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Review Article

Physical, thermal, mechanical, antimicrobial and physicochemical properties of starch based film containing aloe vera: a review

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ABSTRACT

Growing consumer awareness of the importance of environmentally friendly products has resulted in the development of a number of substitutes for synthetic polymers. The starch-based film is one of the best alternatives; it is a cost-effective material that has been investigated as an excellent raw material for the production of a biodegradable film. Additionally, the development of starch-based films for use as antimicrobial packaging or coating is one of the most promising active packaging systems. Recently, interest in using aloe vera as an organic antimicrobial agent derived from plants has risen significantly. Due to its film-forming properties, antimicrobial properties, and biochemical properties, aloe vera gel has been identified as one of the best biodegradable films. *Aloe vera* rind also contributes to the film's exceptional properties. This review article summarises and discusses the film formation and properties of aloe vera-based starch-based films, including their physical, thermal, mechanical, antimicrobial, and physiochemical properties.

1. Introduction

Preventing microbial and chemical food deterioration is a constant focus of research in the fields of food engineering and science. Microbial food spoilage occurs primarily on the food's surface [1]. According to the literature, edible films and coatings are particularly advantageous for microbial contamination control on the ground because they can act as additive carriers and release active compounds onto food surfaces, where they can be used to inhibit microbial growth [2].

Farmers typically used a variety of preservation techniques to keep their plantation free of bacterial disease, fungal attack,

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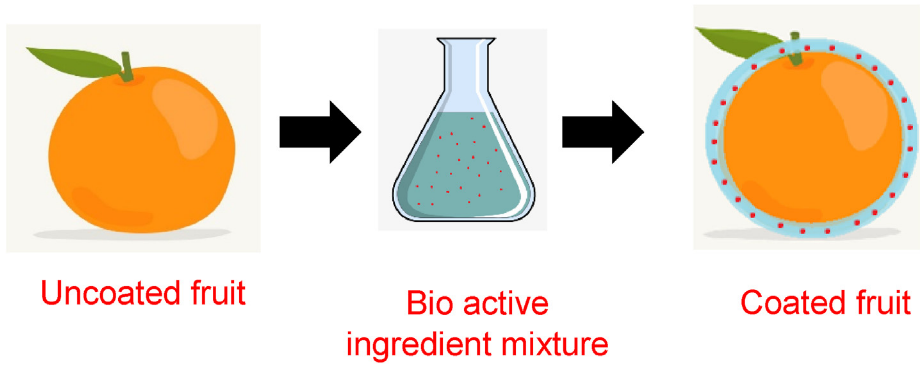

Fig. 1 – Schematic representation of active and barrier function of edible films/coating.

and pests. One of the popular post-harvest treatments in plantation is waxing. In waving treatment, certain chemicals must be added to wax in order to prevent bacteria and mould from breeding [3]. Morpholine and its derivatives (MAID) such as 4-(4- aminophenyl) Morpholine, 4-(2-aminophenyl) Morpholine, and Benzophenone-N-ethyl Morpholine ethers are among the chemicals used. Morpholine was added to the EPA's (Environmental Protection Agencies, United States of America) master list for the Toxic Substances Control Act in 1996 (61 Fed. Reg. 65936, 13 December 1996) and EPA-registered pesticides in 1997 (EPA inert ingredients list 03) and is classified as a volatile organic compound (VOC) [3]. Due to a chemical compound's water solubility, significant amounts are released into the atmosphere via industrial effluents, where it undergoes chemical or microbiological nitrosation, resulting in the formation of the N-nitrosomorpholine (NMOR) and transforming it into a carcinogenic compound. Thus, when the wax-coated fruit is consumed directly, it has the potential to cause cancer in consumers [3].

Synthetic fungicide treatments are also prohibited due to their potential toxicological effects on consumers [4]. Synthetic fungicides including benomyl, carbendazim, prochloraz, fludioxonil, and bromuconazole 6 have been the backbone of postharvest disease control [5]. However, because of their carcinogenicity, teratogenicity, high and acute residual toxicity, protracted degradation period, environmental contamination, and negative impacts on human health, these fungicides have been prohibited [6]. Antimicrobial chemicals such as silver, copper, zinc oxide, and zinc rod are used in food packaging applications to create an antimicrobial film, but these chemicals have some drawbacks, including toxicological effects on human health and environmental concerns. Many researchers are concerned about the materials and chemicals used to coat fruits due to increase awareness of the harmful effect of those chemicals and materials. As a result, alternative treatments are critical to replace some of the hazardous chemicals in treatments, particularly in edible films, by incorporating environmentally friendly antimicrobial agents.

Edible films may also be used as edible packaging. Direct application of antibacterial substrates to food via dipping, dusting, or spraying has limited benefits because the active ingredients are neutralised on contact or rapidly diffuse into the product from the surface [2]. Thus, the use of edible films containing antimicrobial agents has a number of advantages over directly applying antibacterial agents to the food surface, as edible films can be designed to retard antimicrobial diffusion from the food surface [2]. In comparison to conventional packaging, edible packaging is regarded as a sustainable and biodegradable alternative in the active food packaging field, as it optimises food quality. The advantages of edible packaging include its ability to preserve food quality, extend shelf life, reduce waste, and contribute to packaging materials' economic efficiency [7].

The development and application of edible films is one of the most exciting areas of food science technology due to their versatility, ability to be made from a variety of materials, and as carriers of various active ingredients such as antioxidants and antimicrobial agents [8]. Edible films and coatings are thin layers of edible materials that can act as a barrier to moisture, gases, and solute movement in food. Due of their superior features including as biocompatibility, edibility, and a wide range of applications, they are excellent alternatives for traditional wrapping materials [9]. The primary distinction between coatings and films is that coatings are applied to foods in liquid form, whereas films are moulded into sheets and then utilised as wrapping materials. Edible films or coatings make it easier to transport, store, and display fresh and processed foods [10]. To formulate edible films or coatings with functional properties, both the film-forming base materials and the bioactive ingredients must be carefully selected. Proteins, polysaccharides, and lipids are the primary base materials used in the manufacture of edible films and coatings, and the choice of a specific material or a combination of different materials is determined by decades of research [11]. One of the bio active component that has potential in producing edible films and coating is aloe vera (AV). Maan et al. [12] stated that AV gel is used in the food industries to produce functional foods, as a natural preservative and as antimicrobial agent material added in edible films and coatings. Fig. 1 depicts a schematic illustration of the application in films or coatings.

Moreover, there are two traditional approaches to developing an effective coating and film formulation: (i) the material science approach and (ii) the application of coating material to the fruit surface [13]. Two additional events are included in the material science approach: (i) biopolymer to gel conversion and (ii) gel to thin film formation [13]. These events are interconnected, which emphasises the importance

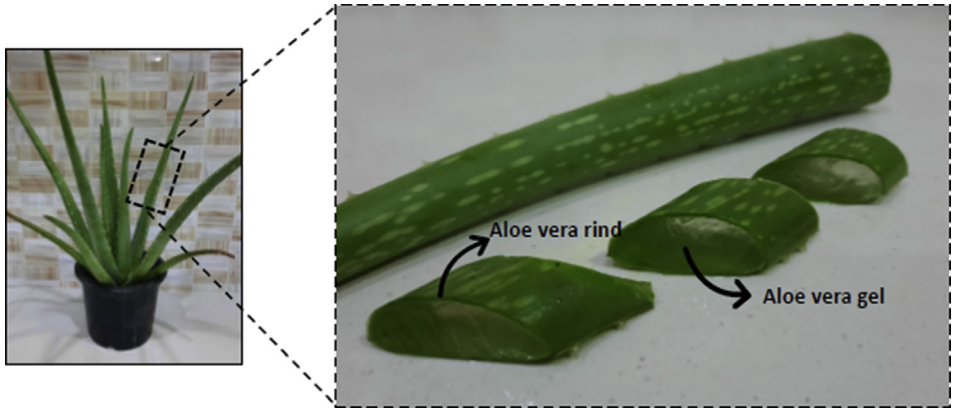

Fig. 2 – Cross-section of Aloe vera leaves.

of considering the application of coating material prior to applying it to the fruit surface. The formulations must be evaluated independently for their film thickness, solubility, moisture content, water vapour (WVP) permeability, oxygen barrier properties, transparency, colour, tensile strength, elongation at break, elastic modulus, and antimicrobial properties. It is also critical to determine the extent to which secondary components such as plasticizers affect thermal (gelatinization) and post–thermal (retro-gradation) events in starch-based edible film formulations. These occurrences are necessary for the formation of a film or coating because they take advantage of the starch unit is intermolecular associations-dissociations [13]. Plasticizers, water and co-biopolymers all have a significant effect on the thermal actions (granule swelling, amylose or amylopectin chain disintegration, and glass transition) of the film, demonstrating their influence on the overall film properties [13].

Renewable resources such as starch are inexpensive, widely available and can be used to make edible films for food applications due to their low oxygen permeability [3]. For example, due to its low cost and abundant supply, corn starch (CS) has garnered exclusive attention for the production of biodegradable films [14]. Additionally, corn starch has excellent film-forming properties as a result of its high amylose content and can thus be used in the development of films [15]. According to recent research, adding plasticizing agents and other active ingredients to starch polymers could further enhance their properties in water barriers. Plasticizers are critical ingredients in the production of edible films and coatings because they increase the versatility and toughness of polymers [13]. Polyols (for example, glycerol and mannitol) were previously described as the most starch-compatible plasticizers [13]. Due to its low cost and widespread availability, the starch-based film has the potential to be used as a food coating or packaging material due to its low oxygen permeability. However, the addition of the antimicrobial agent is necessary to enhance the starch film's antimicrobial ability and to protect the food [16]. Synthetic antimicrobial chemicals are currently being used, but their use is restricted due to the potential for toxicological effects on consumers. As a result, using aloe vera as a natural antimicrobial and antifungal agent is one way to avoid harmful antimicrobial agents and chemicals. Additionally, aloe vera rind may be used as reinforcement in starch-based films.

As a result, this review article discusses the application of starch-based films infused with AV. The use of AV gel as an antimicrobial agent and AV rind as a reinforcement in starch-based films will be highlighted. This article discusses several critical properties of starch-based films in order to investigate the potential of starch-based films infused with aloe vera for applications such as packaging. This article discusses the physical, mechanical, thermal, physicochemical, and antimicrobial properties of starch-based films infused with AV.

2. Aloe vera

Aloe vera (AV) is a tropical and subtropical plant or herb that has been cultivated for centuries for its medicinal and therapeutic properties [17]. Yellow latex and clear gel (mucilage) produced by large parenchymatic cells in the leaf are the two major sources of liquid in AV [17]. It belongs to the *Aloaceae* family and is the most well-known of the *Aloe* genera, which has over 500 species and is native to Northern Africa [18]. Fig. 2 illustrates the cross-section of AV leaves. Numerous researchers have discovered that AV possesses a variety of biological activities, including anti-inflammatory, antioxidant, immune modulatory, and cell growth stimulating properties, as well as antibacterial, antiviral, and antifungal properties [19–21].

The majority of AV gel is composed of water and the list of composition of aloe vera is summarized in Table 1. Beside of huge amount of water content, there is approximately 1% contains bioactive compounds such as aloin, emodin (anthraquinones), flavonoids, saponin, and aloe-mannan, in addition to a variety of amino acids and vitamins [23]. These bioactive compounds contribute significantly to aloe gel's antibacterial activity. As a result of the presence of these bioactive compounds, AV is a natural organic antibacterial agent. Additionally, the AV's outer green rind is beneficial for a

Table 1 – Composition of *Aloe vera* by w/w% [22].

Composition of *Aloe vera*	Weight by weight (w/w%)
Water	96
Dry matter	4
Organic acid	22.8
Dietary fiber	18.8
Polysaccharide	8.8
Protein	4.7
Lipid	2.7
Ashes	16.0

variety of applications. One of the applications of AV rinds is as a source of cellulose nanofibers for the formation of AV nanofibers films on plants [24]. AV rind has the potential to serve as reinforcement for composites, enhancing certain properties of the composites. For example, the addition of AV nanofiber improved the composite's mechanical properties by increasing the level of adhesion of the materials in the composites [25].

3. Biopolymer of starch

3.1. *Structure and properties of starch*

The photosynthesis process initiates the formation of starch in the plant [26]. Glucose is the most abundant monosaccharide and the fundamental unit of plant metabolism. Glucose is required for photosynthesis to occur. To begin, the plant utilises carbon dioxide from the atmosphere and converts it to glucose [26]. The basic glucose molecule is used to synthesise the starch polymers. Amylose and amylopectin are two types of polymers found in starch [26]. Amylose is a linear macromolecule composed of alpha-D-glucopyranose residues connected by α-1,4-glycosidic bonds and containing between 350 and 1000 glucose units [27].

There will be linear addition of glucose units with an α-1,4-glycosidic bond in the highly branched polymer amylopectin (70% of the structure) [26]. The branching at α −1,6-glycosidic bonds for every 24–30 glucose repeating units results in a soluble molecule that is easily degraded due to the presence of numerous endpoints for enzymes to attack [26]. There are numerous hydroxyl groups in the starch chain, including two secondary hydroxyl groups at the C-2 and C-3 positions of each glucose residue, as well as one primary hydroxyl group at C-6 when it is not linked, which makes starch a hydrophilic material [28]. Hydrogen bonds are formed when hydroxyl groups are present in starch chains [28]. Fig. 3 illustrates the structure of amylose and amylopectin [26].

When starch is heated to a certain temperature, it becomes soluble in water, causing the grains to swell and burst [29]. The semi-crystalline structure is also lost during this process, and the minor amylose particle begins percolating out of the granule and forming a network. As water is compressed, this network increases the viscosity of the mixture. This is referred to as starch gelatinization [29]. When starch is processed, its amylose content provides strength to the film [26]. Tharanathan [30], discovered that when amylopectin is the predominant component of starch, the mechanical strength of films, such as tensile stress, decreases. Due to the fact that starch is non-toxic, biodegradable, and strong, it was used as a biodegradable and edible film and can be used in place of plastic polymers that can have a negative impact on the environment and consumers. Table 2 shows the percentages of amylose and amylopectin in various starches [29].

4. Plasticizer

4.1. *Properties of plasticizer*

The IUPAC (International Union of Pure and Applied Chemistry) Council defined a plasticizer as a polymer material that is combined with another material, such as plastic or elastomer, to increase the material's flexibility and workability [31]. When a plasticizer is used in a film or other application, it reduces the deformation tension, the density, the hardness, the viscosity, and the electrostatic charge of the polymer [31]. Additionally, a plasticizer is added to the film to increase its flexibility and decrease the second-order transition temperature, or glass transition temperature (T_g), in polymers [31]. Nowadays, plasticizers are widely used as additives in the polymer industry and constitute a significant class of non-volatile low molecular weight compounds [31]. Several research using thermoplastic corn starch to develop biopolymer films with various plasticizing agents have been conducted [32,33]. Sun et al. [34] used corn starch and urea plasticizer to create chitosan/zein film. The results reveal that as the amount of urea plasticizer is increased, the mechanical characteristics of starch biopolymers improve.

Plasticizers' ultimate purpose in the production of starch-based films is to increase starch's flexibility by reducing the strong intermolecular interactions between starch molecules [35]. If starch is used exclusively to produce the starch-based film, the film will exhibit a brittle effect with numerous surface cracks, reducing the film's mechanical strength. This issue, however, can be resolved by adding a plasticizer to the starch in the film formulation [36]. As a result, it increases the film's brittleness and minimises the occurrence of surface cracks [35]. As a result, the polymeric chain's mobility increases, resulting in increased film flexibility, extensibility, and ductility [37]. Additionally, the amount and type of plasticizer have a significant impact on the physical, thermal, mechanical, and barrier properties of films [35].

4.2. *Types of plasticizers*

Different types of plasticizers have varying effects on the film properties. While preparing starch-based films, various plasticizers such as glycerol, sorbitol, ascorbic acid, and citric acid are added [36]. Glycerol is a natural plasticizer that is frequently used in the production of starch-based films with the primary goal of reducing the film's brittleness by reducing intramolecular and intermolecular hydrogen bonds [38]. Additionally, because glycerol is a significant byproduct of biodiesel production, it is used as a plasticizer in starch-based

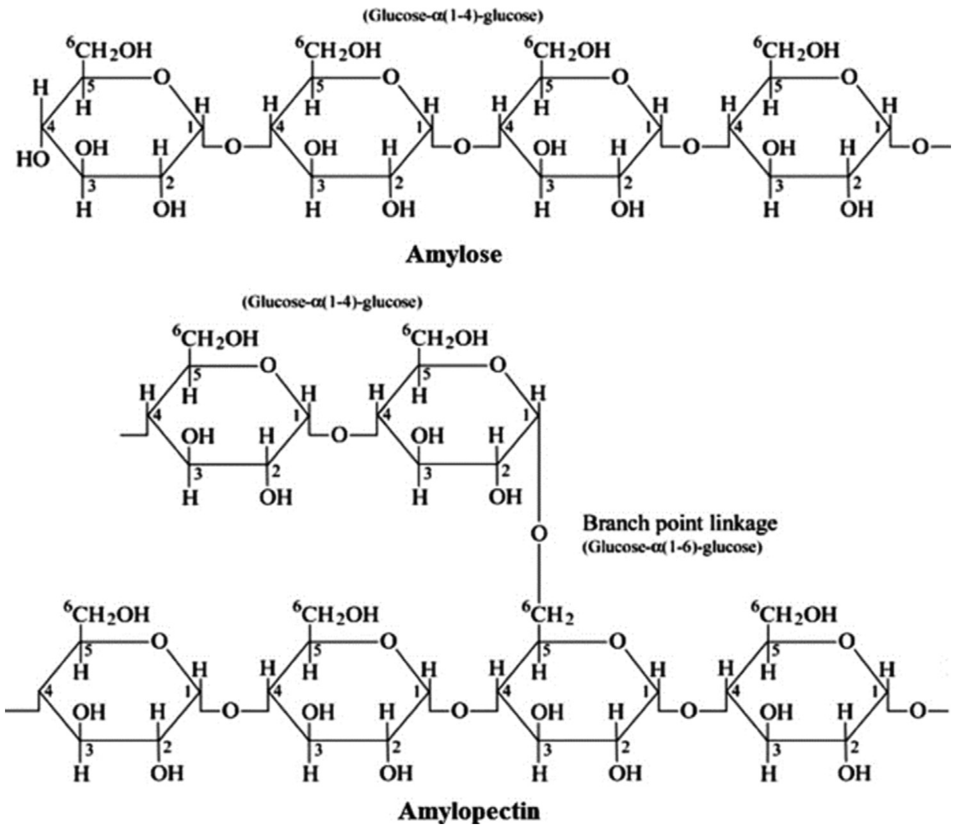

Fig. 3 – Chemical structure of amylose and pectin [26].

films [39]. According to Ojogbo et al. [36], glycerol is the most effective plasticizer for improving the mechanical properties of starch-based films.

Sorbitol is another type of plasticizer that can reduce intramolecular hydrogen bonding, resulting in increased mechanical strength [40]. Joseph Boussingault, a French scientist, discovered sorbitol in the berries of mountain ash in 1872. Sorbitol is found in a variety of plants, including apples, pears, peaches, prunes, and berries. Chemical sweeteners may also be created for use in sweets, cookies, pudding, and oatmeal, among other foods and beverages [41]. According to Rahmawati et al. [40]; as the concentration of sorbitol increased, the thickness of edible film increased as well. This is because the total solid content of the edible film solution increased, causing the film to become thicker. The film thickness is critical for packaging applications. Numerous studies have also documented the plasticizing effect of combining various types of plasticizers.

According to Adhikari et al. [42], when multiple plasticizers are combined with glycerol and xylitol in a film matrix, a strong interaction between the plasticizers occurs, enhancing certain properties of the starch-based film. According to Krogars et al. [43]; a 1:1 mixture of glycerol and sorbitol was found to be more stable than using glycerol and sorbitol separately as a plasticizer for producing maize starch-based films. In fabrication of aloe vera film, plasticizer is important to enhance the mechanical properties and to avoid formation of crack of film. Many researchers discovered the usage of plasticizer in producing films to maintain the mechanical properties. Table 3 summarized paper published of aloe vera film with various plasticizer.

Table 2 – The concentration amylose and amylopectin in various starch [29].

Sources	Amylose (%)	Amylopectin (%)
Arrowroot	20.5	79.5
Banana	17	83
Cassava	18.6	81.4
Corn	28	72
Potato	17.8	82.2
Rice	35	65
Tapioca	16.7	83.3
Wheat	20	80

Table 3 – Paper published in *Aloe vera* film with various plasticizer.

Type of plasticizer	Plant parts used	References
Citric acid, glycerol	Commercial aloe vera powder	[44]
Glycerol	*Aloe vera* gel	[45]
Glycerol	*Aloe vera* gel	[46]
Citric acid	*Aloe vera* gel	[47]
Glycerol	*Aloe vera* gel	[48]

5. *Aloe vera* rind as reinforcement in films

The AV rind is the tougher outer layer of AV leaves that contains cell wall components. AV rind is typically used as a fertiliser for plants or as a waste product. Because the AV rind has the potential to act as a reinforcement agent, extensive research has been conducted on the AV rind's properties as a reinforcement agent in films. The AV rind is composed of 15 cell layers and functions as a protective agent for the AV gel as well as a source of carbohydrates, fat, and protein [24]. Cheng et al. [24] demonstrated excellent properties in their study using cellulose nanofibers with a diameter less than 20 nm extracted from AV rind due to the high -cellulose content of approximately (57.72% ± 2.18%).

Additionally, Kakrodi et al. [25] investigated the mechanical, thermal, and morphological properties of nanocomposites composed of polyvinyl alcohol (PVA) and cellulose nanofiber from AV rind. They investigate the use of AV rind as a novel reinforcement for PVA by employing the solvent casting method and varying the composition of the AV rind. They observed that when a small amount of AV rind is added, the nanocomposite's tensile modulus increases. This can be explained by the presence of a strong hydrogen bond between cellulose nanofibers and PVA, which results in good nanofiber dispersion in the matrix. This aids in the transfer of greater loads from the matrix to the reinforcement. They discovered that adding AV rind fibre increases the thermal stability of the nanocomposite, which can result in a higher degradation temperature.

6. Antimicrobial agent in general

Numerous microbes cause problems and serious problems in the environment, the food and packaging industries, the health care industry, synthetic textiles, and the manufacturing of biomedical devices [49]. The most concern issues all around the wold is on food safety. During food safety procedures, packaged food materials are given special attention during preparation so that no harm is made to a consumer when eating the packaged food. This is still the main source of worry in worldwide food safety practises [50]. Food must be protected from physical, chemical, and biological contamination throughout the production, handling, marketing, and distribution processes [51]. Microorganisms come in a variety of forms, including bacteria, viruses, fungi, and parasites [52]. These microbes are capable of attacking and growing on both living and non-living organisms. These factors contribute to the spread of various infectious diseases, which claim thousands of lives each year. Thus, employing an antimicrobial agent is critical for resolving this issue [49].

Antimicrobial agents can be used to control both the general microflora and microbes associated with a product, resulting in a product of higher quality and safety [53]. At the turn of the twenty-first century, the evolution of antimicrobial agents significantly decreased the morbidity and mortality associated with these microorganisms [52]. As a result, the growth of microorganisms is inhibited. Thus, incorporating antimicrobial agents into film or packaging materials enhances their protective properties against food-borne microorganisms. Antimicrobial agents can be classified as organic (e.g., essential oil) and inorganic (e.g., ZnO, TiO_2, and Ag) based on their chemical composition [54]. The antimicrobial activities are contributed by damage to cell membrane integrity [55] impairment of biomolecules (e.g., DNA and protein) inside cells [56], regulation of metabolic processes [57] and oxidative stress [51].

6.1. Inorganic antimicrobial agents

Metal oxides play an important role as an inorganic antimicrobial agent that widely used in packaging materials [49]. This is because antimicrobial agents have a broad spectrum against several pathogenic microorganisms [53]. More research has been done using inorganic nanoparticle include zinc oxide (ZnO), titanium dioxide (TiO_2), calcium oxide (CaO) [58], copper oxide (CuO) [59,60], iron (iii) oxide (Fe_2O_3) [60], magnesium oxide (MgO) and silver zeolite [53]. Among the many reported semiconductor nanomaterials, ZnO, an n-type semiconductor material, has been widely researched as an antimicro-bial agent when compared to other materials [61]. It is biocompatible, non-toxic, and photochemically stable among other qualities. Furthermore, the US Food and Drug Administration has classified it as a generally recognised as safe (GRAS) compound (21CFR182.8991) [62]. It has bactericidal properties against a wide range of Gram-positive and Gram-negative bacteria, including *Escherichia coli*, *S. enteritidis*, *Streptococcus pyogenes*, *Aeromonas hydrophila*, *Bacillus subtilis*, *Staphylococcus aureus*, *L. monocytogenes*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, *Salmonella typhimurium*, and *Escherichia faecalis* [63].

As studied by Park et al. [64]; silver zeolite and silver-silicon oxide ($AgSiO_2$) are capable to inhibit bacterial growth such as *P. aeruginosa, Shewanella gaetbuli, Clostridium, Listeria monocytogens* except for *Clostridium perfringem*. Next, ZnAg is capable in inhibiting all spotted microorganism except *L. monocytogens*. This research has also shown that zinc-silver (ZnAg) can decrease the growth rate of *C. perfringem* compared to silver zeolite and $AgSiO_2$. All these bacteria are active for fish deterioration while in transporting freshly harvested fish for selling purpose [64].

The TiO_2 is one of the non-toxic inorganic antimicrobial agents that is suggested by the Food and Drug Administration (FDA) used in drugs, food processing and food contacts materials. Bodaghi et al. [65] in their study revealed that several *Pseudomonas* spp. declined significantly after 3 h by 4 and 1.35 log CFU/mL of ultraviolet after added into TiO_2 LDPE film using a blown film extruder. MgO is one of the efficient inorganic antimicrobial agents, very stable and biocompatible. The properties from MgO such as high concentration alkaline and existence of oxygen division on it, also give antibacterial properties on it. When added with other antimicrobial agents, they can give full destruction of pathogenic microbes [66]. From published reports, MgO can cause the cell membrane to damage and peroxidation of lipid occurs. Hence, promoting the crack of intracellular component, that resulting in cell cancer death [66].

6.2. *Organic antimicrobial agents*

By the action of one or more reactive sites contained in the organic antimicrobial agent, natural antimicrobial agents and essential oils contribute significantly to the development of permeabilized and destabilised bacterial cell membranes [67]. Natural antimicrobial and essential oils from seafood have been discovered to have the potential to fight microorganisms and protect the quality of seafood [53]. Antimicrobial properties are conferred by the presence of hydrophilic functional groups and or lipophilicity in essential oil compounds, which are more prevalent against Gram-positive bacteria than Gram-negative bacteria [68]. Besides, organic antimicrobial agents are marketed as having fewer safety concerns and are perceived as being safer [69]. Nowadays, consumers seek fresh seafood that has not been tainted with synthetic additives to maintain the seafood's quality. As a result, the use of organic antimicrobial agents is a viable option, and extensive research is being conducted on these agents and specific spoilage microorganisms. Natural compounds used as organic antimicrobial agents include bacteria, enzymes, and plant extracts. Numerous researchers have investigated the use of plant extracts as organic antimicrobial agents due to the presence of highly reactive sites such as phenolic compounds that help plants resist microbial attack [69].

On the recent study by Thielmann et al. [70]; they found that the potential of *Litsea cubeba* fruit essential oil in antimicrobial packaging material. From their finding, citral coatings had bactericidal effects against *E. coli* and *S. aureus*. They explained L. *cubeba* essential oil has a distinct sensory profile that makes it suitable for preserving a wide range of fruits and vegetables. Furthermore, citral is a traceable molecule that can be used in antibacterial and analytical chemistry studies. The advantages of plants part such as leaves, flowers, seeds, and roots benefits towards anti-allergic, antioxidant, anticarcinogenic, antibiotic and antibacterial properties. According to the research, approximately 80% of people around the world rely on herbal medicine for health treatment due to its efficacy [12].

6.2.1. *Antimicrobial activity of aloe vera gel*

AV, commonly referred to as the cactus-like plant, is a perennial succulent belonging to the Liliaceae family that thrives in dry and hot climates. The plant has fleshy serrated leaves, yellow tubular flowers, and seeds-filled fruits. Each of AV's leaves is composed of three layers: (1) contains an inner clear gel, dubbed AV gel, that is 99 percent water and the remainder is amino acids, glucomannans, lipids, sterols, and vitamin; (2) the latex layer in the middle, which contains glycosides and anthraquinones; (3) the thick outer layer of 15–20 cells called the rind, which serves as a protective layer against AV and is responsible for protein and carbohydrate synthesis [71]. *Aloe vera* gel has been used in a variety of nanomaterials in the past, including antibacterial nonwoven fabric [72], wound healing process [73], and antibacterial and antioxidant edible films [74].

AV gel has been studied as a potential component of edible films and coatings that extend the shelf life of various fruits and vegetables in recent years. Habeeb et al. [75] discovered that AV gel inhibited the growth of gram-positive and gram-negative bacteria by using an AV gel inhibition zone. Numerous constituents of AV gel contribute to its antimicrobial properties against a variety of microorganisms. The constituents of AV are classified as follows in Table 4 [20]. Lone et al. [76] demonstrated that the presence of anthraquinones in AV acts as an antimicrobial agent against *S. aureus* and *E. coli* strains by inhibiting solute transport across membranes. Additionally, another component, emodin, has been shown to be effective against a variety of Gram-positive and Gram-negative bacteria. Pure aloe-emodin exhibited similar antimicrobial activity to the juice, inhibiting the growth of Gram-negative bacteria *A. hydrophila* and *E. coli*. Pure aloe-emodin, on the other hand, demonstrated antibacterial activity against Gram-positive bacteria such as *B. subtilis* [77].

Apart from its antibacterial properties, AV is also used as an antifungal against a variety of fungi. According to Nidiry et al. [78], methanol extracts of AV have the strongest antifungal activity against *Colletotrichum* species mycelial growth. The concentration of AV gel required to inhibit the growth of mycelium *Penicillium digitatum* and *Aspergillus niger* has also been studied [79]. They hypothesised that increasing the gel concentration would inhibit mycelium growth. They discovered that using 500 mL/L doses of AV gel inhibited *P. digitatum* 100% and *A. niger* 64%.

Table 4 – The component aloe vera represent in following class [20].

Class	Compounds
Anthraquinones	Aloin/Barb-aloin, Aloe-emodin, Emodin, Aloetic acid, Ester of cinnamic acid, Anthranol, Chrysophanic acid
Vitamins	B1, B2, B6, A-Tocopherol, β–Carotene, Choline, Folic acid, Ascorbic acid
Enzymes	Cyclo-oxygenase, Oxidase, Amylase, Catalase, Lipase
Miscellaneous	Cholesterol, Steroids, Tricylglycerides, β – Sitosterol, Lignins, Uric Acid, Gibberellin, Lectin like substances, Salicylic Acid, Arachidonic Acid
Saccharides	Mannose, Glucose, L-Rhamnose, Aldo-pentose
Carbohydrates	*Cellulose,* acetylated mannan, Arabinogalactan*,* Xylan*,* Pure mannan*,* pectic substance, glucomannan, Glucogalctomannan, Galactan
Inorganic Compounds	Calcium, Sodium, Chlorine, Manganese, Zinc, Chromium, Copper, Magnesium, Iron
Non-essential Amino acids	Histidine, Arginine, Hydroxyproline, Aspartic Acid, Glutamic acid, Proline, Glycine, Alanine
Essential Amino acids	Lysine, Threonine, Valine, Leucine, Iso-leucine, Phenyl- alanine, Methionine

7. Extraction method of *Aloe vera*

7.1. Aloe vera *gel preparation*

Numerous researchers have discovered the benefits of AV gel as an excellent component in film formulation over the last few years due to its properties. There are numerous works of literature on the preparation of AV gel from previous studies. Pinzon et al. [74] investigated the effect of AV gel incorporation on the physical, chemical, and mechanical properties of edible banana starch-chitosan films. They prepare the AV gel by thoroughly cleaning the AV leaves to remove dirt and soil. They rinsed the AV leaves with tap water, then dried them with a paper towel. Following that, the green outer skin leaves were scraped away with a knife, and the AV gel, or AV parenchyma, was extracted. The AV gel was washed with distilled water heated to 40 °C, dried with paper towels, and blended for approximately 3 min. Finally, AV gel was filtered in a vacuum using cheesecloth to remove solid residues from cell walls.

Sui Chin et al. [80] conducted additional research to determine the effect of AV gel on the physical and functional properties of fish gelatine films used as active packaging. In their study, the method for preparing the AV gel extract began with cleaning the AV leaves with tap water and then rinsing them with distilled water to remove any soil from the leaves' surface. To obtain the gel, the AV rind was separated. After that, the gel was cleaned with tap water. Following that, AV gel was scraped from the flesh using a sterilised spatula. Spatulas must be sterilised to prevent contamination from affecting the outcome. To maintain the extracted AV gel's properties and bioactive compounds, it was refrigerated below 5 °C.

Apart from using tap water and distilled water to wash the AV leaves, Shweta et al. [81] used a mild chlorine solution of approximately 25% in their study. They investigated the use of biodegradable AV gel to prevent post-harvest decay and extend grapes' shelf life. The AV gel was separated from the leaf's outer cortex and the colourless hydroparenchyma was ground in a blender. This grinding process aids in the extraction of fibres and fresh AV gel. The Aloe gel matrix was pasteurised for approximately 45 min at a temperature of 70 °C. The gel was cooled to stabilise it, and ascorbic and citric acids were added to the formulation to immediately control the pH. To avoid oxidation of the stabilised AV gel, it was stored in a brown Amber bottle.

Purwanti et al. [82] followed the same procedure as previous researchers for AV gel extraction. They used freshly washed AV leaves. The pulp or gel was filleted and then washed with water before being pulverised for 10 s at maximum speed in a blender. The pulp was then accommodated at a speed of 10,000 revolutions per minute for approximately 30 min at a temperature of 5 °C. Filtration followed by pasteurisation at 70–75 °C for approximately 15 min while ascorbic acid and citric acid were added to the homogenised pulp. They investigated the synthesis and characterization of edible films based on AV and incorporating shellac resin and hydrocolloids.

In their study, Razali et al. [83] used AV gel to coat fruits and vegetables with cinnamon oil. The AV leaves were cleaned with distilled water and approximately 2% (v/v) sodium hypochlorite was added (NaClO). Sodium hypochlorite was added to the solution to remove the contaminant from the AV leaves' surface. The AV gel was then separated from the leaves' outer cortex. The colourless hydroparenchyma or AV was then homogenised at an optimal speed in a blender. After that, the AV gel was sieved to remove any remaining components of fresh AV gel and unwanted fibres.

7.2. *Soxhlet extraction method*

Numerous researchers have investigated numerous methods for extracting AV leaves and gel in the modern era. Soxhlet extraction is a popular technique. This method is advantageous for preparative purposes, as it concentrates the analyte from the matrix in its entirety or separates it from interfering substances [84]. According to Nafiu et al. [85]; soxhlet extraction is necessary only when the desired compound has a low solubility in the solvent and the impurity is insoluble in the solvent. When a desired compound is highly soluble in a solvent, it is separated from an insoluble substance using simple filtration [85]. Recently, Mohan Raj et al. [86] studied on drug loaded chitosan and aloe vera nanocomposite on titanium for orthopaedic application. In their research, they extracted AV leaves by soxhlet extraction process. in their work, they Plant leaves more than three years were decontaminated with 3% hypochlorite before the extraction procedure started. The rinsed gel was placed in a thimble after cutting the rind with a scalpel. The ethanolic Soxhlet extraction process was used to extract the aloe vera gel, which lasted 48 h at 80 °C. The solvent was then evaporated at 37 °C to get powder.

Saniasiava et al. [87] extracted AV leaves using soxhlet extraction to determine the antifungal activity of Malaysian AV leaf extract against selected fungal species. Two solvents were used: aqueous and 70% ethanol. After filling the soxhlet thimble with the dried powder AV as shown in Fig. 4(a), it was inserted into the soxhlet main chamber and sealed. About 70% ethanol was inserted into the main chamber of the soxhlet apparatus and attached to the soxhlet apparatus as illustrated in Fig. 4(b). The apparatus was then heated until the main chamber was completely filled with solvent. After condensing and dripping down, the solvent vapour is released into a chamber containing AV leaf extract. Following that, 70% ethanol was evaporated from the AV leaf extract using a rotary evaporator at 30 °C and concentrated to 50 ml before being freeze-dried. Then, the freeze-dried AV powder was kept in a refrigerator to preserve the critical compound. They used a similar method for extraction in aqueous solution, using 70% distilled water as a solvent. Finally, *Candida albicans* and *A. niger*, both from otomycosis, were employed in this investigation and were obtained from the Microbiology Laboratory of the School of Medical Sciences, Universiti Sains Malaysia. On Sabouraud dextrose agar (SDA) plates, *A. niger* and *C. albicans* were cultivated as shown in Fig. 4(c).

Following that, Yuharmon et al. [88] demonstrated that AV gel was extracted using soxhlet extraction. They used

Fig. 4 – a) Oven dry of AV leaves, b) Soxhlet extraction method, c) *Candida albicans* and *Aspergillus niger* SDA method [87].

scanning electron microscopy to apply an electrolyte to a soxhlet extracted AV gel (SEM). They filled the soxhlet thimble with AV gel. They used hexane and ethanol as solvents. These solvents were combined in a specific ratio to isolate the various bioactive compounds extracted. To begin, the solvent was added to the flask with a round bottom. The solvent was heated with a heating mantle to its boiling point and then refluxed for approximately 4 h. After that, the extraction was completed, and the extracted gel and gel residue were separated. The subsequent process was carried out in extracted gel using a rotary evaporator to form gel, while the gel residue was dried for 2 h at 65 °C to obtain cellulose.

7.3. *Aloe leaf gel powder by freeze-dry method*

Consumers receive numerous benefits from AV gel, including its therapeutic potential as an antidiabetic, antioxidant, anti-inflammatory, anti-ulcer, and moisturising agent [89]. However, when AV gel comes into contact with a thermal process, it alters the chemical structure of the gel, resulting in thermal damage and denaturation [90]. Another technique for preserving the psycho-chemical properties of AV gel is freeze drying. Freeze drying is another method for dehydrating fresh AV gel to create a foam-like surface. Fig. 5 illustrates the AV foam after it has been freeze-dried. Freeze drying is a method that has been used consistently because it preserves the product's physical and chemical properties such as colour, vitamins, antioxidant content, and other sensory properties such as its original aroma and flavour [91].

Chen et al. [11] used freeze-dried aloe leaf gel powder and gelatine to create an edible antimicrobial aloe/gelatine composite film. In their experiment, they kept the AV powder formed by the AV gel frozen at −80 °C. The frozen aloe leaf gel was then freeze-dried at −45 °C in a pressure range of 200–1000 mTorr using a Lyolab ST3B; Lyophilization System Inc., New Paltz, NY, USA. *Aloe vera* powder was ground with a blender made from freeze-dried aloe leaf gel and then screened (60 mesh). The powder should be stored in a freezer at −20 °C until used. Silva et al. [92] conducted research on the biomedical applications of AV sponges. To create a thin layer of materials, moulded AV gel was combined with gellan gum. Rinse the solution with phosphate buffer solution (PBS). After stabilising the solution at 60 °C for 15–20 min and 4 for 5 min, it was overnight frozen at 80 °C and freeze-dried for 3 days.

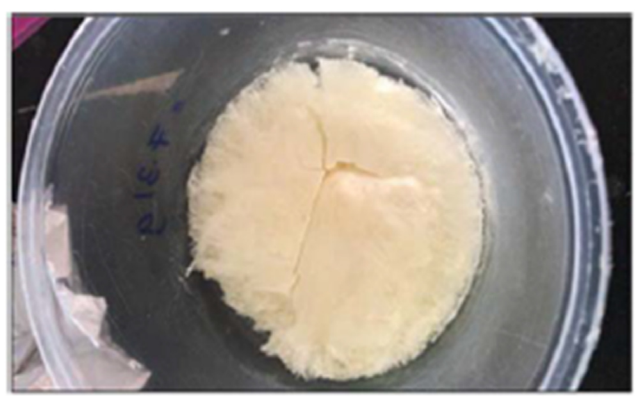

Fig. 5 – *Aloe vera* freeze dried form.

Chakaraborty et al. [93] developed statistical model equations for predicting moisture content (MC), yield (y), and wettability (w) as a function of process parameters in an IR assisted vacuum. They reported that the physicochemical properties of freeze-dried aloe vera samples under optimal conditions are superior to those of fresh aloe vera samples dried conventionally.

8. *Aloe vera* starch-based film obtained by casting

Numerous researchers investigated the potential of films made from native starches derived from a variety of sources, as well as starches that have been chemically or physically modified to form a variety of applications. The formulation of films is critical because it enables tailoring of these materials' barrier and mechanical properties [94]. As a result, the efficiency of food coating and packaging is increased. The microstructure of films and the interaction of their constituents provide insight into both fundamental properties of materials science and practical technology for future applications [94]. Prior to mixing the formulation, the matrix, plasticizer, or other materials such as antimicrobial agent must be well-formulated. This is critical for producing a high-quality film. Plasticizers such as glycerol, sorbitol, citric acid, and ascorbic acid are added to the film formulation to prevent the film from cracking and becoming brittle, as well as to increase the film's flexibility and extensibility. It is an organic compound with a low molecular mass that must be compatible with film-forming polymers.

The plasticizer can increase the mobility of polymer chains and weaken intermolecular forces. Lipids and polyols, among other oligosaccharides, are chemically compatible with hydrocolloid [95]. Numerous researchers created films through the process of solution casting. According to Ortega-Toro et al. [4]; the process of creating film formulations containing AV began with pregelatinized corn starch being dispersed in water and mixed with various ratios of glycerol as a plasticizer and AV gel using an appropriate ratio of AV dry solid to starch to create six distinct formulations. The formulations were homogenised at the optimum speed and time using a rotor-stator homogenizer. Casting with 1.5 g of total solid spread over a Teflon casting plate produced films. Following that, the films were dried for approximately 72 h at a relative humidity of 45 percent and a temperature of 20 °C. After the films have dried completely, they can be peeled away from the casting surface to determine the mechanical and physical properties.

Gutiérrez & Alvarez [96] investigated the same process and obtained a film formulation solution (FFS) by combining native plain flour, glycerol, and distilled water. To create films, various concentrations of AV gel were used. The solution was then heated in a water bath at 90 °C for 30 min with constant stirring to cause starch to gelatinize and inhibit the activity of the enzyme isolated from AV gel. Following that, the solution was poured into a tray using the solution casting method and dried for 24 h at 45 °C in a Mitchell dehydrator (Model 645 159). Kathiresan and Lasekan [97] used the solution casting method to create films to investigate the effect of glycerol and stearic acid on chicken starch-based coatings used on fresh-cut papaya.

In their study, Razali et al. [83] used a solution casting technique to prepare AV films infused with cinnamon oil for fruit and vegetable coating. They used 18 cm diameter Teflon-coated trays to cast the films. The solutions were cast over the Teflon-coated baking trays by pipetting 250 mL of the degassed film-forming solutions (pH 5.7) into the trays that had been levelled. The trays containing the solutions were then dried at 40 °C in an oven for 24 h prior to the test, maintaining a constant relative humidity (RH) of 50%. Following that, dried films were selected and peeled from the tray to determine which films formed properly without cracking, bubbles forming on the film surface, or holes. Fig. 6 illustrates the film solution casting process.

9. Properties enhancement of starch-based film using *Aloe vera*

Biopolymers such as proteins and polysaccharides have been used as edible films in the food industry for a long time. To develop composite films with enhanced biological and technological functionality, more than one polymer is usually used. All of the materials in a composite film must be compatible with one another, and their interactions must enhance the structure and performance of the film [10]. As mentioned elsewhere, unlike polymers can form a variety of covalent and non-covalent interactions (electrostatic, hydrogen bonding, hydrophobic, and Van der Wall interactions) [98]. Notably, AV gel and rind was discovered to be compatible with a number of biopolymers used in edible coatings and films. The AV rind and gel may act as a reinforcement and antimicrobial agent in starch-based films, respectively. The AV gel contains an antimicrobial agent that is incorporated into a starch-based film to significantly increase microbial resistance, shelf life, and quality, particularly for perishable foods [99]. Additionally, the inclusion of AV rind

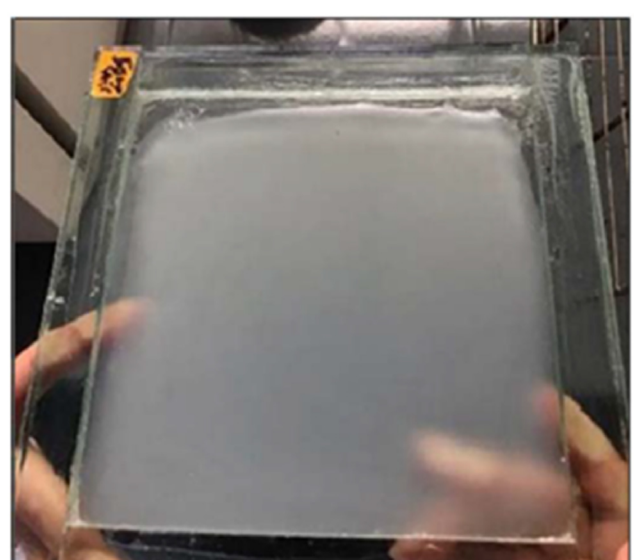

Fig. 6 – Solution casting method.

improves mechanical properties due to the fibre's high interfacial adhesion and dispersion. Additionally, the addition of AV rind improves the thermal stability and density of the composite [25]. Thus, the addition of AV rind and gel enhances the film's physical, thermal, mechanical, antimicrobial, and physiochemical properties. These characteristics must be emphasised to ensure product shelf life, safety, environmental friendliness, longevity, durability, and microbial resistance.

9.1. Physical properties

9.1.1. Thickness

In terms of thickness, the addition of AV gel to starch-based films had a noticeable effect. Pinzon et al. [74] discussed the effect of *Aloe vera* gel incorporation on the physicochemical and mechanical properties of a banana starch-chitosan edible film in their research. The results indicated that the addition of AV gel increased the thickness of films as the concentration of AV gel increased. They tested five different AV gel concentrations ranging from 0 to 100, 200, 300, and 500 g L^{-1} and discovered that the film thickness increased from 59.3 ± 0.2 m to 174.5 ± 1.5 m, respectively. It has been stated that the thickness of a film is determined by its composition [71]. As a result, it is worth noting that film thickness is also related to the dry matter increase observed in film-forming solutions as a function of AV gel concentration.

Additionally, Silva-Weiss et al. [100] investigated the increase in film thickness caused by the crosslinking effect caused by the addition of a phenolic compound to a starch-chitosan blend film. Gutiérrez & González [101] created a similar view using banana flour-AV edible film. They discovered the polyphenolic compound's crosslinking effect on starch molecules in AV gel. This results in more transparent, smoother, less moist, and hydrophobic surfaces on the films. Additionally, they demonstrated that surface energy materials defined the surface properties of these materials. It is dependent on intermolecular interactions between plantain flour, such as van der Waals forces (hydrogen bond) and new bonds (crosslinking).

Gutiérrez & Alvarez [96] also investigate the thickness of films with varying concentrations of AV gel. They observed that as the AV gel content increased, the thickness of the film increased. According to Gutiérrez et al. [102]; the increased thickness of the starch film is due to increased interaction between the starch plasticizer and hydrogen bond formation between glycerol and starch. Additionally, they noted that these interactions become stronger as the film's AV gel content increases. Ortega-Toro et al. [4] demonstrate in their study that varying the concentration of AV gel has an effect on the thickness of films. They created six distinct AV gel formulations. According to their findings, the highest concentration of AV results in the thickest film when compared to other films.

In contrast to other research by Sui Chin et al. [80]; they observed the thickness of control film and the film with 1% AV gel were observed to have no significant different ($p \geq 0.05$). The solid component of the film-forming fluid determines the film thickness [103]. Aloe gel, on the other hand, is made up of 99% water and only 1% solid components [104]. With the presence of AV gel, the peptide bond of fish gelatine may still create a tight network. This means that the Aloe gel's components might be spread throughout the film without compromising its thickness [11].

9.2. Thermal properties

9.2.1. Thermogravimetric analysis (TGA)

Thermogravimetric analysis (TGA) is an analytical technique for determining the thermal stability of materials and the percentage of volatile components in them by monitoring the weight changes of samples heated at a constant rate [105]. Typically, the measurement is made in air or an inert atmosphere such as argon or helium. The weight is calculated as a function of temperature increase [105]. Numerous studies using thermogravimetric analysis have been conducted on the thermal degradation of aloe vera starch-based films (TGA).

Bajer et al. [106] investigated the thermal stability of starch-chitosan films and the effect of AV gel inclusion and concentration in the polymer matrix on the thermal stability. The maximum thermal degradation temperatures (T_{max}, °C) of starch film, starch-chitosan film, and starch-chitosan film incorporated with 50% AV gel were determined to be 293 °C, 298 °C, and 302 °C, respectively. While the maximum rate of decomposition of the starch film was increased by the addition of chitosan and AV gel, the temperature at which degradation begins (T_0, °C) has already been shifted to lower temperatures. This is explained by the fact that certain crosslinking reactions occur between the amorphous region of starch and the natural agents that enter the matrix. The addition of starch and AV gel altered the thermal resistance of starch for a variety of reasons, including their effective contribution, intercalation, and agglomeration within the starch matrix. They concluded that the addition of AV gel and chitosan improves the thermal resistance of starch-based films, thereby delaying the maximum decomposition rate when compared to pure starch films.

Additionally, Gutiérrez & Alvarez [96] investigated the thermal stability of plantain starch at various concentrations of AV gel (0, 2, 4 and 7%). They observed an increase in thermal degradation resistance in films as the AV gel content increased, as evidenced by less weight loss at the same temperature. This could be because the cross-linking reactions increase the starch's average molecular weight and form chemical bonds between various molecules. In the third stage, stable thermal degradation curves up to 500 °C were observed. Weight loss was found to be less in films with a higher AV gel content. This could be because the AV gel contains minerals and oxidation products of aromatic rings (coal residues) of active compounds such as polyphenols.

Nieto-Suaza et al. [48] investigated the effects of aloe vera gel and curcumin-loaded nanoparticles on native green banana starch (NSNp) and acetylated banana starch (ASNp). Thermal stability testing had to be performed over a wide temperature range. The TGA curves of the banana starch-AV gel composite films with various curcumin-loaded nanoparticles are shown in Fig. 7. Three stages of decomposition were visible in all composite films. At 105 °C, the first stage of decomposition occurred, which is consistent with the evaporation of water from the film's composite. The second stage

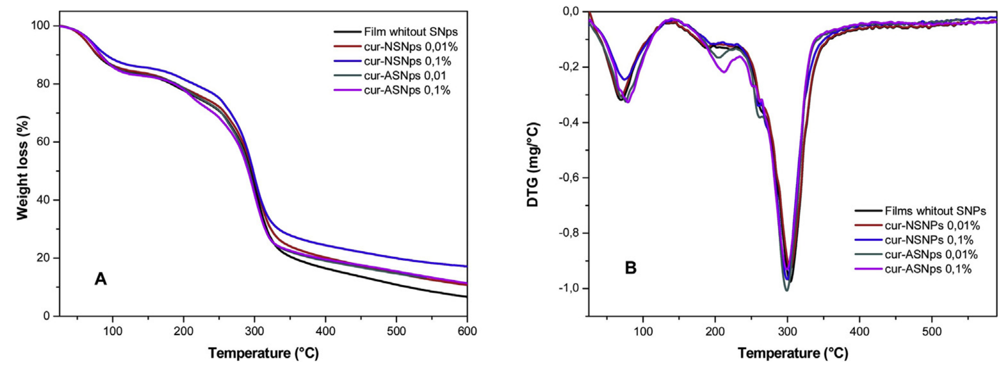

Fig. 7 – TGA (A) and DTG (B) curves of banana starch-AV gel and curcumin-loaded native (cur-NSNps) and acetylated (cur-ASNPs) composite films [48].

of decomposition occurred between 180 and 250 °C, while the third stage occurred above 250 °C, as a result of the complex degradation of the amylose and amylopectin polymer chains found in starch, which included dehydration of saccharide rings.

Additionally, they stated that the composite films exhibited three peaks at 70 °C, 201 °C, and 300 °C, which corresponded to the thermal decomposition stages depicted in Fig. 7. It is critical to emphasise that in composite films containing ASNp, the second peak was observed to be more pronounced than in other films. These results are possible because the acetylated and deacetylated groups depolymerize and decompose in the modified starch nanoparticles.

9.3. *Mechanical properties*

Rawdkuen [107] defined mechanical properties as critical in the production of starch-based films, particularly for food packaging, to avoid food surface deterioration caused by physical damage such as indentation, detaching, and blackening. The mechanical properties of starch-based films can be used to determine the film's resistance to external or internal forces and its flexibility. This fact is critical in determining the efficiency of starch-based films during handling, storage, and use.

Pinzon et al. [74] investigated the mechanical properties of edible banana starch-chitosan films at various AV gel concentrations. They concluded from their findings that the tensile strength decreased with increasing AV gel concentration. Tensile strength (TS) was 9.71.2 MPa at a 100 g L^{-1} AV concentration and 4.60.4 MPa at a 500 g L^{-1} AV concentration. A similar result was obtained in terms of elongation at break (%E), where elongation at break decreased as the concentration of AV gel in the film was increased. Nonetheless, without the addition of AV gel, the values of TS and %E were the highest, and these values decreased when AV gel was added at a specific concentration to banana starch-chitosan films. Khoshgozaran et al. [71] demonstrated that when AV gel is added to chitosan films, a threshold value of 20% is observed, after which the TS and (%E) values decrease. These are primarily due to AV gel's high moisture content. Due to these characteristics, it has a low plasticizing effect and degrades mechanical properties.

Gutiérrez & Alvarez [96] also observed a decrease in the mechanical properties of the banana flour-glycerol-AV film as the concentration of the AG gel increased. This could be because AV gel contains a high concentration of polyphenolic compounds. These compounds cause starch molecules to crosslink, resulting in the formation of more rigid banana flour-glycerol-AV films. Sartori & Menegalli [108] explained that unripe banana starch contains a high amount of amylose, which can form strong interactions with chitosan molecules, resulting in a low E content in this edible film. This issue can be resolved by including sorbitol in the film formulation as a plasticizer. When AV gel is added, it acts as a crosslinker, lowering the films' %E and TS values. According to other sources of information, AV gel is composed of a complex mixture of glucomannan, amino acids, and organic acids that forms a complex matrix and heterogeneous structure. These molecules can interact with chitosan and starch molecules in a limited way. These interactions focused on sorbitol's ability to reduce its plasticizing effect, but Pinzon et al. [74] suggested that additional research is necessary before broad application.

Additionally, the study of biodegradable films reinforced with AV rind was investigated. Mechanical properties of AV rind films were investigated, including tensile strength, Young's modulus, and percentage of elongation. Cheng et al. [24] investigated the mechanical properties of aloe vera rind nanofibers (AVRNF) obtained through a chemi-mechanical process. The mechanical properties of nanofibrous films were examined in their study, as well as those of other wood nanofibers. They observed that presenting AVRNF reduces the tensile strength and Young's modulus required to break AVRNF. Following that, a lower percentage of elongation was observed in AVRNF film, which they attributed to the film being more brittle than other wood nanofibers. Mechanical properties of the AVNF film were low as a result of severe fibre degradation during the chemi-mechanical treatment. Additionally, they explained the decrease in mechanical properties as a result of the inherent properties of AV rind fibres. Additionally, they determine the crystallinity and degree of polymerization of these fibres, which indicates that the strength of

AVRNF films is less than that of wood cellulose nanofibers. The mechanical properties of nanofibrous films derived from AV rind, wood, and other lignocellulosic materials are listed in Table 5.

9.4. *Antimicrobial and antifungal properties of* Aloe vera *gel*

Numerous studies have demonstrated that AV gel may act as a natural antimicrobial agent. The bioactive components of AV gel, such as glycoprotein, acemannan, and emodin, have been shown to be resistant to a variety of bacteria. As a result, AV gel is safe to add to film used for food packaging and coating. Valencia [111] stated that there are numerous methods for determining a film's antimicrobial properties against a specific microbial organism. To begin, antimicrobial assays such as agar diffusion tests, zone tests, or what is commonly referred to as inhibition tests are tests in which a film with antimicrobial properties is placed over a lawn of a target area to determine the effect of the film on the growth of microorganisms on an agar medium plate. Second, a cell count or log reduction assay is another method in which the film is placed in a growing microorganism in broth solution and samples are removed from the solution at the specified time.

Numerous studies investigated the antimicrobial and antifungal properties of AV gel in starch-based films. Ortega-Toro et al. [4] investigated antifungal edible films based on starch and containing AV gel. They discovered that when AV gel was added to the medium, fungus growth was inhibited, defining the inhibitory effect of fungi growth. *Fusarium oxysporum* (MGI: 65.16), *Biporis spicifera* (MGI: 53.09), and *Curvularia hawaiiensis* (MGI: 53.09) were three fungi that demonstrated a high degree of Mycelium Growth Inhibition (MGI) (MGI: 43.21).

Jasso De Rodrguez et al. [112] reported a similar result when they investigated the antifungal activity of AV pulp and liquid fraction against plant pathogenic fungi in vitro. These findings established that the antifungal activity of AV gel was a result of a bioactive component. Bajer et al. [106] conducted microbial tests on various concentrations of AV gel in starch-chitosan composites used in bio-packaging materials. They examined two different concentration levels: 10% and 50%. They observed the growth of microorganisms in the studied samples, which they determined to be (*Bacillus* sp.) and fungi acting as a carbon source (*Fusarium culmorum*). As a result, all samples have undergone biodegradation, as determined by mass losses. They discovered that *Bacillus* sp. was more susceptible than *F. culmorum*. They concluded that by adding AV gel to the film, the microbial resistance increased as well, providing benefits for packaging applications in the food, pharmaceutical, and cosmetics industries.

Pinzon et al. [113] conducted an investigation into fungal decay and microbial analysis. They investigated fungal decay on strawberries during storage using a coated and uncoated application. The decay of fungal growth on coated fruits was determined during storage, and this was found to be highly dependent on the AV gel concentration. The results indicated that the addition of AV gel increased the antifungal activity on chitosan-starch-based coatings. This is because fungal decay has been reduced by nearly half when the amount of AV gel used is increased.

Additionally, it was discovered that the addition of AV gel can inhibit microbial growth. As a result, increasing the amount of AV gel increased antimicrobial activity, extending the shelf life of strawberries by fifteen days by inhibiting fungal and microorganism growth. Hajji et al. [114] described the antifungal mechanism used to coat chitosan films. Initially, activation of chitinase involved in the formation to hydrolysis of chitin inhibits fungal growth. Secondly, the capacity to cause fungal cellular damage. Additionally, Sánchez-Ortega et al. [115] demonstrated that the inclusion of AV gel in edible coatings exhibits antifungal activity against a variety of fungi.

In comparison to research conducted by Al-Ahbabi et al., [116]; they studied the potential of AV methanol extract on antimicrobial susceptibility by well diffusion method and disk diffusion method (Fig. 8). The result revealed the *S. aureus* was reported to be more affected by the antibacterial action of AV extract in both methods disk and well diffusion method than other bacterial isolates method. Furthermore, the results showed that AV extract was more effective on the bacterial inhibition zone than AV gel, which could be returned to extract concentration. This research is corresponding to study by [117]. In their research, they observe the effectiveness of methanol extract from AV leaves extract against *E. coli, P. aeruginosa* and *Acinetobacter baumanii*.

9.5. *Physiochemical characteristics*

9.5.1. *Water vapour permeability*

The water vapour permeability (WVP) of a material is defined as the ability of water vapour to flow through when subjected to pressure between two opposite faces [118]. This parameter is determined by the physical properties of the material, such as tortuosity and pore diameter, and has a strong correlation with air permeability [118]. In other words, water vapour permeability can also be defined as the ability of moisture to transfer and penetrate through a hydrophilic film [71].

Table 5 – Mechanical properties of nanofibrous film of *Aloe vera* rind, wood and other lignocellulosic materials.

Nanofibrous film	AV	Wood	Rice Straw	Potato Tuber	Wood
Density (g/cm^3)	1.28 (±0.06)	1.26 (±0.05)	1.36	1.34	–
Tensile strength (MPa)	102.12 (±10.22)	132.90 (±8.98)	230 (±30)	230 (±10)	240 (±12)
Young' Modulus (GPa)	5.29 (±1.63)	7.1 (±1.79)	11 (±1)	11.4 (±0.6)	11 (±0.6)
Percentage of elongation (%)	7.33 (±1.44)	11.49 (±1.57)	–	–	–
References	[24]	[24]	[109]	[109]	[110]

*Values in parentheses are the standard deviation.

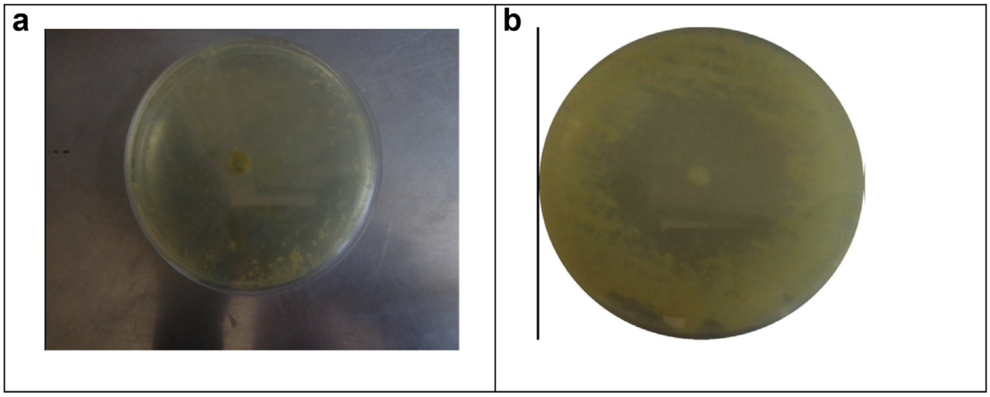

Fig. 8 – Inhibition zone of S aureus by using (a) well diffusion method and (b) disk diffusion method [116].

According to the literature, films containing starch will have a high moisture permeability, limiting their application in the food industry. As a result, many researchers are concentrating their efforts on reducing the starch film's water vapour permeability.

In their study, Pinzon et al. [74] demonstrated the WVP of banana starch-chitosan-AV gel edible films. They explained that the water vapour permeability of the edible films is determined by the film's major properties. They are primarily concerned with the ratio of hydrophilic to non-hydrophilic groups in the film, as this ratio dictates how the film interacts with water. According to their findings, adding AV gel to films reduces their water vapour permeability. They explained that the presence of AV gel in films impairs the crosslinking effect of starch–chitosan with the starch molecule by reducing the hydrophilicity of starch. As a result, the water vapour permeability of films is reduced.

9.5.2. Water solubility

The water solubility (WS) test can be used to determine the hydrophilicity or hydrophobicity of samples. WS is a critical parameter, and it is necessary to characterise the WS of samples before they can be used commercially. Bajer et al. [106] demonstrated in their study that incorporating an active antimicrobial agent into a starch matrix had no effect on the water solubility. Additionally, they investigated the solubility of water under the influence of ultraviolet (UV) radiation. They discovered that when the amount of AV gel in the starch-chitosan blends is increased to about 40%–50%, the radiation effect becomes less vivid. According to Gutierrez et al. [102]; this change in hydrophilicity occurred as a result of a novel cross-linked reaction between the hydroxyl groups of starch, the glycerol plasticizer, or/and amino groups in the protein present in the blend components.

Bajer et al. [106] also reported that UV light has an effect on the crosslinking reaction, causing a tightening effect on all matrix components. As a result, this helps to avoid water penetration and decreases the solubility of blended samples. Additionally, they concluded that increasing the AV gel loading results in a more rigorous crosslinking process following UV radiation, resulting in a decrease in sample solubility.

According to Khoshgozaran-Abras et al. [71]; the WS properties degrade with the addition of AV gel. In comparison, Gutiérrez & Alvarez [96] discovered that films with a lower AV are more soluble in water. They explained that a strong hydrogen bond is formed between the hydroxyl groups of the starch chains and the glycerol molecule, which reduces the amount of water in the molecule and makes it more sensitive. Thus, a high AV gel content in the film will react more vigorously with glycerol, causing it to become insoluble in water, increasing the resistance of water to penetrate the film and decreasing its solubility.

Pinzon et al. [74] investigated the effect of aloe vera gel on the water solubility of edible films composed of banana starch, chitosan, and AV gel. They examined water solubility at two different temperatures, 25 °C and 100 °C, and discovered that it increased at both temperatures. Additionally, they correlated the WVP results with the WS results. Typically, when edible films have a low WVP, they also have a low WS. Thus, it was expected that when the WVP was reduced, the WS of the banana starch-chitosan-AV gel edible films would decrease in value. However, it is necessary to consider that the major components of the AV gel are organic acids, sugars, and amino acids, all of which have a high WS content. This demonstrates why some films' WS samples increase as the component tends to solubilize in edible films.

10. Conclusions and future outlook

Recent advancements in food packaging materials included (a) developing renewable resource-based biopolymers (e.g., cellulose, starch, and protein); (b) incorporating reinforcing agent to enhance their mechanical, thermal and physicochemical properties; and (c) providing antimicrobial, antioxidative, and other functions to packaging materials using antimicrobial agent such as organic (e.g., essential oil, plant extract) and inorganic (e.g., ZnO, TiO_2, and Ag). Starch based film is becoming a popular alternative to petroleum-based polymers as packaging materials due to its low cost, biodegradability, and its ability to form films by thermoplastic processing. Many components have been introduced to the starch matrix, and process variables have been modified, to improve film properties. Nonetheless, retrogradation phenomenon and the brittleness of starch films limit their applicability. Some additives, such as plasticizers, or reinforcing agents, can help to alleviate these issues, resulting in more stable materials with improved properties. The resulting films exhibit good mechanical, barrier, and optical properties when the optimal formulation is used.

The development of starch-based films for use as antimicrobial packaging or coating is one of the most promising active packaging systems. The addition of natural antimicrobial compound helps to preserve fresh and minimally processed foods is a significant challenge for industry and a very active research area on a global scale. Recently, interest in using aloe vera as an organic antimicrobial agent derived from plants has risen significantly. There is a wealth of information available regarding the chemical compounds found in AV, particularly AV gel. Numerous bioactive compounds are present in AV gel and contribute significantly to the gel's antibacterial activity. The presence of these bioactive compounds in AV gel qualifies it as a natural organic antibacterial agent. Additionally, AV rind has the potential to act as reinforcement for composites, thereby enhancing certain properties of the starch film. AV starch-based films are great example of a natural and active food packaging material. However, some challenges, including efficient extracting method of the AV gel from aloe vera leaves, selection of suitable types of plasticizers and the development of starch-based film incorporating AV packaging materials with adequate mechanical, physical, thermal, antimicrobial, and physicochemical properties that can be prepared at a reasonable cost for both producer and consumers, remain in the development of antimicrobial active packaging. In this sense, the analysis of different properties of the starch films incorporating AV with different plasticizer types and process conditions, is necessary to optimize film formulation and process conditions.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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REFERENCES

[1] Yehuala G. Antimicrobial activity, physicochemical and mechanical properties of aloe (aloe debrana) based packaging films. Br J Appl Sci Technol 2013;3(4):1257–75.

[2] Min SC, Krochta J. Edible coatings containing bioactive antimicrobial agents. *Packaging for nonthermal processing of food*, 29. In: Han JH, editor. Packaging for nonthermal processing of food. Blackwell Publishing Ltd; 2007. p. 29.

[3] Kumar R. Health effects of morpholine based coating for fruits and vegetables. Int J Med Res Health Sci 2016;5(9):32–8.

[4] Ortega-Toro R, Collazo-Bigliardi S, Roselló J, Santamarina P, Chiralt A. Antifungal starch-based edible films containing Aloe vera. Food Hydrocolloids 2017;72:1–10.

[5] Amini J, Sidovich DF. The effects of fungicides on *Fusarium oxysporum F . Sp . Lycopersici* associated with *Fusarium Wilt* of tomato. J Plant Protect Res 2010;50(2).

[6] Herrera-t I, Cruz-olmedo AK, Plasencia J, Gavilanes-ru M, Arce-cervantes O, Hern S, et al. The protective effect of trichoderma asperellum on tomato plants against Fusarium oxysporum and botrytis cinerea diseases involves inhibition of reactive oxygen species production. Int J Mol Sci 2019;20(8):1–13.

[7] Aminzare M, Hashemi M, Hassanzadazar H, Amiri E, Abbasi Z. Antibacterial activity of corn starch films incorporated with *Zataria multiflora* and *Bonium persicum* essential oils. Ann Res Rev Biol 2017;19(1):1–9.

[8] Petkoska AT, Daniloski D, D'Cunha NM, Naumovski N, Broach AT. Edible packaging: sustainable solutions and novel trends in food packaging. Food Res Int 2021;140:109981.

[9] Flores-Martínez NL, Valdez-Fragoso A, Jiménez-Islas H, Pérez-Pérez MC. Physical, barrier, mechanical and microstructural properties of Aloe vera-gelatin-glycerol edible films incorporated with *Pimenta dioica L. Merrill* essential oil. Revista Mexicana de Ingeniería Química 2017;16(1):109–19.

[10] Maan AA, Reiad Ahmed ZF, Iqbal Khan MK, Riaz A, Nazir A. Aloe vera gel, an excellent base material for edible films and coatings. Trends Food Sci Technol 2021;116:329–41.

[11] Chen CP, Wang BJ, Weng YM. Physiochemical and antimicrobial properties of edible aloe/gelatin composite films. Int J Food Sci Technol 2010;45(5):1050–5.

[12] Maan AA, Nazir A, Khan MKI, Ahmad T, Zia R, Murid M, et al. The therapeutic properties and applications of Aloe vera: a review. J Herb Med 2018;12:1–10.

[13] Thakur R, Pristijono P, Scarlett CJ, Singh SP, Vuong QV. Starch-based films: major factors affecting their properties. Int J Biol Macromol 2019;132:1079–89.

[14] Jiang B, Li S, Wu Y, Song J, Chen S, Li X, et al. Preparation and characterization of natural corn starch-based composite films reinforced by eggshell powder. CyTA - J Food 2018;16(1):1045–54.

[15] Aisyah Y, Irwanda LP, Haryani S, Safriani N. Characterization of corn starch-based edible film incorporated with nutmeg oil nanoemulsion. IOP Conf Ser Mater Sci Eng 2018;352(1).

[16] Salleh E, Muhamad II. Starch-based antimicrobial films incorporated with lauric acid and chitosan. AIP Conf Proc 2010;1217(March):432–6.

[17] Arowora KA, Williams J, Adetunji CO, Afolayan SS, Olaleye OO, Ogundele BA, et al. Effects of aloe vera coatings on quality characteristics of oranges stored under cold storage. Greener J Agri Sci 2013;3(1):39–47.

[18] Grace OM, Buerki S, Symonds MRE, Forest F, Van Wyk AE, Smith GF, et al. Evolutionary history and leaf succulence as explanations for medicinal use in aloes and the global popularity of Aloe vera. BMC Evol Biol 2015;15(1):1–12.

[19] Khan MS. Determination of chemical composition, total flavonoid content, total phenolic content and antioxidant capacity of various crude extracts of manihot esculenta crantz leaves. Int J Res Appl Sci Eng Technol 2018;6(4):2433–44.

[20] Misir J, Brishti H, Hoque M. *Aloe vera* gel as a novel edible coating for fresh fruits: a review. Adv J Food Sci Technol 2014;2(3):93–7.

[21] Khatri D, Panigrahi J, Prajapati A, Bariya H. Attributes of Aloe vera gel and chitosan treatments on the quality and biochemical traits of post-harvest tomatoes. Scientia Horticulturae 2020;259:108837.
[22] Zhang Y, Bao Z, Ye X, Xie Z, He K, Mergens B, et al. Chemical investigation of major constituents in Aloe vera leaves and several commercial Aloe juice powders. J AOAC Int 2018;101(6):1741–51.
[23] Ghafoor B, Ali MN, Ansari U, Bhatti MF, Mir M, Akhtar H, et al. New biofunctional loading of natural antimicrobial agent in biodegradable polymeric films for biomedical applications. Int J Biomater 2016;2016.
[24] Cheng S, Panthapulakkal S, Sain M, Asiri A. Aloe vera rind cellulose nanofibers-reinforced films. J Appl Polym Sci 2014;131(15):1–9.
[25] Kakroodi AR, Cheng S, Sain M, Asiri A. Mechanical, thermal, and morphological properties of nanocomposites based on polyvinyl alcohol and cellulose nanofiber from Aloe vera rind. J Nanomater 2014;2014(i):12–8.
[26] Niranjana Prabhu T, Prashantha K. A review on present status and future challenges of starch based polymer films and their composites in food packaging applications. Polym Compos 2018;39(7):2499–522.
[27] Silveira Hornung P, Ávila S, Apea-Bah FB, Liu J, Lopes Teixeira G, Hoffmann Ribani R, et al. Sustainable use of Ilex paraguariensis waste in improving biodegradable corn starch films' mechanical, thermal and bioactive properties. J Polym Environ 2020;28:1696–709.
[28] Muscat D, Adhikari B, Adhikari R, Chaudhary DS. Comparative study of film forming behaviour of low and high amylose starches using glycerol and xylitol as plasticizers. J Food Eng 2012;109(2):189–201.
[29] Marichelvam MK, Jawaid M, Asim M. Corn and rice starch-based bio-plastics as alternative packaging materials. Fibers 2019;7(4):1–14.
[30] Tharanathan RN. Biodegradable films and composite coatings: past, present and future. Trends Food Sci Technol 2003;14(3):71–8.
[31] Vieira MGA, Da Silva MA, Dos Santos LO, Beppu MM. Natural-based plasticizers and biopolymer films: a review. Eur Polym J 2011;47(3):254–63.
[32] Ghasemlou M, Aliheidari N, Fahmi R, Shojaee-aliabadi S. Physical, mechanical and barrier properties of corn starch films incorporated with plant essential oils. Carbohydr Polym 2013;98:1117–26.
[33] Lopez O, Garcia MA, Villar MA, Gentili A, Rodriguez MS, Albertengo L. Thermo-compression of biodegradable thermoplastic corn starch films containing chitin and chitosan. LWT - Food Sci Technol (Lebensmittel-Wissenschaft -Technol) 2014;57(1):106–15.
[34] Sun Y, Liu Z, Zhang L, Wang X, Li L. Effects of plasticizer type and concentration on rheological, physico-mechanical and structural properties of chitosan/zein film. Int J Biol Macromol 2020;143:334–40.
[35] Sanyang ML, Sapuan SM, Jawaid M, Ishak MR, Sahari J. Effect of plasticizer type and concentration on tensile, thermal and barrier properties of biodegradable films based on sugar palm (Arenga pinnata) starch. Polymers 2015;7(6):1106–24.
[36] Ojogbo E, Ogunsona EO, Mekonnen TH. Chemical and physical modifications of starch for renewable polymeric materials. Mater Today Sustain 2020;7–8:100028.
[37] Zhong Y, Li Y. Effects of glycerol and storage relative humidity on the properties of kudzu starch-based edible films. Starch 2014;66(5–6):524–32.
[38] Jiménez A, Fabra MJ, Talens P, Chiralt A. Edible and biodegradable starch films: a review. Food Bioprocess Technol 2012;5(6):2058–76.
[39] Sessini V, Arrieta MP, Kenny JM, Peponi L. Processing of edible films based on nanoreinforced gelatinized starch. Polym Degrad Stabil 2016;132:157–68.
[40] Rahmawati M, Arief M, Satyantini WH. The effect of sorbitol addition on the characteristic of carrageenan edible film. IOP Conf Ser Earth Environ Sci 2019;236(1).
[41] Pappu A, Pickering KL, Thakur VK. Manufacturing and characterization of sustainable hybrid composites using sisal and hemp fibres as reinforcement of poly (lactic acid) via injection moulding. Ind Crop Prod 2019;137(2018):260–9.
[42] Adhikari B, Chaudhary DS, Clerfeuille E. Effect of plasticizers on the moisture migration behavior of low-amylose starch films during drying. Dry Technol 2010;28(4):468–80.
[43] Krogars K, Heinämäki J, Karjalainen M, Niskanen A, Leskelä M, Yliruusi J. Enhanced stability of rubbery amylose-rich maize starch films plasticized with a combination of sorbitol and glycerol. Int J Pharm 2003;25(1–2):205–8.
[44] Zarandona I, Cong N, Si T, De K, Guerrero P. International Journal of Biological Macromolecules Evaluation of bioactive release kinetics from crosslinked chitosan fi lms with Aloe vera. Int J Biol Macromol 2021;182:1331–8.
[45] Salama HE, Aziz MSA. Development of active edible coating of alginate and aloe vera enriched with frankincense oil for retarding the senescence of green capsicums. LWT 2021;145:111341.
[46] Salama HE, Aziz MSA. International Journal of Biological Macromolecules Optimized alginate and Aloe vera gel edible coating reinforced with n TiO 2 for the shelf-life extension of tomatoes. Int J Biol Macromol 2020;165:2693–701.
[47] Kanatt SR, Makwana SH. Development of active, water-resistant carboxymethyl cellulose-poly vinyl alcohol- Aloe vera packaging film. Carbohydr Polym 2020;227:115303.
[48] Nieto-suaza L, Acevedo-guevara L, Sánchez LT, Pinzón MI, Villa CC. Characterization of Aloe vera-banana starch composite fi lms reinforced with curcumin-loaded starch nanoparticles. Food Struct 2019;22:100131.
[49] Parham S, Wicaksono DHB, Bagherbaigi S, Lee SL, Nur H. Antimicrobial treatment of different metal oxide nanoparticles: a critical review. J Chin Chem Soc 2016;63(4):385–93.
[50] Pal M. Nanotechnology: a new approach in food packaging. J Food: Microbiol Safety Hygiene 2017;2(2):8–9.
[51] Mei L, Wang Q. Advances in using nanotechnology structuring approaches for improving food packaging. Ann Rev Food Sci Technol 2020;11:339–64.
[52] Kale Sangeeta N, Kitture R, Ghosh S, Chopade BA, Yakhmi JV. Nanomaterials as enhanced antimicrobial agent/activity- enhancer for transdermal applications: a review. Antimicrobial Nanoarchitectonics; 2017. p. 279–321.
[53] Singh S, ho Lee M, Park lnsik, Shin Y, Lee YS. Antimicrobial seafood packaging: a review. J Food Sci Technol 2016;53(6):2505–18.
[54] Mousavi Khaneghah A, Hashemi SMB, Limbo S. Antimicrobial agents and packaging systems in antimicrobial active food packaging: an overview of approaches and interactions. Food Bioprod Process 2018;111:1–19.
[55] Bondarenko OM, Sihtmäe M, Kuzmičiova J, Ragelienė L, Kahru A, Daugelavičius R. Plasma membrane is the target of rapid antibacterial action of silver nanoparticles in *Escherichia coli* and *Pseudomonas aeruginosa*. Int J Nanomed 2018;13:6779–90.
[56] Biswas MC, Tiimob BJ, Abdela W, Jeelani S, Rangari VK. Nano silica-carbon-silver ternary hybrid induced

antimicrobial composite films for food packaging application. Food Packag Shelf Life 2019;19:104–13.
[57] Hoseinnejad M, Jafari SM, Katouzian I. Inorganic and metal nanoparticles and their antimicrobial activity in food packaging applications. Crit Rev Microbiol 2018;44(2):161–81.
[58] Allahverdiyev AM, Abamor ES, Bagirova M, Rafailovich M. Antimicrobial effects of TiO_2 and Ag_2 O nanoparticles against drug-resistant bacteria and *leishmania* parasites. Future Microbiol 2011;6(8):933–40.
[59] Azam A, Ahmed AS, Oves M, Khan MS, Habib SS, Memic A. Antimicrobial activity of metal oxide nanoparticles against Gram-positive and Gram-negative bacteria: a comparative study. Int J Nanomed 2012;7:6003–9.
[60] Chang YN, Zhang M, Xia L, Zhang J, Xing G. The toxic effects and mechanisms of CuO and ZnO nanoparticles. Materials 2012;5(12):2850–71.
[61] Kumar R, Umar A, Kumar G, Nalwa HS. Antimicrobial properties of ZnO nanomaterials: a review. Ceram Int 2017;43(5):3940–61.
[62] Hackenberg S, Scherzed A, Technau A, Froelich K, Hagen R, Kleinsasser N. Functional responses of human adipose tissue-derived mesenchymal stem cells to metal oxide nanoparticles in vitro. J Biomed Nanotechnol 2013;9(1):86–95.
[63] Luo Z, Wu Q, Xue J, Ding Y. Selectively enhanced antibacterial effects and ultraviolet activation of antibiotics with Zno nanorods against *Escherichia coli*. J Biomed Nanotechnol 2013;9(1):69–76.
[64] Park Is SS. Comparative study on antimicrobial efficiency of AgSiO2, ZnAg and Ag-zeolite for the application of fishery plastic container. J Mater Sci Eng 2015;4(4).
[65] Bodaghi H, Mostofi Y, Oromiehie A, Zamani Z, Ghanbarzadeh B, Costa C, et al. Evaluation of the photocatalytic antimicrobial effects of a TiO_2 nanocomposite food packaging film by in vitro and in vivo tests. LWT-Food Sci Technol 2013;50(2):702–6.
[66] Krishnamoorthy K, Moon JY, Hyun HB, Cho SK, Kim SJ. Mechanistic investigation on the toxicity of MgO nanoparticles toward cancer cells. J Mater Chem 2012;22(47):24610–7.
[67] Gurtler JB, Fan X, Jin T, Niemira BA. Influence of antimicrobial agents on the thermal sensitivity of foodborne pathogens: a review. J Food Protect 2019;82(4):628–44.
[68] Del Nobile MA, Lucera A, Costa C, Conte A. Food applications of natural antimicrobial compounds. Front Microbiol 2012;3:287.
[69] Irkin R, Esmer OK. Novel food packaging systems with natural antimicrobial agents. J Food Sci Technol 2015;52(10):6095–111.
[70] Thielmann J, Theobald M, Wutz A, Krolo T, Buergy A, Niederhofer J, et al. Litsea cubeba fruit essential oil and its major constituent citral as volatile agents in an antimicrobial packaging material. Food Microbiol 2021;96(June 2020):103725.
[71] Khoshgozaran-Abras S, Azizi MH, Hamidy Z, Bagheripoor-Fallah N. Mechanical, physicochemical and color properties of chitosan based- films as a function of Aloe vera gel incorporation. Carbohydr Polym 2012;87(3):2058–62.
[72] Tummalapalli M, Berthet M, Verrier B, Deopura BL, Alam MS, Gupta B. Composite wound dressings of pectin and gelatin with aloe vera and curcumin as bioactive agents. Int J Biol Macromol 2016;82:104–13.
[73] Alven S, Khwaza V, Oyedeji OO, Aderibigbe BA. Polymer-based scaffolds loaded with aloe vera extract for the treatment of wounds. Pharmaceutics 2021;13(7):961.
[74] Pinzon MI, Garcia OR, Villa CC. The influence of Aloe vera gel incorporation on the physicochemical and mechanical properties of banana starch-chitosan edible films. J Sci Food Agric 2018;98(11):4042–9.
[75] Habeeb F, Shakir E, Bradbury F, Cameron P, Taravati MR, Drummond AJ, et al. Screening methods used to determine the anti-microbial properties of Aloe vera inner gel. Methods 2007;42(4):315–20.
[76] Lone MA, Dinisha M, Pooja M, Aarti D, Saxena RC. Antiinflammatory and antimicrobial activity of anthraquinone isolated from Aloe vera (Liliaceae). Asian J Chem 2009;21(3):1807–11.
[77] Cock IE. Antimicrobial activity of Aloe barbadensis Miller leaf gel components. Internet J Microbiol 2008;4(2):17.
[78] Nidiry ESJ, Ganeshan G, Lokesha AN. Antifungal activity of some extractives and constituents of Aloe vera. Res J Med Plant 2011;5(2):196–200.
[79] Nabigol A, Asghari A. Antifungal activity of Aloe vera gel on quality of minimally processed pomegranate arils. Int J Agron Plant Prod 2013;4(4):833–8.
[80] Sui Chin S, Han Lyn F, Nur Hanani ZA. Effect of Aloe vera (Aloe barbadensis Miller) gel on the physical and functional properties of fish gelatin films as active packaging. Food Packag Shelf Life 2017;12(December 2016):128–34.
[81] Shweta C, Gupta KC, Mukesh A. Application of biodegradable Aloe vera gel to control post harvest decay and longer the shelf life of grapes. Int J Curr Microbiol Appl Sci 2014;3(3):632–42.
[82] Purwanti N, Yunus F, Darmawati E. Synthesis and characterization of aloe vera-based edible film incorporated with shellac resin and hydrocolloids. IOP Conf Ser Mater Sci Eng 2019;557(1):012076.
[83] Razali RM, Ganeson K, Mubarak A. Preparation and characterization of edible Aloe vera films incorporated with cinnamon oil for fruits and vegetables coating. Malays Appl Biol 2017;46(4):171–8.
[84] De Castro ML, Garcıa-Ayuso LE. Soxhlet extraction of solid materials: an outdated technique with a promising innovative future. Analytica Chimica Acta 1998;369(1–2):1–10.
[85] Nafiu MO, Hamid AA, Muritala HF, Adeyemi SB. Preparation, standardization, and quality control of medicinal plants in Africa. Medicinal spices and vegetables from Africa. 2017. p. 171–204.
[86] Mohan Raj R, Duraisamy N, Raj V. Drug loaded chitosan/aloe vera nanocomposite on Ti for orthopedic applications. Mater Today: Proc 2020. In press.
[87] Saniasiaya J, Salim R, Mohamad I, Harun A. Antifungal effect of Malaysian aloe vera leaf extract on selected fungal species of pathogenic otomycosis species in in vitro culture medium. Oman Med J 2017;32(1):41–6.
[88] Yuharmon NAS, Mohamed NM, Chong FK, Cheong KY. Scanning electron microscopy of soxhlet extracted aloe vera gel for electrolyte application. J Phys Conf Ser 2018;1123(1):012070.
[89] Ray A, Dutta Gupta S, Ghosh S, Aswatha SM, Kabi B. Chemometric studies on mineral distribution and microstructure analysis of freeze-dried Aloe vera L. gel at different harvesting regimens. Ind Crop Prod 2013;51:194–201.
[90] Gulia A, Sharma HK, Sarkar BC, Upadhyay A, Shitandi A. Changes in physico-chemical and functional properties during convective drying of aloe vera (Aloe barbadensis) leaves. Food Bioprod Process 2010;88(2–3):161–4.
[91] Santacruz-Vázquez V, Santacruz-Vázquez C, Laguna Cortés JO. Physical characterization of freeze-dried foam prepared from aloe vera gel and guar gum. Revista Vitae 2015;22(2):75–86.
[92] Silva SS, Oliveira MB, Mano JF, Reis RL. Bio-inspired Aloe vera sponges for biomedical applications. Carbohydr Polym 2014;112:264–70.

[93] Chakraborty R, Bera M, Mukhopadhyay P, Bhattacharya P. Prediction of optimal conditions of infrared assisted freeze-drying of aloe vera (Aloe barbadensis) using response surface methodology. Separ Purif Technol 2011;80(2):375–84.
[94] Versino F, Lopez OV, Garcia MA, Zaritzky NE. Starch-based films and food coatings: an overview. Starch Staerke 2016;68:1026–37.
[95] López OV, García MA, Zaritzky NE. Film forming capacity of chemically modified corn starches. Carbohydr Polym 2008;73(4):573–81.
[96] Gutiérrez TJ, Álvarez K. Physico-chemical properties and in vitro digestibility of edible films made from plantain flour with added Aloe vera gel. J Funct Foods 2016;26:750–62.
[97] Kathiresan S, Lasekan O. Effects of glycerol and stearic acid on the performance of chickpea starch-based coatings applied to fresh-cut papaya. CyTA - J Food 2019;17(1):365–74.
[98] Wijaya W, Patel AR, Setiowati AD, Van der Meeren P. Functional colloids from proteins and polysaccharides for food applications. Trends Food Sci Technol 2017;68:56–69.
[99] Bastarrachea L, Dhawan S, Sablani SS. Engineering properties of polymeric-based antimicrobial films for food packaging. Food Eng Rev 2011;3(2):79–93.
[100] Silva-Weiss A, Bifani V, Ihl M, Sobral PJA, Gómez-Guillén MC. Structural properties of films and rheology of film-forming solutions based on chitosan and chitosan-starch blend enriched with murta leaf extract. Food Hydrocolloids 2013;31(2):458–66.
[101] Gutiérrez TJ, González G. Effect of cross-linking with aloe vera gel on surface and physicochemical properties of edible films made from plantain flour. Food Biophys 2017;12(1):11–22.
[102] Gutiérrez TJ, Morales NJ, Tapia MS, Pérez E, Famá L. Corn starch 80:20 "Waxy":regular, "native" and phosphated, as bio-matrixes for edible films. Proc Mater Sci 2015;8:304–10.
[103] Ahmad M, Hani NM, Nirmal NP, Fazial FF, Mohtar NF, Romli SR. Optical and thermo-mechanical properties of composite films based on fish gelatin/rice flour fabricated by casting technique. Prog Org Coating 2015;84:115–27.
[104] Moghaddasi S, Verma SK, Publications B. Aloe vera their chemicals composition and applications: a review. Int J Biol Med Res 2011;2(1):466–71.
[105] Rajisha KR, Deepa B, Pothan LA, Thomas S. Thermomechanical and spectroscopic characterization of natural fibre composites. Interface Eng Nat Fibre Compos Max Performance 2011:241–74.
[106] Bajer D, Janczak K, Bajer K. Novel starch/chitosan/aloe vera composites as promising biopackaging materials. J Polym Environ 2020;28(3):1021–39.
[107] Rawdkuen S. Edible films incorporated with active compounds: their properties and application. Active antimicrobial food packaging. Işıl Var and Sinan Uzunlu, IntechOpen; 2019. https://doi.org/10.5772/intechopen.80707. Available from: https://www.intechopen.com/books/active-antimicrobial-food- packaging/edible-films-incorporated-with-active-compounds-their-properties- and-application.
[108] Sartori T, Menegalli FC. Development and characterization of unripe banana starch films incorporated with solid lipid microparticles containing ascorbic acid. Food Hydrocolloids 2016;55:210–9.
[109] Abe K, Yano H. Comparison of the characteristics of cellulose microfibril aggregates of wood, rice straw and potato tuber. Cellulose 2009;16(6):1017–23.
[110] Panthapulakkal S, Sain M. Preparation and characterization of cellulose nanofibril films from wood fibre and their thermoplastic polycarbonate composites. Int J Polym Sci 2012.
[111] Valencia-Chamorro SA, Palou L, Delŕio MA, Pérez-Gago MB. Antimicrobial edible films and coatings for fresh and minimally processed fruits and vegetables: a review. Crit Rev Food Sci Nutr 2011;51(9):872–900.
[112] Jasso De Rodríguez D, Hernández-Castillo D, Rodríguez-García R, Angulo- Sánchez JL. Antifungal activity in vitro of Aloe vera pulp and liquid fraction against plant pathogenic fungi. Ind Crop Prod 2005;21(1):81–7.
[113] Pinzon MI, Sanchez LT, Garcia OR, Gutierrez R, Luna JC, Villa CC. Increasing shelf life of strawberries (Fragaria ssp) by using a banana starch-chitosan-Aloe vera gel composite edible coating. Int J Food Sci Technol 2020;55(1):92–8.
[114] Hajji S, Younes I, Affes S, Boufi S, Nasri M. Optimization of the formulation of chitosan edible coatings supplemented with carotenoproteins and their use for extending strawberries postharvest life. Food Hydrocolloids 2018;83:375–92.
[115] Sánchez-Ortega I, García-Almendárez BE, Santos-López EM, Reyes-González LR, Regalado C. Characterization and antimicrobial effect of starch-based edible coating suspensions. Food Hydrocolloids 2016;52:906–13.
[116] Al-Ahbabi HH, Al-Ahbab A,H, amer M, Hasson O, abed S,WF, Jassim M. Antimicrobial activity of aloe vera extract on cases of keratoconjunctivitisin sheep (in vivo and invitro study) and compared with penicillin –streptomycin. Basrah J Vet Res 2016;15(2):227–45.
[117] Bendjedid S, Lekmine S, Tadjine A, Djelloul R, Bensouici C. Analysis of phytochemical constituents, antibacterial, antioxidant, photoprotective activities and cytotoxic effect of leaves extracts and fractions of Aloe vera. Biocatalysis Agri Biotechnol 2021;33:10991.
[118] Gidik H, Bedek G, Dupont D. Developing thermophysical sensors with textile auxiliary wall. In: Smart textiles and their applications. Woodhead Publishing; 2016. p. 423–53.

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