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Review

Application of Edible Film with Asian Plant Extracts as an Innovative Food Packaging: A Review

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Abstract: Asian plants (AP) have long been used as natural food preservatives in the food industry. Asian plant extracts (APE) and essential oils (EOs) with antioxidant and antimicrobial properties were incorporated into edible film (EF) for the inhibition of microbial growth in the food matrix. However, information on the utilization of these antibacterial EFs on the storage application of different local food products has not been thoroughly reviewed. Hence, this review gives an overview of the physicochemical, mechanical, antioxidant, and antibacterial properties of EF incorporated with AP and their storage application for the preservation of food products. For their applicability as food packaging, the potency of these EFs to be used as food packaging in preventing food spoilage or foodborne pathogens was also thoroughly reviewed. The addition of APE and EOs into the packaging matrix demonstrated the potential to prolong the storage of food products by preserving food quality (pH, colors, and lipid oxidation) and safety during storage, and the inhibition zones of some extracts against the pathogens demonstrated are weaker in comparison to the standard antibiotic drug used (WHO standards). In conclusion, the freshness of food products could be retained and lengthened by using EF with APE and Eos as active edible food packaging. However, additional research is required to significantly improve its antibacterial activity, producibility, and technical feasibility for long-term market use.

Keywords: Asian plant extracts; essential oils; edible film; physicochemical; mechanical; storage application

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1. Introduction

Edible film (EF) is a thin covering that is applied as a separate layer between food components or directly to the food to act as a barrier for gas, moisture, oil, and vapors [1]. It is made of food-grade materials and can be consumed alongside the package and food during application. Biopolymers commonly applied in EF including polysaccharides (gums, alginate, agar, and starch), proteins (gelatin, casein, and whey), and lipids (glycerides, waxes, and paraffin). Food is shielded and protected from deterioration by EF on a physical, chemical, and biological level while also improving the visual appearance [2]. They also act as barriers and carriers for bioactive compounds (e.g., antioxidants, antimicrobials, flavorings, and colorants) which help to improve food quality by extending shelf life and improving food safety [3].

Asia has a diverse range of plants due to the wide variation of continents in latitude, elevation, and climate. Aside from that, the monsoonal climate of some regions produces hot and rainy summers, giving rise to a diverse range of temperate and tropical plants. Asian has Asian medicinal plants and spices which are used not only for medical purposes but also as food preservatives and flavorings [4]. The addition of natural additives such as APE and EOs can considerably improve the antioxidant and antimicrobial activity of

the EF. Several studies have correlated various APE and EOs, for example, hawthorn berry, black soybean, and mangosteen peel, for properties which inhibit microbial growth in the food matrix [5–7]. Other advantages of incorporating these natural additives are to retard the oxidation rate of the product (fresh food), and to reduce the microbial load which can lengthen the storage of food products [8–11].

One of the AP such as Moringa (*Moringa oleifera* Lam. moringaceae) is a highly valuable plant that is mostly grown in the tropics and subtropics. This plant has been investigated by incorporating *Moringa oleifera* Lam. leaf extract (ethanol extract) with pufferfish skin gelatin to make an EF. This helps to increase the mechanical strengths of the film, which are the tensile strength (TS) and elongation at break (EAB). The film also demonstrated antibacterial activity against *Listeria monocytogenes* with improved antioxidant activity [12]. On the other hand, in eastern Asia countries, black soybean with black seed coatings is a functional food that is nutritionally rich. The incorporation of black soybean seed extract (ethanol extract) in chitosan EF showed outstanding barrier properties, for example, the water vapor (WVP) and UV-vis light and strengthen mechanical strength (TS and EAB), compared to the control (chitosan film). The black soybean seed extract chitosan film also demonstrated improved antioxidant activity, with 2,2-diphenylpicrylhydrazyl (DPPH) radical scavenging activities of the film gradually increasing as black soybean seed extract content increased from 5% to 15% *(w/w)* [6].

Besides APE, EOs, composed in a complex way with volatile chemicals produced by plants (aromatic), are also used as natural preservatives in the food industry. The addition of EO may also impact the mechanical and functional properties of the film [13]. Chrysanthemum EO is a liquid substance (aromatic) produced from the *Chrysanthemum morifolium*, one of 300 species in the *Asteraceae* (Compositae) family that was first cultivated in China as a blooming herb. The addition of the *Chrysanthemum morifolium* EO (1% to 6% (*v*/*v*)) in chitosan EF improved the scavenging effect of the antioxidant assay (from 4.97% to 18.63%) and the meat storage (raw chicken and beef) from 3 to 5 days during storage by maintaining the pH level (safe to consume), with an increase in *Chrysanthemum morifolium* concentration and with antibacterial activity against *Staphylococcus aureus* [14]. There is a trend reported that with nanoemulsified ginger, EO in gelatin EFs improve their thickness while reducing their water solubility, moisture content, and surface hydrophobicity when combined with montmorillonite (MMT) [15].

The incorporation of various types of APE and EOs as additive to EF provides benefits, as EF can provide different functional properties and also ensure consumer acceptability [16]. These extracts may come from different parts of the plant and spices including leaves, buds, roots, seeds, fruits, flowers, and barks which contain various phenolic compounds attributing to the biological properties [17]. Most of the review papers have focused on general plant extracts (PE) and EOs commonly used in Western regions, such as oregano, cinnamon, and thyme [18–20]. There have been numerous investigations on APE and EO incorporation in EF due to their antibacterial properties; however, these findings have not been thoroughly reviewed. Hence, the purpose of this review is to discuss the effects of different EF formulations containing APE and EOs on the physicochemical and mechanical properties of the EF, to provide a better perspective of the current state of study of improving the overall functionality of EF as food packaging. The possible use of these EFs in various food products as food packaging will also be discussed to provide better comprehension and raise awareness of the importance of utilizing these AP in the food packaging industry.

2. EF Formulations Containing Different APE and EOs

Due to its antioxidant and antibacterial properties, AP have also been extensively utilized in industries such as in the food industry as preservatives and flavorings [4,21]. Antioxidant and antibacterial agents from PE extracted using different solvents such as ethanol, methanol, and aqueous were previously incorporated into EF [6,22,23]. EOs from AP are also commonly extracted using hydro-distillation for use in natural medicine or

natural food preservation [14,21]. Recent studies have shown that incorporating these extracts into different biopolymers (polysaccharides, protein, and lipids) could help in enhancing the qualities of active EF. Different food grade ingredients, processing aids, and additives were used as plasticizers or solvents to develop an EF that shows enhanced properties, with the addition of APE and EOs to produce the film, forming suspensions. Table 1 lists examples of the various APE and EOs incorporation of EF.

Table 1. Various APE and EOs incorporation of EF.

Asian Plant	Plant Part	Extract		Base	Other Ingredients	References
		Type	Amount (%)			
Black soybean	Seed	Ethanolic extract	5, 10, 15 (*w*/*w*)	Chitosan	Acetic acid (1% (*v*/*v*)) Glycerol (0.6% (*w*/*v*))	[6]
Chrysanthemum morifolium	N/A	Essential oil	0, 1, 2, 3, 4, 5, 6 (*v*/*v*)	Chitosan	Acetic acid (1% (*v*/*v*)) Glycerol (0.75% (*w*/*v*)) Tween 80 (0.2% (*v*/*v*))	[14]
Eriobotrya japonica Lindl.	Leaves	Ethanolic extract	2, 3, 4 (*w*/*w*)	Banana peel starch	Cornstarch (1.4% (*w*/*v*)) Glycerol (0.76% (*w*/*v*))	[24]
Ginger	N/A	Essential oil	2 (*w*/*w*)	Gelatin	Montmorillonite (MMT) (5% (*w*/*w*)) Glycerol (30% (*w*/*w*))	[15]
Ginger, turmeric and plai	Root	Essential oil	25, 50, 100 (*w*/*w*)	Fish skin gelatin	Glycerol (30% (*w*/*w*)) Tween 20 (25% (*w*/*w*))	[25]
Hawthorn berry (Crataegus pinnatifida)	Fruits	Ethanolic extract	1, 2, 3, 4 (*v*/*v*)	Alginate	Glycerol (0.75% (*v*/*v*)) Calcium chloride (1% (*w*/*v*))	[5]
Kiam (*Cotylelobium lanceolatum* craih)	Wood	Aqueous extract	1, 2, 3, 4, 5 (*v*/*v*)	Hydroxypropyl methylcellulose (HPMC)	Sorbitol (0.4% (*w*/*w*))	[22]
Mangosteen	Peel	Ethanolic extract	1 (*v*/*v*)	Porang glucomannan	Sorbitol (3% (*v*/*v*))	[7]
Moringa oleifera Lam.	Leaves	Ethanolic extract	0.03, 0.05, 0.07, 0.1 (*w*/*v*)	Gelatin (Pufferfish skin)	Sorbitol (2% (*v*/*v*))	[12]
Neem (*Azadirachta indica*)	Flowers and leaves	Aqueous extract	0, 0.1, 0.3, 0.5 (*w*/*v*)	Gelatin	Glycerol (25% (*w*/*w*))	[11]
Piper Betle Linn.	Leaves	Aqueous extract	1, 2, 3 (*v*/*v*)	Chitosan	N/A	[26]
Sophora japonica	N/A	Ethanolic extract	1, 3, 7, 9 (*w*/*w*)	*Artemisia sphaerocephala* Krasch. Gum (ASKG)	Glycerin (0.3% (*w*/*v*))	[10]
Turmeric (Curcuma longa L.)	N/A	Aqueous extract	13 (*w*/*w*)	Alginate	Glycerol (1% (*v*/*v*)) Calcium chloride (1% (*w*/*v*))	[9]

Various APE (e.g., black soybean, *Chrysanthemum morifolium*, *Eriobotrya japonica* Lindl., ginger, turmeric and plai, hawthorn berry, kiam, mangosteen, neem, *Moringa oleifera* Lam., *Piper Betle* Linn., and *Sophora japonica*) have been selected to incorporate into different polymer-based EFs to improve the functional properties of food packaging [5–7,9–12,14,15,22,24–26]. According to the review, many studies have extracted APE with ethanol for incorporation into various biopolymer-based EFs (alginate, chitosan, and gelatin). Most of the research used ethanolic PE in the EF in concentrations ranging from 1% to 15% (*w*/*w*), with some incorporating aqueous extracts and EOs. These studies used different

polysaccharides and protein polymer bases to produce EFs with APE; however, most of the studies used gelatin as the base for EF development. Gelatin was incorporated with extracts of neem and *Moringa oleifera* Lam leaves [11,12]. Glycerol or sorbitol are common plasticizers used in gelatin EFs [11,12,15,25].

APE have been extensively researched with their incorporation into gelatin EF. This combination is possibly due to the widespread use of gelatin in different industries' aspects [27]. This could be owing to its functional properties (water-binding, gel formation, foam forming, film forming, and emulsification ability). Most importantly, gelatin has excellent gas barrier characteristics which are perfect for food packaging properties; conversely, it has poor mechanical strength with high water vapor permeability [28]. As a result of its poor water vapor barrier performance, gelatin's application as a packaging material is restricted [29]. However, by combining gelatin with other ingredients (functional or active agents) such as APE and EO, this can be improved [30].

When compared to gelatin (0.03% to 0.5% (*w*/*v*)), alginate and chitosan EFs have a higher range of APE (5% to 15% (*w*/*w*)). Glycerol (a plasticizer) and calcium chloride (a firming agent) are common ingredients in the production of alginate-based EFs [9]. The glycerol content of EF is typically 0.75% to 1% (*w*/*v*). Studies showed that turmeric (*Curcuma longa* L.) and hawthorn berry extract were incorporated into alginate EFs [5,9]. The APE can be added in amounts ranging from 0.13% to 1% (*v*/*v*) to form an alginate EF. Chitosan was also used in the making of EFs containing APE [6,14,26]. Glycerol was also used as a plasticizer in chitosan EF incorporated with AP [6,14]. In most formulations, 1% acetic acid is added to the chitosan solution, as acetic acid is commonly used to solubilize chitosan [31]. APE, such as black soybean seed coat (BSSC) and *Piper Betle* Linn. leaf (PBLL) extract, have been added into chitosan EFs [6,26]. With APE in the concentration range of 0.1% to 5% (*v*/*v*), a chitosan EF could be formed.

Other polymers, such as hydroxypropyl methylcellulose (HPMC), porang glucomannan, and *Artemisia sphaerocephala* Krasch. gum, have been incorporated with kiam wood, mangosteen peel, and *Sophora japonica* extract, respectively [7,10,22]. Sorbitol was used as a plasticizer in hydroxypropyl methylcellulose (HPMC) and porang glucomannan-based EFs, whereas glycerin was used in *Artemisia sphaerocephala* Krasch. Based on Table 1, the EO content of EF is comparable to APE, which contain less than 6% (*v*/*v*). Hydro-distillation was used to extract EO from *Chrysanthemum morifolium*, ginger, turmeric and Plai root [14,15,25]. Previous literature has reported that Asian plant essential oils (APEOs) incorporated into EF, and EF incorporated with EOs require an emulsifier such as Tween 80 or Tween 20 to mix different bases of solution (oil-based and water-based) [32].

In addition to the ingredients, knowing the types of materials delivered by PE and EOs in EF is very crucial in order to make EF. Common active compounds found in PE and EOs include antioxidant and antimicrobial agents. The EF produced can act as a carrier for these active compounds, providing a novel method for improving food safety and shelf life [33]. Some of the antimicrobial substances that could possibly be used in EF include organic acids, polypeptides, plant Eos, and nitrites and sulfites [34].

According to Lim et al. [5], the antibacterial effects of hawthorn berry extract were most likely due to its specific constituents, specifically the favones and procyanidins [35] delivered by the alginate EF. Because black soybean is high in anthocyanins [6], the extract-incorporated EF served as a carrier for antioxidant agents, which helped to improve the EF's 2,2-diphenylpicrylhydrazyl (DPPH) radical scavenging activity. Curcumin contains polyphenol, which is responsible for its antioxidant capacity when incorporated into EF [9]. Mangosteen peel, on the other hand, contains xanthones, that are very favorable to the body for biological purposes (antioxidant and antibacterial) and could be delivered by using EF as a carrier for this compound when used as food packaging [7].

Artemisia sphaerocephala Krasch. Gum (AsKG) with *Sophora japonica* extract (SJe) has the potential to be an antioxidant EF [10]. In addition, *Sophora japonica* has been widely used in studies for the extraction of flavonoids, particularly rutin, which has a high ability to scavenge DPPH and superoxide anion radicals [36]. Because of these active antioxidant

compounds (phenolic, flavonoids, and limonoids), neem leaf extract has shown high antioxidant activity (DPPH radical scavenging activity increased from 0% to 0.5% (*w*/*v*)) when incorporated into EF [11]. On the other hand, in *Moringa oleifera* Lam. Extract, there are flavonoids (kaempferol and quercetin), and many other phytochemicals that exhibit good antioxidant and antimicrobial properties. Gelatin EF can serve as a carrier for these phytochemical compounds, helping to improve food quality during storage [12].

Kiam with high concentrations of polyphenolic compounds can contribute to the antibacterial activity of hydroxypropyl methylcellulose EF by inhibiting the growth of various bacteria (*Escherichia coli*, *Listeria monocytogenes*, and *Staphylococcus aureus*) [22]. EFs containing *Eriobotrya japonica* Lindl. extract contain phenolic compounds, which are assessed by finding out the total phenolic compound content. The film with the highest extract content demonstrated the highest values (6.6 mg GAE/g^{-1} of total phenolics) [24]. Because of the polyphenol compounds found in the PE, chitosan EF with *Piper Betle* Linn. extract had the potential to serve as an antibacterial EF. These natural compounds can cause cell membrane permeability denaturation, nucleic acid synthesis inhibition, and physiological changes in cell membranes, ultimately leading to cell death [37].

3. Characterization of EF Incorporated with APE and EOs

3.1. Physicochemical Properties

3.1.1. Thickness

Different APE were incorporated into EFs in various concentrations with the incorporation of other ingredients to enhance the properties of the films. Film thickness is highly related to the strength of an EF in terms of the mechanical strength and barrier. These are the basic factors to determine the safety and viability of food packaging [38]. The incorporation of APE increased the thickness of the EF produced. The resistance to mass transfer across the film increased as the thickness of the film increased, which is beneficial in food packaging [39]. Table 2 shows the physicochemical and mechanical properties of EF incorporated with different APE and EOs.

It was discovered that incorporating hawthorn berry extract into alginate films at concentrations ranging from 0% to 4% (*v*/*v*) resulted in an increase in film thickness, with values ranging from 0.073 ± 0.013 mm to 0.216 ± 0.003 mm [5]. The banana peel starch EF with the highest concentration of *Eriobotrya japonica* Lindl. leaves extract (4% (*w*/*w*)) produced the greatest thickness (0.069 ± 0.002 mm) [24]. Chitosan-BSSC extract (0.3%) film had a greater thickness (0.086 ± 0.007 mm) than plain chitosan film (0.078 ± 0.008 mm) [6]. Previous research has discovered that the inclusion of extract in the polymeric matrix increases the total solid content (TSC) of the film and may explain the increase in the thickness of the EF with APE [40].

With increasing concentrations of *Chrysanthemum morifolium* EO, the thickness of the chitosan EF increased from 0.05 to 0.15 mm [14]. Similarly, increases in film thickness were found when EOs from the root of Plai, turmeric, and ginger were added at 50% and 100% concentrations to fish skin gelatin EFs [25]. Zaman et al. [41] explained the rise in thickness of the EF with the incorporation of APEO, where EO filled an EF matrix and increased the thickness value. The increase in thickness of EF is helpful because it enhanced the film's ability to improve the mechanical integrity of foods [42].

3.1.2. Moisture Content and Water Solubility

The moisture content must be in a homeostasis state for EF with packaged food to prevent the transfer of moisture from one medium to another [43]. It was discovered that EFs containing APE have a lower moisture content than EFs that do not contain any extracts. The edible turmeric alginate-based film had a low MC (23.83%), which is similar to that reported by Musso et al. [44], with 22.1% in the curcumin-gelatin film [9]. This is explained by the interaction of hydrogen bonding between amino groups and proteins and the hydroxyl (OH) groups from water molecules, enhancing their proneness to hydration and thus influencing the film's solubility, MC, and water vapor permeability [45]. When

hawthorn berry extract was added at 4% (*v*/*v*), the moisture content of alginate-hawthorn berry extract films (14.54% ± 0.43%) decreased significantly from 20.32 ± 2.54% [5].

Table 2. Physicochemical and mechanical properties of EF incorporated with APE and EOs.

Essential Oil and/or Plant Extracts	Thickness (mm)	Moisture Content (%)	Water Solubility (%) at Room Temperature	Tensile Strength (MPa)	Elongation at Break (%)	Water Vapor Permeability	References
Black soybean seed extract	0.081–0.086	21.22–31.01	12.79–32.02	20.64–23.24	64.58–73.88	12.58–15.41 ($\times 10^{-11}$ g·m^{-1}·s^{-1}·Pa^{-1})	[6]
Chrysanthemum morifolium essential oil	0.050–0.150	N/A	N/A	5.12–15.477	7.770–17.877	18.99–38.83 (%)	[14]
Eriobotrya japonica leaves extract	0.060–0.069	N/A	19.00–42.00	0.50–0.64	38–47	0.29–0.32 (g·mm·h^{-1}·m^{-2} kPa^{-1})	[24]
Ginger essential oil	0.066–0.068	15.00–17.00	37.00–42.00	30.2–32.4	48.2–58.7	0.27–0.30 (g·mm·h^{-1}·m^{-2} kPa^{-1})	[15]
Ginger, turmeric and Plai root essential oils	0.041–0.057	N/A	N/A	17.20–43.62	19.59–74.68	1.88–3.11 ($\times 10^{-11}$ g·m^{-1}·s^{-1}·Pa^{-1})	[25]
Hawthorn berry (*Crataegus pinnatifida*) extract	0.127–0.216	14.54–20.32	37.87–77.60	1.85–39.17	27.48–43.57	N/A	[5]
Kiam wood (*Cotylelobium lanceolatum* craih) extract	N/A	N/A	N/A	18.48–38.61	11.19–28.82	15.09–27.77 (g mm/m^2 day kPa)	[22]
Mangosteen peel extract	0.213–0.235	N/A	N/A	12.574–15.573	N/A	N/A	[7]
Moringa oleifera Lam. leaf extract	N/A	N/A	N/A	55.68–84.49	29.85–65.93	1.38–1.64 ($\times 10^{-9}$ g m/m^2 s Pa)	[12]
Neem (*Azadirachta indica*) extract	0.039–0.044	N/A	59.00–94.30	13.9–17.2	31.2–43.5	12.0–12.3 ($\times 10^{-11}$ g m^{-1}·hour^{-1}·Pa^{-1})	[11]
Piper Betle Linn. leaf extract	N/A	8.73–13.19	12.70–29.33	16.67–48.24	3.49–22.21	644.32–793.3 (g/m^2/24 h)	[26]
Sophora japonica extract	N/A	N/A	N/A	25.99–29.62	23.00–59.67	N/A	[10]
Turmeric (*Curcuma longa* L.) extract	0.096 ± 0.002	23.83 ± 1.05	100 ± 0.01	8.26 ± 1.79	35.94 ± 2.75	1.73 ± 0.049 (g mm/k Pa·h^{-1}·m^{-2})	[9]

Based on chitosan, the BSSC extract content increased (5% to 15% (*w*/*w*)), and the moisture content of chitosan-BSSC extract films decreased from 26.93% to 21.29% [6]. The moisture content (13.19% ± 0.24% to 10.72% ± 0.50%) appeared to decrease after different concentrations of PBLL extracts were added to the chitosan network, according to the study [26]. The frequent contact between the phenolics from the extract and the -OH groups from the polymer matrix may explain the decrement in moisture content of the EF due to the addition of APE. As a result, the polymer's interaction with water molecules is limited. A lower amount of water was present in the film as a result of the polymer's decreased affinity for water molecules [46]. It is critical to consider the moisture content of EFs because controlling moisture content as well as moisture migration at the beginning of food storage is essential to food quality and safety [47].

The movement of bioactive compounds that are encapsulated in EF depends on their solubility in aqueous or humid environments [46]. Most studies found that adding APE to EF increased its water solubility. Due to the hydrophilic characteristic of alginate, determined by different units of amino acid, the EF was also completely soluble in water (100%) [9]. The addition of hawthorn berry extract (0% to 4% *(v/v)*) resulted in an increment of film solubility (37.87% ± 6.02% to 77.60% ± 0.60%) [5]. The addition of 4% *Eriobotrya japonica* Lindl. leaves extract increased water solubility (42% ± 4%) over the control (19% ± 2%) (banana peel starch EF) [24]. Similarly, the water solubility of chitosan–BSSC extract films increased as the BSSC extract content increased (5% to 15% (*w*/*w*)) [6]. The alginate EF with turmeric extract was completely soluble in water. The high solubility

of polymers such as alginate is because of the hydrophilic character, which is largely determined by α-D-mannuronic acid and β-L-guluronic acid [9].

The increment of water transfer into the film network was caused by the presence of APE. This is explained by the presence of the extracts which weakens the contact between the molecules of the polymer [48]. The excess molecules of the extract are prone to escaping from the film's cross-linkage of network, resulting in a film with higher solubility [49]. The addition of APE to EF increases water solubility, which may have an impact on their food packaging uses. Water insolubility of EF may be required for further uses to improve product reliability and water resistance [50]. On the other hand, neem extract has been incorporated into gelatin EF [11]. Increasing the amount of extract will cause the solubility of gelatin EF to decrease from 94.3% ± 3.45% to 62.6% ± 0.25%. This phenomenon is explained by the cross-linking of proteins and phenolics found in neem extract. This result is due to hydrogen bonding, which may reduce the contacts in protein water [11].

3.1.3. Water Vapor Permeability

By limiting the transmission of lipid, aroma and flavor compounds, oxygen (O_2), carbon dioxide (CO_2), moisture, and carbon monoxide (CO) in food systems, EFs can increase food attributes and lengthen the storage period of food products. Water vapor permeability (WVP) is a parameter that represents the moisture transfer between EFs and food [9]. Previous research has reported on the WVP of EF containing various APE and EOs. The addition of 4% *Eriobotrya japonica* Lindl. leaves extract also reduced WVP (0.29 ± 0.02 g/mm·h^{-1}/m^{-2}/kPa^{-1}) compared to the control (0.19 ± 0.03 g/mm·h^{-1}/m^{-2}/kPa^{-1}) (banana peel starch EF) [24]. Besides that, as the concentration of the PBLL extract increased, the WVP of the chitosan film decreased gradually from 740.9 ± 1.98 to 644.32 ± 3.88 g/m^2 [26]. The WVP of EF decreased as the concentration of APE increased, which can be explained by the fact that extract compounds filled the gaps in the polymeric matrix, reducing water vapor from diffusing through the film [24]. The addition of APE resulted in low WVP in EF, which is favorable because moisture migration control is critical to food quality and safety in terms of limiting the microbial growth and maintaining the film texture [47].

There are studies showing an increase in WVP when APE and EO are added to EF. Increments of the amount of kiam wood extract from 300 to 1500 mg/L caused a rise in the WVP of edible HPMC films from 15.09 to 27.77 gmm/m^2·d/kPa [22]. On the other hand, the addition of *Chrysanthemum morifolium* EO (0% to 4% *v*/*v*) increased the WVP of chitosan EFs from 18.99% to 38.83% [14]. Increments of WVP of EF after the incorporation of APE or EOs could be attributed to the extract's hydrophilicity, as introducing hydrophilic additives, which are favorable to water molecule adsorption and desorption, was investigated to reduce the WVP of hydrocolloid-based films [45]. It was reported that when the concentration of herbal extracts was increased, the covalent bonding association between chitosan molecules decreased, resulting in a spatial structure loss in the film [51].

3.2. Mechanical Properties

3.2.1. Tensile Strength

The tensile properties of films are directly related to their integrity and barrier properties [52]. According to conventional guidelines, food packaging must have a TS bigger than 3.5 MPa so that it can be considered acceptable [53]. The edible alginate-based film produced with turmeric had a TS value of 8.26 MPa [9], which was slightly higher than the 7.4 MPa obtained by Wang et al. [54]. These results show that the EF was more capable of sustaining extensibility under external tensile stress before rupturing. According to Wang et al. [6], chitosan-BSSC extract films had a higher TS (23.24 ± 0.83 MPa) than plain chitosan films (14.83 ± 0.78 MPa). When PE is incorporated into the EF, the TS increases with the polymer, the internal union, and any contacts between the matrix and the active component [55].

The TS of the alginate–hawthorn berry EF, on the other hand, showed a decrement (39.17 ± 1.17 to 1.85 ± 0.65 MPa) as the amount of hawthorn berry extract increased (0% to 4% (*v*/*v*)) [5]. A similar trend was observed when *Chrysanthemum morifolium* EO (0% to 4% (*v*/*v*)) was added, with the TS of chitosan EFs decreasing from 8.813 ± 0.055 to 5.120 ± 0.020 MPa [14]. Besides that, fish skin gelatin films with higher levels of EOs from roots of Plai, ginger, and turmeric also showed a lower TS [25]. It can be explained that adding EOs reduced intermolecular interactions, making the film brittle and fragile [51]. The decrease in TS in EFs after incorporating APE and EOs could be attributed to increased film thickness [22]. By acting as a plasticizer, the extract or EO in the film matrix caused a reduction in the TS. This will also weaken the strength in terms of mechanical strength, while flexibility improvement and the chain mobility of film can be achieved by reducing the intermolecular interactions between adjacent molecules in the polymer network [56].

3.2.2. Elongation at Break

Elongation at break (EAB) is a common test for the mechanical strength of EFs. Percent elongation is defined as the increment in length (%) of the EF material measured from the time of withdrawal to fracture [57]. EFs require plasticity or extension to keep their integrity for food products application [58]. In terms of EAB, the edible alginate-based film produced with turmeric had an EAB of 35.94%, which is higher than the 30.8% reported by Wang et al. [54] in curcumin-caseinate/zein films, respectively [9]. This could be because the film contains phenolic compounds, which may increase the EAB. It could also be because of curcumin-alginate interactions, which result in a more flexible and cohesive matrix [58]. It was also discovered that increasing the PBLL extract content from 1 to 2% in chitosan EF (3.60% ± 0.86% to 5.19% ± 1.00%) increased the EAB value [26].

APE incorporation into EFs may increase the EAB due to the compounds in the extract and with high quantities of APE in the film, it can increase the polymer chains transfer (starch and flour). This could result in the replacement of the original polymer chain bonds with new bonds formed by the extract compounds and starch chains [24]. The polymer system was disrupted and chain continuities were reduced when a large number of hydrophilic components were added to the chitosan matrix, resulting in poor rupture resistance [59]. APE in EFs resulted in increased elongation, which is beneficial because it improves the ability of the film to wrap and package food [60].

The EAB of AsKG EF incorporated with *Sophora japonica* extract, on the other hand, decreased as the amount increased from 1% to 9% (*w*/*w*) [10]. Similarly, as the incorporation of *Chrysanthemum morifolium* EO increased from 0% to 4% (*v*/*v*), the EAB of chitosan EFs decreased (16.180% ± 0.225% to 7.770% ± 0.178%) [14]. This phenomenon could be caused by the addition of a conflicting material in the EO due to the discontinuous network and irregular matrix of the polymer [51]. According to other studies, the decreasing order of the EAB in EFs with APE may be due to an overabundance of extracts causing a disruption in the homogeneous film [61,62].

3.3. In Vitro Antioxidant and Antibacterial Activity

Antioxidant-rich extracts in EFs can improve their protective function. In vitro antioxidant studies on EF were conducted to assess the effect of these EF containing APE and EOs on metabolic activities in food [63]. Alginate EFs containing 13% (*w*/*w*) turmeric extract demonstrated antioxidant activity (38.282% DPPH) [9]. Antioxidant films were made by incorporating AsKG with SJe. SJe (1%, 3%, 7%, and 9% (*w*/*w*)) addition caused a significant increment in the total phenolic content (from 0.37 to 1.73 mg/g) and DPPH scavenging activity (3.60% to 81.65%) of the films while inhibiting oil oxidation during storage [10]. On the other hand, the incorporation of the ethanol extract of *Eriobotrya japonica* Lindl. leaves (2% to 3% (*w*/*w*)) into the banana peel flour film significantly increased the antioxidant activity in terms of phenolic contents (from 4.8 to 6.6 mg GAE/g^{-1}), ABTS (from 35 to 59 μM Trolox/g^{-1}), FRAP (from 120 to 192 μM $FeSO_4$/g^{-1}), and DPPH (from 75% to 120%) [24].

Antioxidant chitosan-based films were made by adding varying BSSC extract content in 5%, 10%, and 15% (*w*/*w*) concentrations [6]. The diphenyl-1-picrylhydrazyl radical scavenging activity of chitosan–BSSC extract films in different concentrations of BSSC extract (5%, 10%, and 15% (*w*/*w*)) was found to be 34.24%, 42.46%, and 52.51%, respectively. Further, the incorporation of *Piper Betle* Linn. leaves ethanol extract into chitosan films demonstrated an improvement in important film properties [26]. With increasing incorporated *Piper Betle* Linn. content (from 1% to 3% (*v*/*v*)), the antioxidant activities of the blend films increased (from 22.81 to 10.63 IC50 g/mL). When the concentration of aqueous extract from the flowers and leaves of neem in the gelatin EF was increased (from 0% to 0.5% (*w*/*v*)), the DPPH radical scavenging activity increased (11.6% to 40.3%) when compared to the control (3.97%) [11]. The antioxidant activity of EFs after incorporation with APE or EOs could be attributed to the polyphenolic compounds found in the AP [26]. Furthermore, phenolic compounds interact with the matrix of the chitosan polymer, which influences the functional properties of these films showing antioxidant activity [9].

The zone of inhibition is a circular area that surrounds the antibacterial point and prevents bacteria colonies from growing. The zone of inhibition can be used to determine how susceptible bacteria are to an antibacterial compound [64]. The diameter of this zone of inhibition will indicate how efficient and effective the sample (APE or EOs) is in treating the patient. The larger the diameter, the more effective the sample. Previous literature on the antibacterial activity of various APE and EOs-incorporated EFs against different pathogens are shown in Table 3.

Table 3. Antibacterial activity of various APE and EOs-incorporated EFs against different pathogens.

Extract		Base	Pathogen	Zone of Inhibition (mm)	References
Type	**Amount (%)**				
Ethanolic hawthorn berry (Crataegus pinnatifida) extract	1, 2, 3, 4 (*v*/*v*)	Alginate	- *Staphylococcus aureus* - *Escherichia coli*	- 8.80 to 10.73 - 9.40 to 11.13	[5]
Aqueous kiam wood (*Cotylelobium lanceolatum* craih) extract	1, 2, 3, 4, 5 (*v*/*v*)	HPMC	- *Listeria monocytogenes* - *Staphylococcus aureus* - *Escherichia coli*	- 17.50 to 29.65 - 20 to 25.33 - 18.33 to 23.00	[22]
Chrysanthemum morifolium essential oil	0, 1, 2, 3, 4, 5, 6 (*v*/*v*)	Chitosan	- *Staphylococcus aureus* - *Escherichia coli* - *Vibrio cholera* - *Salmonella typhimurium*	- 2.67 to 3.82 - 1.03 to 1.10 - 0 - 0	[14]

An increase in hawthorn berry extract content (1% to 4% (*v*/*v*)) resulted in larger inhibition zones against two bacteria (*Staphylococcus aureus* and *Escherichia coli*) [5]. The inhibition zones of *Staphylococcus aureus* (ranged from 8.800.26 to 10.73 0.55 mm) and *Escherichia coli* (ranged from 9.400.26 to 11.130.96 mm) increased significantly. Similarly, EFs containing kiam wood extract inhibited the growth of various bacteria (*Escherichia coli, Listeria monocytogenes,* and *Staphylococcus aureus*) [22]. It was also discovered that as the concentration of *Chrysanthemum morifolium* in chitosan EFs increased from 2% to 4%, the inhibition zone for *Staphylococcus aureus* increased (2.667 to 3.822 mm) [14]. It was also discovered that the PBLL extract-incorporated chitosan films strongly inhibited the growth of all tested microorganisms (*Bacillus subtilis*, *Staphylococcus aureus*, *Salmonella typhimurium*, *Pseudomonas aeruginosa,* and *Escherichia coli*). Furthermore, increasing the concentration of PBLL extract resulted in improved inhibition efficiency [26]. This demonstrates that the concentration of the EF affects their ability to inhibit bacterial growth. The increased antibacterial efficacy of the film was linked to higher concentrations of extracts or EOs containing more phenolic and flavonoid compounds [65]. The standard antibiotic drug has strong antibacterial effects when evaluated using the zone of inhibition method. According to the WHO standard, the standard zone inhibition range of a standard antibiotic drug is around 16 to 26 mm [66]. Table 3 shows that EFs containing kiam wood extract had an equivalent antibacterial effect in terms of the zone of inhibition to a standard antibiotic

drug. The antibacterial effect of hawthorn berry extract and *Chrysanthemum morifolium* EO is weaker compared to kiam wood extract in EFs. More research can be done to improve the antibacterial activity of these extracts in EFs in order to validate their effectiveness as food packaging in preventing food spoilage or pathogens in food.

4. Food Application of EF Incorporated with APE and EOs

4.1. pH

The utilization of EFs incorporated with APE and EOs on food products is critical to ensuring the potency of active packaging, which entails adding specific additives to packaging film or packaging containers to extend food product shelf-life [67]. For the storage application of EF, different food quality aspects such as pH, color, lipid oxidation, and microbiological analysis can be investigated. Table 4 shows the effect of various food products wrapped in various APE and EO-incorporated EFs. Meat pH is associated with freshness and quality traits such as color, tenderness [68], bacteria growth, and natural antioxidant properties [69]. When an EF containing APE and EOs was applied to meat products, it slowed the increase in pH during storage. It was discovered that by wrapping meat in an alginate EF containing 13% (*w*/*w*) turmeric extract, the pH increased slower than the control (without wrapping) during storage [9]. After 7 days, the pH values of minced beef covered with a gelatin EF with 0.3% neem extract increased from 5.31 to 5.40, while the sample covered in polyvinyl chloride (PVC) film increased slightly more from 5.31 to 5.51 after 7 days of storage [11].

Tan et al. [14] found that 2%, 3%, and 4% *Chrysanthemum morifolium* EO-chitosan films could keep a pH below 6.7 from the first (5.59) to the fifth (6.25) day of beef and chicken storage at 4 °C for 5 days. Meanwhile, the control sample (without wrapping) showed quality deterioration, with an increase in pH value from the first day (Day 0) to the fifth day (Day 5) of the storage period in chicken (5.86 to 6.77) and beef (5.53 to 7.06) samples, respectively. Because beef meat with a pH of more than 5.6 to 6.0 is unsafe for consumption and the color of beef meat is affected (darkening of red meat) if the pH is greater than 6.0, the control sample (without wrapping) was unfit for human consumption [70]. All the pH of the samples showed increments during storage due to protein degradation and the buildup of alkaline byproducts, which are all produced during amino acid breakdown via lipid oxidation or microbial reactions [71]. However, the slowing of pH increments when the meat product was wrapped with an EF containing APE and EOs is explained by the fact that the extracts have antibacterial activities in addition to antioxidant effects that can help to slow down the increase in pH, which is associated with an increase in microbial growth [72].

4.2. Colour

Color is a key quality parameter in food, influencing consumer preferences and choices. Food product color assessment has been employed as an alternate solution to indicating other quality characteristics, such as flavor and pigment content. It is relatively simple, quicker, and tends to be associated well with other physicochemical characteristics [73]. When the L* value is high, the pH value is low which causes the meat to appear "bright" [74]. The L* value of beef, pork loin, and chicken breast samples wrapped or not wrapped in an alginate EF containing 13% (*w*/*w*) turmeric extract was affected significantly during the 16 days of storage period at 4 °C [9]. Except for the chicken, the meat wrapped in an EF (pork and beef) has a higher L* value than the control. This effect could be attributed to the EF's oxygen barrier property, which could have slowed the transfer of oxygen and myoglobin interaction [9]. A higher L* value of meat is advantageous because it indicates brighter meat, which influences consumer acceptance and purchase decisions [9].

Table 4. Application, quality characteristics, and shelf life of various food models wrapped with different APE and EOs-incorporated EF.

Food Model	Storage Condition (Temperature and Period)	Extract/ Essential Oil	Amount (%)	Quality Improvement	References
Chicken breast, pork, and beef loin	4 °C (16 days)	Turmeric (*Curcuma longa* L.) aqueous extract	13 (*w*/*w*)	- Reduce the pH value in meat - Maintain the color of the meat - Reduce meat lipid oxidation	[9]
Lard	Room temperature (20 days)	*Sophora japonica* ethanolic extract	1, 3, 7, 9 (*w*/*w*)	- Reduce the lipid oxidation of lard	[10]
Minced beef	4 °C (7 days)	Neem (*Azadirachta indica*) aqueous extract	0, 0.1, 0.3, 0.5 (*w*/*v*)	- Reduce the pH value in meat - Maintain the redness of the meat - Reduce meat lipid oxidation	[11]
Gouda cheese	4 °C (16 days)	*Moringa oleifera* leaf ethanolic extract	0.03, 0.05, 0.07, 0.1 (*w*/*v*)	- Reduce cheese lipid oxidation - Lower the microbial count of the cheese	[12]
Chicken and beef	4 °C (5 days)	*Chrysanthemum morifolium* essential oil	0, 1, 2, 3, 4, 5, 6 (*v*/*v*)	- Reduce the pH value in meat - Lower the microbial count of the meat	[14]

A lower a* values indicate a decrease of the redness in meat, which is caused by the myoglobin oxidation to metmyoglobin [75]. When EFs containing APE was applied to the meat during storage, the meat was able to retain its redness (a* value). During the 7 days storage period in 4 °C, the gelatin EF with 0.3% neem extract wrapped minced beef had a higher value in a* than the sample covered in PVC film [11]. The antioxidant properties of AP in the film provide an explanation for this. The application of the APE-incorporated EF on meat products could maintain the redness. As a result, the desirable color of the meat product was preserved during refrigeration.

4.3. Lipid Oxidation

The acid value of oil indicates its free fatty acid content. During oil storage, the oxidation reaction raises the acid value, while the reduction reaction lowers the acid value [10]. Meat lipid oxidation is frequently evaluated using the thiobarbituric acid reactive substances (TBARS) value by assessing auto-oxidation (second stage) products such as malondialdehyde (MDA) [76]. It is recommended that the perceivable level of TBARS in food as an inappropriate odor be around 1–2 mg MDA eq/kg [77]. The TBARS analysis revealed that pork, chicken, and beef wrapped in an alginate EF containing 13% (*w*/*w*) turmeric extract (0.30 ± 0.01, 0.37 ± 0.01 and 0.28 ± 0.01 mg MDA·kg^{-1} meat, stored for 12 days) had lower TBARS values than those not wrapped (0.30 ± 0.01, 0.33 ± 0.04 and 0.31 ± 0.01 mg·MDA·kg^{-1} meat, stored for 8 days) [9]. Similarly, the acid values of lard when being exposed to air as well as wrapped in polyethylene cling film were higher (0.3478 and 0.3084 mmol/kg) than the acid values of lard wrapped in AsKG film with SJe (0.2439 mg/g) [10]. When wrapped in EF and stored at room temperature for 20 days, it was discovered that EFs made by combining AsKG and SJe could slow down the lipid oxidation of lard [10].

For the 7 days of storage, the minced beef wrapped in the gelatin EF with 0.3% neem extract (2.51 mg·MDA·kg^{-1}sample) had a lower TBARS value than the PVC film (4.06 mg MDA·kg^{-1} sample) [11]. Similarly, Gouda cheese wrapped in a pufferfish skin gelatin (PFSG) film containing 1% *Moringa oleifera* Lam. leaf extract showed the lowest

increase in TBARS value in comparison to the control (without wrapping) [12]. According to Lee et al. [78], the storage duration significantly influenced the lipid oxidation in meat, but there is an inhibitory effect on the oxidation in food products with EF, the antioxidant properties of APE, and its ability to block oxygen, particularly due to its high polyphenol content [79]. It has also been reported that APE have antioxidant properties due to the active compounds such as phenolics and flavonoids [80].

4.4. Microbiological Analysis

To investigate the antibacterial activity of EF containing extracts with antibacterial compounds, storage applications on various food products should be carried out in order to evaluate the efficiency of these EFs in preserving food quality and shelf life. Previous research has looked into the microbial analysis of applying an EF incorporated with various APE and EOs on food products. Past microbiological studies have mostly focused on refrigerated meat products such as pork and beef at 4 °C [9,11,14]. It was discovered that during the five-day storage test, 4% *Chrysanthemum morifolium* EO in chitosan film was most effective in regulating *Staphylococcus aureus* bacteria growth in food (chicken and beef) in comparison to the control groups, 2% and 3% EO. The Food Safety Authority of Ireland mentioned that the threshold value of *Staphylococcus aureus* is 105 log CFU/mL because when toxins are produced at that level, they are not safe for consumption. The total plate count of *Staphylococcus aureus* in meat such as beef and chicken from the first day (Day 1) to the fifth day (Day 5) of storage was 3.6 to 4.7 log CFU/mL with 4% *Chrysanthemum morifolium* EO in the film, which is safe for consumption [14].

Besides meat products, PFSG film containing 1% *Moringa oleifera* Lam. leaf extract was used to package Gouda cheese [12]. The microbial count (*Listeria monocytogenes*) in the cheese after packing with PFSG film with 1% *Moringa oleifera* Lam. leaf extract decreased by 1.21 log CFU/g after the 16 days storage period in comparison to the control sample (without wrapping). Furthermore, there was a 0.62 log CFU/g reduction when compared to the sample wrapped in PFSG film without *Moringa oleifera* Lam. leaf extract. APE and EOs can be used as a natural preservative to limit the food-borne pathogens growth in food. Furthermore, these findings suggest that as an active packaging material, the APE and EOs-containing EF can keep the food quality during storage.

5. Future Prospects

Nanoemulsions are colloidal dispersions that are isotropic and kinetically stable when a surfactant stabilizes and disperses two incompatible liquids [81]. EOs are well-protected against deterioration or evaporation by microcapsules; they have no effect on antimicrobial activity in general. Nanometric delivery systems, on the other hand, may lead to an increase of passive cellular absorption mechanisms due to their subcellular size, limiting mass transfer resistances and also improving the antimicrobial activity. Due to the improved physical stability and antimicrobial activity of the nanoemulsion, there is growing interest in using it as a delivery system. In addition, there is a rising trend of using nanoemulsified EOs as an encapsulation method in EFs. The EO nanoemulsion has a denser morphology (E-SEM), higher barrier properties, and better mechanical properties, which are advantageous to producing EF [82]. Furthermore, it has been reported that the antibacterial activity of EO nanoemulsion is superior to that of EOs in bulk [83]. According to recent research, in comparison to standard emulsions, EO nanoemulsions have greater physical and antibacterial properties [84]. According to findings, the nanoparticle of nanoemulsion increases the surface area per unit mass of lipophilic molecules, enhancing their physicochemical characteristics, consistency, and bioactivities [85]. Future EF research could focus on nanoemulsifying APE and incorporating it into EFs to improve the physicochemical, mechanical, antioxidant, and antibacterial properties of the EF.

Previous literature has reported numerous studies on the production of various EFs using the casting method [5–7,9–12,14,15,22,24–26]. When the EF is formed using the casting method, it usually adopts the shape of the drying vessel instead of the food product

shape it is intended to wrap around. Therefore, the application of EFs to food can be expanded with the aid of 3D printing, in which it combines computer systems, precision drive, numerically controlled, and material science technology. Further, the manufacturing process of 3D printing is able to produce EF with the proper consistency in terms of size, shape, and thickness [86]. Corn starch-gelatin EFs with hawthorn berry extract and 4% (*w*/*v*) glycerol produced using 3D printing showed an improvement in characteristics in terms of mechanical and antimicrobial properties [87]. However, to come up with an innovative idea and a feasible solution for the production of EFs incorporated with various APE and EOs in packaged foods, more research on 3D printed EF is needed.

The release kinetic of substances encapsulated in biomaterials is an important parameter that must be controlled in industrial applications because it indicates the time required to deliver the bioactive substance across the film [88]. Although there are many reported studies on the incorporation of extracts and EOs extracted from APE into EF, information on the release kinetics of these active compounds from EF remains unknown. Research is necessary to elucidate the release kinetics of these APE or EOs-incorporated EF to provide a better understanding of the kinetics as well as the antibacterial and antioxidant properties of EFs as active compound carriers in food preservation. Shen et al. [89] investigated the release characteristics of clove EO from a pullulan-gelatin-based EF. Clove EO was found to be releasing more frequently during the incubation period. The rate at which clove EO in the film sample was released increased along with the temperature. The manner in which clove EO was observed to transfer from the film matrix to the release medium provides an explanation to this observation.

Extensive research could be conducted to create a statistical model that can be employed to demonstrate the release profile of various bioactive compounds from the EF into the food matrix [90]. It is critical to make sure the concentration of these compounds is retained in packed food using EF in order to maintain the food quality and shelf life. Following that, many bioactive components derived from PE or Eos can be added to the matrix to improve the film properties. The conditions or formulations should be optimized so that the resulting films have good physicochemical, mechanical, barrier, and optical properties. Additives (lipids, other hydrocolloids, or reinforcement agents) may be used to address these problems and develop more consistent materials with enhanced properties. Extensive research on other approaches to improving different biopolymer EFs with the incorporation of functional compounds should be conducted to determine the most appropriate EF bases for these PE and EOs to exhibit their maximum functional properties. The release kinetics of grapefruit EO from plum seed protein isolate conjugates prepared with gum acacia (PSPI-GA) emulsion-based films were evaluated in Li et al. [90]. The rate of EO release from PSPI-GA films was exponential as is usually the case, with the n-value of the Peppas model being less than 0.5, implying that the release mechanism combines partial diffusion through an enlarged matrix with water-filled pores [91].

With the extensive research already conducted on EF and its incorporation with EOs, EFs have yet to cover the commercialized scale [92]. It is necessary to develop continuous film-making with shorter production times and higher production rates to scale up the manufacturing of EF [93]. Moraes et al. [94] formed a continuous film using the tape casting method, a casting method variant. A different method of producing larger scale EFs using the continuous casting method should be investigated. The method should be compromised to ensure that there is no loss of volatile antimicrobial compounds during processing, and the opportunity to increase the commercialization scale should be granted. Furthermore, the effects of different drying conditions (method and parameter) on the bioactive compounds, release characteristics, and intermolecular interaction of EFs containing varying concentrations of APE or EOs should be thoroughly investigated to design a controlled release system for chitosan films in food packaging applications.

6. Conclusions

Active compounds found in AP, their extracts, and EOs have formed an innovative and exciting field in all sciences, particularly in EF-making research. Their contributions as active compounds to producing EF have already led to the development of a new food packaging industry. This paper discussed the various types of APE and EOs used in the production of active EFs, the different properties (physicochemical, mechanical, antioxidant, and antibacterial properties) as well as conceivable uses for which the preservation of various kinds of perishable foods could be put to use with these APE and EOs-containing EFs. The incorporation of APE and EOs in EFs improved the properties of EF in terms of physicochemical and mechanical properties (thickness, moisture content, water vapor permeability, TS, and EAB). It also contributes to the antioxidant and antibacterial activity of the EF. Due to its higher phenolic content, antioxidant, and antibacterial activity, EF can lengthen the period of food storage by lowering the pH and lipid oxidation while also preserving the attribute of the food product (color and appearance). However, the antibacterial activity of these EFs is called into question. This may have an impact on their marketability as food packaging. More research can be conducted to improve the overall properties of EF, such as the nanoemulsification of extracts for improved antibacterial activity and active compound release during storage. Extensive research is required to address these limitations in order to successfully market EF in the food packaging and storage industry. However, the most recent forecast for the use of APE and EOs in EF as a genuine sustainable substitute to conventional packaging materials (plastic formulations) in active food packaging reflects their high likelihood of market introduction in the coming years.

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