used a flat die containing screw extruder coupled with peristaltic pump for injecting the plasticizer before the introduction of the cellulose acetate powder. After which the extrusion was perform at an appropriate temperature and screw speed according to the plasticizer proportion. Isosorbide diesters are other plasticizers of organic origin effective in inducing structural changes in polymeric products, including membranes. This group of compounds includes isosorbide dibutyrate (SDB), isosorbide dihexanoate (SDH), isosorbide dioctanoate (SDO), and isosorbide didecanoate (SDD). According to Yang et al. (Yang et al., 2017), the higher the carbonyl group content of the isosorbide diesters used in the blend, the greater the flexibility of a material made from a polymer, such as PVC. The high number of carbonyl groups in isosorbide diesters is accompanied by a shorter length of the alkyl chain in the compounds. Dibutyl sebacate, another bio-based compound is a promising plasticizer used in polymers, such as cellulose triacetate (CTA) and so helpful in providing the needed mechanical strength in the membrane (Merlo et al., 2022). Bio-based compounds, including diheptyl succinate (Jagarlapudi et al., 2023), ethylene glycol monoester (Nosal et al., 2021), and many others, play a significant role in preventing brittleness.

According to Kumar (Kumar, 2019), a plasticizer content of 20-30% in the blend tends to provide an excellent plasticization effect, resulting in optimum flexibility of the polymer film. Therefore, it suffices to say that playing around with these proportions yields films of desired quality and performance.

Application of Universal Testing Machine in Membrane Assessment

A Universal Testing Machine (UTM) is commonly employed to evaluate the impact of force on membranes, determining their resilience to operational pressures. This apparatus measures the maximum load a membrane can endure before failure, providing critical information for membranes used in filtration and separation processes (Mataram et al., 2017). The machine usually has two opposing clamping jaws for clamping the ends of the membrane. The membrane sample is fixed by first releasing the clamping jaws, inserting the sample and then closing them. The tensile stress or elongation at break measurements are then carried out by following the instructions on the control panel or using the computer connected to the device. The stress-strain curve shows the extent of load that the membrane can bear. The slope of the linear portion of the stress-strain curve determines Young's modulus, which Equation 1 defines as the ratio of stress (σ) to strain (ε) within the linear elasticity range. The stress-strain curve shows the extent of load that the membrane can bear. At the end of the tensile test, the elongation at break of the membrane could be computed using Equation 2,

where ΔX is the change in length and X is the original length of the tested sample.

$$Y = \frac{\sigma}{\varepsilon} \quad (1)$$

$$E_b = \left(\frac{\Delta X}{X}\right) * 100 \quad (2)$$

The assessment techniques

The mechanical characteristics of membranes are widely measured using two types of specimen shapes the rectangular and the dumbbell-shaped (Yuan et al., 2023). Both techniques provide a unique way to evaluate the strength and elasticity of membrane materials, giving detailed information on how they behave mechanically in different scenarios. The methods involve the gripping of the both ends of a specimen. To ensure that tensile measurements are accurate, the clamping test requires that both ends of the specimen be precisely gripped with the appropriate amount of pressure to prevent sample failure. The rectangular specimen is a regular rectangular shape, while the dumbbell-shaped approach uses a sample that has been painstakingly carved into the shape of a dumbbell. This particular shape is designed to ensure that breaking occurs in a controlled area during the tensile test by concentrating the stress on the central, narrower segment of the specimen. This arrangement allows for a more accurate assessment of the mechanical properties of membrane, including its elongation capacity and tensile strength. The two shaped methods employed in the tensile testing of polymer membranes are displayed in Figure 2.

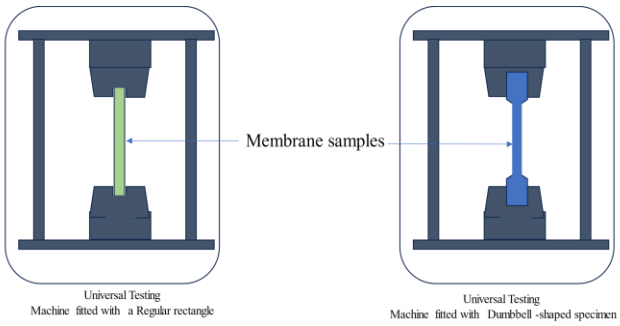

Figure 2. Two types of sample shape utilized tensile test

Recent applications of bio-based plasticizers in addressing membrane brittleness

The biobased plasticizer application method in biofilms and membrane preparation mostly involves blending with the polymer (Jost & Langowski, 2015), (Tian et al., 2022). The use of bio-based plasticizers to impart flexibility to polymeric membranes has proven to be highly beneficial in ensuring the sustainability and cost-effectiveness of membrane applications across various aspects of human endeavours, as reported by several researchers. A significant portion of these studies has focused on the field of film fabrication for applications such as bioplastics (J. Liu et al., 2023), food packaging materials (Omar Anis Ainaa et al., 2021), (Chaos et al., 2019), (Dai et al., 2022), (Sanyang et al., 2015), (Harussani et al., 2021), (Tarique et al., 2021), (Syafiq et al., 2022) drug delivery (H. Lim & Hoag, 2013), air purification (Ghosh et al., 2021) and battery cells (Abdulwahid et al., 2023), (Raut et al., 2019). The researchers used tensile strength (MPa), Young's modulus (MPa) and elongation at break (%) to assess the effectiveness of the plasticizers and have consistently reported a decrease in tensile strength and Young's modulus, along with an increase in elongation at break. This does not come as a surprise looking at the mechanism of polymer plasticization by additives. The reduced intermolecular forces within the polymer chains resulting from the fragmentation by the plasticizer lead to a decrease in both tensile strength and Young's modulus. However, it also promotes the deformation of the polymer chains, leading to an increase in elongation at break. To enhance these characteristics, fillers like nanofibrillated cellulose can be incorporated as reinforcement into the plasticizer-polymer solution (Tian et al., 2022). This can expand its applications in systems that involve pressure, such as water purification.

Tensile strength (MPa) indicates the maximum load per unit area that a membrane can withstand without breaking, and it is often measured by a Universal Testing Machine (UTM). It is a measure of the allowable operating pressure of a membrane system and depends on various factors, such as the nature and thickness of the membrane support (Charlton et al., 2020). Additionally, it relies on the properties of the polymer material and the structure of the membranes. Therefore, membranes that exhibit higher mechanical strength tend to resist mechanical degradation and may potentially have a longer lifespan (Ngobeni et al., 2021). The elasticity of membranes is typically evaluated by determining Young's modulus. A tensile tester can be used to generate stress-strain plots (Williams, 2022). After which the Young's modulus of the membrane can be computed. Elongation at the break of a membrane indicates the membrane's ability to deform when subjected to pressure. It is computed as the ratio of the change in length after breakage to the initial length. Nonetheless, the decrease in tensile stress can diminish the membrane's suitability in such applications, particularly when pressure is used to drive the process.

To minimize the compromise between strength and flexibility, fillers such as nanofibrillated cellulose can be added as reinforcement to the plasticizer-polymer solution (Tian et al., 2022). Javed (Javed, 2015), also

noted that 'curing' can be applied to lessen the decrease in strength of plasticized membranes. This can be achieved by placing the membrane in a desiccator and heating it in a well-ventilated oven at 105°C for a day. Zafar et al. (Zafar et al., 2022) reported the blending of polycaprolactone-modified cellulose with PLA to fabricate a flexible film with maintained tensile strength and improved resistance to plasticizer migration. Nevertheless, these attempts to prevent the decrease in strength of plasticized films are accompanied by a decrease in flexibility themselves, necessitating the optimization of filler proportion and the curing process. This can help to expands its applications in pressure-based systems like water purification.

Some bio-based plasticizers can dissociate from the polymer material into the environment through valorization or dissolution, resulting in plasticizer loss and a reduced lifespan. However, certain plasticizers demonstrate remarkable migration resistance, attributed to factors such as low volatility and high compatibility with the polymer among others. This is evident from the recent efforts of several researchers, including (Brdlík et al., 2022; Feng et al., 2019; Gao et al., 2016). In addition to increasing mechanical strength, the use of biobased plasticizers such as Cyrene and Cygnet have been reported to enhance the permeability, morphology, and thermal stability of membranes (Milescu et al., 2021).

Conclusion

In summary, the investigation of bio-based plasticizers has revealed their significant potential to improve the flexibility and strength of membranes, which is useful in a variety of applications, particularly in the biomedical field and in separation processes. The switch to these bio-based alternatives is particularly important to reduce reliance on traditional, toxic plasticizers such as phthalates, ushering in a new era of safer and more sustainable use of materials. The dual functionality of bio-based plasticizers, which act as both solvents and plasticizers, represents a significant advance in membrane manufacturing technology and makes them excellent candidates for the development of future membrane materials.

The widespread use of biobased plasticizers in the production of biomedical membranes is a noteworthy development, as it now surpasses their application in separating membranes. This discrepancy is particularly notable when one considers the extent of application and demand for separation membranes worldwide, suggesting that there is an urgent need to increase acceptance and promotion in this sector. Despite the promising properties of bio-based plasticizers, there are some challenges, such as the need for high temperatures in the preparation of the doping solution to effectively dissolve the polymers. In addition, the risk of the polymers leaching from the membranes is a critical area for further investigation.

In light of these factors, it is critical that future research projects address the new issues surrounding the use of biobased plasticizers in membrane technology in addition to improving the performance characteristics and application techniques of these materials. With a focus on sustainability and environmental safety, these investigations will be crucial to maximizing the potential of biobased plasticizers and advancing membrane technologies for a broad range of applications.

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Author Contributions
Conceptualization, writing—original draft, editing and revising -Ibrahim Maina Idriss

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