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Review Article

A Review on the Utilization of Epicuticular Wax from Plant Samples as a Hydrophobic Surface Coating Agent

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ABSTRACT

The rapid increase in pollution caused by plastic, especially packaging material, is raising concern across the globe. The statistics are only increasing with time, and without prompt action, this issue shows no signs of slowing down. Various approaches, like the use of paper bags and the introduction of bio-degradable plastics, have been taken in an attempt to reduce plastic waste. Although these approaches help in the reduction of plastic waste the change in numbers is not significant. Biological plant species like *Colocasia esculent* and many others consist of a layer of bio-wax on their leaves, which is hydrophobic in nature. Numerous research studies have explored the potential of utilizing the bio-wax derived from *Colocasia esculenta*, apple, tomato, lotus, and other plants for the synthesis of a surface coating agent. A biological hydrophobic surface coating agent might be able to reduce the amount of waste produced due to the use of plastic as a packaging material. It could be used for the production of hydrophobic paper, an alternative packaging material in the form of paper bag. The objective of this review article is to investigate various studies that have examined the use of bio-wax as a surface coating agent, with the intention of exploring its potential as a viable alternative to plastic packaging materials.

Keywords: Epicuticular, Bio-wax, *Colocasia esculenta*, Hydrophobic, Plastic, Pollution.

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INTRODUCTION

Plastic, like other synthetic polymers, is extremely stable. The degradation cycle of synthetic polymers is infinite due to their extreme stability.[1] The use of plastic, especially as a packing material, has been incredibly popular across the world. The major reasons behind the popularity of plastic as a packaging material are its lightweight, strong, easy of sterilizing, ease of shape, poor conductivity of heat and electricity, and water resistance.[2] Plastic has been beneficial to humanity since its invention. However, the extensive use of plastic, coupled with inadequate waste management systems, has emerged as a significant cause of land and water pollution.[3] Plastics are resistant to microbial degradation, which makes them non-biodegradable. It is this property of plastic that makes it a global concern. Its frequent practices, poor waste management, and negligence of individuals have led plastic to become one of the major reasons for aquatic and terrestrial pollution. Plastic presents a choking hazard to animals, endangering their lives in both aquatic and terrestrial environments.[4] Some plastics are labeled as "bio-degradable," implying that they can break down under certain conditions. However, the complete degradation of these plastics by microorganisms is temperature-dependent. It requires prolonged exposure to temperatures of 50°C or higher, a condition typically only found in industrial settings and not in the natural environment.[5]

Indeed, a polymer is a type of chemical compound composed of numerous repeating units. These Polymers can be classified into bio-based or petrochemical-based, depending on their origin. The bio-based polymers are mainly composed of sugars, chitin, nucleotides, lipids, proteins, and polysaccharides.[6] Natural rubber and some polyester, produced by either plants or microorganisms, also fall under this category. Whereas the petrochemical-based polymers are synthesized from monomers derived from petrochemicals. But in reality, the commercially produced polymers are often a combination of both bio-based and petro-chemical based polymers. It helps in the reduction of cost and increase of performance. Therefore, the bio-degradable polymers are synthesized by combining both bio-based and petrochemical polymers.[7] In addition, if a degradable hydrophobic plastic, after degradation, is not assimilated completely by microorganisms, then it will pose a much greater threat than a non-biodegradable

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plastic. Factors like heat, sunlight, enzymes, and moisture play an important role in the weakening of chains of polymer, which results in the formation of fragments of plastic and cross-linking as well. Due to the fragmentation and cross-linking, more intractable residues are created. In a controlled environment, it is possible to accelerate the process of degradation of plastic, which might result in the formation of microscopic fragments as well. However, this degradation or fragmentation of plastic cannot be considered as bio-degradation until the fragments are completely assimilated by microorganisms during the process.[8]

Due to the immense threat that plastic bags pose to nature, many countries across the globe want to ban the use of plastic bags. Countries like Singapore have already prohibited the utilization of plastic bags, and numerous countries in both Europe and Asia are expressing their desire for a similar ban on plastic bags.[9] The next highly sought-after alternative, paper (paper bags), even being bio-degradable and eco-friendly, has not been able to become as popular as its plastic counterpart. The major drawback of paper is its hydrophilic nature. Moreover, attempts to make paper hydrophobic using polyolefin cause loss of the bio-degradable nature and difficulty in recycling. Therefore, the need for an alternative biodegradable, hydrophobic packaging material is immediate.[10]

This brings the need to look into the various studies that have been conducted across the Globe on cuticular wax of plants to synthesize a hydrophobic polymer or a surface coating agent. The choice of the best coating agent is crucial when it comes to surface coatings since it affects both the durability and effectiveness of protective measures. This review study investigates the possible application of plant sample-derived epicuticular wax as a hydrophobic surface coating agent (Table 1). The need for materials that can withstand environmental influences, increase lifespan, and guarantee strong adhesion is driven by the complex specifications of coating applications. It's fascinating chemical composition and distinct physical features are the reasons behind the attention on epicuticular wax as a coating agent.[11] The complex blend of long-chain aliphatic chemicals and triterpenoids found in epicuticular wax has shown extraordinary water-repellent properties. Through a careful analysis of these indications, this research seeks to clarify why epicuticular wax is such a strong contender for hydrophobic surface coatings.[12] As indicated by the increasing amount of research on environmentally friendly materials in coatings, it also aims to contribute to the current discussion on sustainable coating solutions. This paper seeks to offer important insights into the possible uses and developments in the field of hydrophobic surface coatings by carefully analyzing the distinctive qualities of epicuticular wax.

National Scenario

Although there has been a significant number of studies done on cuticular wax of plants, the number is comparatively now in the national scenario. Here are a few of the studies on plant cuticular wax that are worth mentioning:

One of the studies on cuticular wax reported that the outermost layer of leaves, buds, and stems is covered with a layer of waxy cuticular wax. It appears as bluish-white in colour. The major functions of cuticular wax are to protect the plant against pathogens, water loss, and abiotic stresses like water loss, light, and temperature.[13] Another study reported that the composition of the cuticular depends upon the genotype, age of the leaf, side of the leaf, and climatic and seasonal conditions. The cuticular wax of plants exhibits high degree of hydrophobicity, crystallinity and a low degree of chemical reactivity. The hydrophobicity of the cuticular wax depends on its chemical composition. The presence of functional groups such as -OH, -COOH, $-NO_{2,}$ or -CO- influences the hydrophobicity. The higher the amount of these functional groups, the higher the hydrophobicity *Caloptropis procera* (Ait.) R. Br., which belongs to the Asclepiadaceae family, is a wild perennial shrub. It can grow up to a height of 2-3 m (in drought places). The width of the leaves is 10 to 13 cm, and the length is around 17 to 19 cm. *C. Procera* grows in hot and arid places as a weed. In preliminary studies, the wax extracted from the adaxial surface of the leaves using ethanol was found to be highest (0.14 $\mu g/cm^2$).[14] In addition to *C. procera*, studies were also conducted on the leaves of *Alstonia scholaris.* The wax was extracted from the leaves from the abaxial and adaxial surfaces and it was then quantified. The content of the wax was found to be highest (0.06 $\mu g/cm^{2)}$ on the adaxial surface, when extracted using ethanol. The results of the hydrophobicity tests performed by loading extracted wax (using benzene) on Whitmann Filter Paper number 1 concluded that the wax extracted from *C. procera* is more hydrophobic and has better yield than the wax of *Alstonia scholaris.* In the end, it was concluded that experiments should be further performed to optimize the extraction of wax from *A. scholaris,* and *C. procera.* to produce a hydrophobic packaging material.[10]

Another plant with hydrophobic epicuticular wax is *Colocasia esculenta.* The bio-wax on the leaves of *C. esculenta* bio-wax can be extracted using solvent extraction method using chloroform. The amount of bio-wax present on the leaves was found to be approximately 0.116 g/1 g of fresh leaves of *C. esculenta.* The extraction of the wax was performed by immersing fragments of leaves in chloroform. During the preliminary study, it was observed that Whitmann filter paper no.1 coated with bio-wax, exhibited hydrophobicity, a property absent in non-coated filter papers. In addition to hydrophobicity, the bio-wax of *C. esculenta* also exhibited anti-bacterial properties against *E. coli* and *Streptococcus.* Thermal stability of the wax was observed till 100°C when exposed to varying temperatures. The study concluded with the note that further experiments should be performed to derive an efficient method of coating wax on paper.[15] Similarly, the bio-waxes extracted from taro leaves and lotus leaves were used to develop a super-hydrophobic water-repellent layer on silicon substrates. The extraction was done by the process of drop-by-drop insertion of chloroform. The chloroform was dropped on the upper surface of the leaves and the solution was simultaneously collected. The hierarchical nanostructures of the wax, which contribute to the hydrophobic property, were confirmed by the images of SEM. The electrical measurements provided evidence of the insulating behavior of both the wax samples. A superhydrophobic layer of wax with relevant dielectric properties can be used in bio-electronics.[16]

International Scenario

In plants, the surface of the stems and the leaves is called cuticles. The cuticle acts as the primary barrier against pathogens and insects. Also, it regulates the retention of water during stress periods like high temperature, low soil moisture, and low atmospheric pressure. The cuticle is a matrix composed of two main components: Cutin (a simple polymer), and lipids (termed epicuticular waxes). The epicuticular waxes are end-products of long-chain lipid metabolism and include fatty acids, alkanes, ketones, primary and secondary alcohols, esters, and aldehydes.[17]

At present, papers are mostly coated with synthetic or fossil-oil-based polymers like Polyvinylidene Chloride (PVDC), polyethylene, and Ethylene Vinyl alcohol (EVOH). However, the limited reserves of fossil-oil, non-biodegradability, and difficulty in recyclability of papers coated with synthetic polymers raise concerns across the world. Biopolymers have the potential to replace synthetic coating materials. They are biodegradable, easy to recycle, and non-toxic. However, the molecular weight, time-dependent crystallization properties, and rheological properties may cause problems in the processing pathway. Therefore, biopolymers would have to be blended with other polymers or bio-based nano-fillers to improve hydrophobicity and their processing. Coating of biopolymers on paper can be done by various techniques such as, solvent coating, dispersion coating, and extrusion. Polymers like protein, lipids, and polysaccharides can be applied as a coating by solvent coating or dispersion coating methods.[18]

The epicuticular waxes can be removed mechanically using gum arabic. The gum arabic was used as an adhesive by applying it to the adaxial surface of the *Ligustrum vulgare* leaves as an aqueous solution using a paintbrush. After the solution had dried and formed a thin polymer film, it was peeled off and extracted overnight with chloroform.[19] Most commercial hydrophobic photographic papers are acidic because their production involves bleaching agents, coatings, and sizing materials. Generally, acidic papers tend to deteriorate faster than alkaline papers. But hydrophobic acidic paper tends to have a longer shelf life due to its ability to resist moisture. Paper produced from the pulp that was obtained from scrap paper was coated with taro leaf bio-wax by pouring chloroform extract of the wax on the paper. Results obtained after the experiments showed that the hydrophobic paper that was obtained is better than photographic paper in terms of pH, solubility, moisture content, and liquid dropping.[20]

Differential Scanning Calorimetry (DSC), Gas Chromatography-Flame Ionization Detector (GC-FID), and Fourier Transform Infra-Red (FTIR) were also used to characterize wax from taro leaves. Findings from studies confirmed that 1-octacosanol is the major component in taro wax. The hydrophobic property of the wax extracted from taro leaf is due to the presence of the 1-octacosanol. The presence of the functional groups OH, CH_2, CH_3, and C=O was also detected. From DSC results, it was found that the taro wax is composed of at least two contents. The lower content has a melting range of 50 to 60ºC, and the upper content has a melting point range of 65 to 75ºC.[21]

The epicuticular wax of *S. domestica* and *C. granatensis* leaves was fully removed by dipping the leaves in chloroform for 3 minutes. The extracted wax was recrystallized *in vitro* in plastic plates. The recrystallization was homogenous but consisted of a tubular projection and a continuous underlying layer. The tubules that were obtained after recrystallization showed the same size, shape, and orientation as the corresponding *in vivo* crystals on the surface of the leaves.[22] In a study by Hokkaido University, properties of wax were extracted from three varieties of banana leaves. Yields of cuticular wax of *Musa liukiuensis, M. acuminate*, and *M. chiliacrpa* were 0.58%, 1.05%, and 1.41% per dry weight, respectively. Bananas are an herbaceous crop and grow throughout the year, i.e. perennial. Natural waxes have found their usefulness in many purposes like cosmetics, medicines, chemical bases, and food coatings. Carnauba wax is a natural commercial wax and is added to other wax to increase their hardness, toughness, melting point, luster and decrease in stickiness, plasticity, and crystallizing tendencies. The wax of banana leaves has a higher melting point than most commercial natural waxes except Carnauba. It is also light, and therefore banana leaves' wax can find advantages in industrial purposes.[23] Among all the natural water-repellent plants, the Lotus plant is considered the supreme of all. It has a high contact angle (>150º) and a low sliding angle (<10º). The super hydrophobicity of the lotus plant is due to the low surface energy that is provided by the epicuticular wax crystalloids and the pockets of air that are trapped in a micrometer-scale papillae structure. It minimizes the contact area of solids and water. Although there are many applications of naturally hydrophobic substances, designing a similar artificial structure remains a challenge. Designing their micro or nano-structure and a surface with low surface energy is quite a task to achieve. Future research should be directed toward enhancing the adhesion of natural superhydrophobic substances onto various surfaces.[24] SEM images showed that the wax tubules on both sides of the lotus leaves are different. The wax tubules of the lower side are longer (1 to 2 micrometer) and thicker (Contact Angle 150 nanometer).

Table 1: List of Plants with Epicuticular Wax.

Sl. No.	Common Name	Part Use	Scientific Name	References
1	Tomato	Fruit, Leaf	Solanum lycopersicum	[24]
2	Rose	Leaf, Petal	*Rosa* spp.	[25]
3	Apple	Fruit	Malus domestica	[26]
4	Citrus fruits	Fruit	*Citrus* spp.	[27]
5	Olive	Fruit	Olea europaea	[28]
6	Eggplant	Fruit	Solanum melongena	[29]
7	Banana	Leaf	*Musa* spp.	[21]
8	Potato	Leaf	Solanum tuberosum	[30]
9	Taro/Kosu	Leaf	Colocasia esculenta	[13]
10	Coffee	Leaf	*Coffea* spp.	[31]
11	Wheat	Leaf	*Triticum* spp.	[32]
12	Christ's plant	Leaf	Euphorbia milii	[33]
13	Lotus	Leaf	Nelumbo nucifera	[34]

Epicuticular wax: Extraction, Composition, and Application.

These tubules are composed of nanocosol. In comparison to the wax on the upper side, the wax tubules on the lower side are short (0.3 to 1 micrometer) and thin (80 to 120 nanometer).[25]

Extraction

The assessment of epicuticular wax's efficacy as a hydrophobic surface coating agent starts with the critical step of removing it from plant samples using a variety of procedures ranging from conventional solvent-based methods to cutting-edge mechanical approaches. The choice of solvent has a significant effect on extraction yields, highlighting the need for careful planning when selecting extraction techniques. By reducing the use of chemical solvents, mechanical methods like scraping and brushing provide sustainable alternatives and have the potential to improve environmental sustainability. For epicuticular wax to be used in coating applications later on, it is necessary to obtain the best extraction results in terms of quantity and quality, which calls for the creation of an effective extraction procedure.[26] A variety of parameters, such as plant species, growing environment, and extraction technique, affect the extraction yield of epicuticular wax, making it a complex parameter. Since different plant species have different levels of epicuticular wax, Samuels *et al.* (2008) and Riederer and Müller (2006) emphasized the need for customized methods based on particular plant sources.[11,12] According to a study that uncovered variances depending on solvent selection, the choice of extraction procedures, whether solvent-based or mechanical, has a substantial influence on the yield. There is variation in the amount of wax on plant surfaces according to environmental factors, including temperature and soil composition.[27] The practical use of epicuticular wax as a coating agent in real-world situations requires scalability and cost-effectiveness, both of which are dependent on optimizing extraction yields. It is in line with the increasing focus on sustainable and ecologically friendly coating materials to acknowledge the potential of epicuticular wax as a feasible hydrophobic surface coating. This emphasizes the importance of improving writing abilities for clear communication in this dynamic field of study.[28]

Chemical Composition of Epicuticular Wax

Epicuticular wax has a complicated molecular makeup consisting of a variety of triterpenoids and long-chain aliphatic chemicals. Because the composition differs throughout plant species, customized coating applications require sophisticated knowledge. The contributions of Riederer and Müller (2006) and Samuels *et al.* (2008) have been significant in clarifying the chemical components, highlighting the differences in composition across various plant species.[11,12] When developing coating solutions, the significance of taking the plant source into account is highlighted by the diversity of chemical composition.

Chemical Properties of Epicuticular Wax

Deciphering epicuticular wax's behavior as a coating agent requires an understanding of its chemical makeup. Due to its complex chemical structure, it has water-repellent properties that make it a desirable choice for surface hydrophobicity.[29] The chemical characteristics were investigated in research that shed light on the material's possible uses in coating technologies. These characteristics, including the wax's capacity to create a shield on surfaces, affect how well it keeps out water and strengthens resistance to outside stresses. Epicuticular wax has the potential as a flexible and long-lasting hydrophobic surface coating material as more research is done to understand its complex chemical makeup.[30-34]

Applications as a Coating Agent

Epicuticular wax has a wide range of possible uses as a hydrophobic surface coating material. Utilizing the water-repellent qualities of epicuticular wax to improve durability and resilience to external conditions, synthetic polymers, in particular, stand out as an important application domain. With the increasing focus on sustainability in material science, using epicuticular wax is consistent with the larger goal of creating environmentally acceptable coating materials. The investigation of applications goes beyond conventional coatings to incorporate creative fixes for current environmental issues.[27,31-34]

DISCUSSION

Epicuticular wax extracted from the plant origin as a hydrophobic water-repellent surface agent promises the number of applications with prompt advantages. They remain present on the surface of plants and are responsible for serving as a protective layer from excessive water loss, pathogens, UV radiation etc. As they are hydrophobic in nature, this property can be valuable in industries such as construction, automotive, and textiles, where water repellency is desired to prevent damage, corrosion, or staining. The use of plant-based material as a hydrophobic surface coating agent is environmentally friendly compared to its synthetic counterparts. It also enhanced the durability and longevity of the coated material.

CONCLUSION

The epicuticular wax is a biodegradable substance found on the outer surface of selected plants that can be utilized as a hydrophobic surface coating agent. By extracting and processing this wax from plant origin, it is possible to develop coatings with excellent water resistance, environmental friendliness, increased durability, and self-cleaning properties. These coatings have wide applications on various ranges of surfaces. Though the epicuticular wax promises lots of beneficial activities, its extraction protocol still needs better standardization. The various methods of coating on the surface are also limited. Further research and development efforts can help overcome these obstacles and unlock the full potential of epicuticular wax as a valuable surface coating agent.

Future Prospect

The use of plastic or plastic-based products is creating a serious threat to the environment. Since epicuticular wax is biodegradable, systematic use of epicuticular wax as a surface coating agent is a good source of alternative to synthetic plastics. However, more research is required to establish epicuticular wax as a surface coating agent on various surfaces. Methods of coating and extraction of epicuticular wax from the plant origin need more focus.

Epicuticular wax has a bright future ahead of it as a coating agent for synthetic polymers because of its natural hydrophobic qualities, research to optimize application efficiency, large volumes that can be obtained from a variety of plant sources, and sustainability. Because of its special chemical makeup of long-chain aliphatic chemicals, esters, and triterpenoids, epicuticular wax is hydrophobic and has a natural water-repellent property. This makes it an efficient and long-lasting coating for synthetic polymers. Optimization studies provide important information on the ideal wax-to-plastic ratio, directing the sector towards coating procedures that are both economical and ecologically responsible. There is flexibility in choosing sources depending on wax content, regional availability, and sustainability considerations since plant species vary in their wax content. A sustainable supply chain is ensured by ethical sourcing procedures, ecologically friendly farming and harvesting techniques, and other factors. Sustainability is still crucial. Finally, it should be noted that further research and development in this area should result in creative, eco-friendly solutions that improve the functionality of synthetic plastics, paving the way for a more robust and sustainable future.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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