Scaling up difficulties and commercial aspects of edible films for food packaging: A review

Jeevahan Jeya, M. Chandrasekaran, S.P. Venkatesan, V. Sriram, Joseph G. Britto, G. Mageshwaran, R.B. Durairaj

PII: S0924-2244(20)30443-X

DOI: https://doi.org/10.1016/j.tifs.2020.04.014

Reference: TIFS 2827

To appear in: *Trends in Food Science & Technology*

Received Date: 24 December 2019

Revised Date: 9 February 2020

Accepted Date: 18 April 2020

Please cite this article as: Jeya, J., Chandrasekaran, M., Venkatesan, S.P., Sriram, V., Britto, J.G., Mageshwaran, G., Durairaj, R.B., Scaling up difficulties and commercial aspects of edible films for food packaging: A review, *Trends in Food Science & Technology* (2020), doi: https://doi.org/10.1016/j.tifs.2020.04.014.

Scaling up difficulties and commercial aspects of edible films for food packaging: a review

[1*]Jeya Jeevahan, [2]Chandrasekaran M, [1]Venkatesan SP, [1]Sriram V, [1]Britto Joseph G, [1]Mageshwaran G, [1]Durairaj RB

[1]School of Mechanical Engineering, Sathyabama Institute of Science and Technology, Chennai, India - 600119.
[2]School of Mechanical Engineering, Vels Institute of Science, Technology, and Advanced Studies, Chennai, India - 600116.

Corresponding author's email ID: jeya.jeevahan@gmail.com

ABSTRACT:
Background: Edible food packaging, produced from edible polymers, is a kind of packaging suitable for human consumption along with the contained food. Despite many advantages, the edible films are still produced in laboratory scale due to problems, such as lack of poor elongation, safety and health issues, high cost, processing difficulties, etc. It is essential to overcome these difficulties for scaling up the production to industrial scale and making the edible films commercially successful.
Scope & approach: Even though some reviews on edible films and coatings have little discussed, there is no dedicated article on scaling up difficulties and commercial aspects of edible films. This article reviews the research progress, confronting problems, and research opportunities ahead for the industrial scaling up and commercial success for edible films in food packaging.
Key findings & conclusions: Incorporation of plasticizer, production of multilayers, composites, and nanocomposite films improved the properties significantly, but some fundamental research on the key factors are still not investigated. Current laboratory scale production of edible films has problems like inability to make continuous films, long drying time and inaccurate thickness control, which must be addressed before the industrial scaling up production. Lack of evidence on edibility, biodegradability, toxicological and health effects, inadequate marketing, lack of awareness, cultural issues, can affect the food safety and customer acceptance. Future research must address all these problems from the view of industrial scaling up and commercial aspects in order to make the industrially viable and commercially successful edible films.

Keywords: food packaging; edible films; commercialization; scaling up difficulties; customer acceptance; nanotechnology.

Highlights:
- Composite films are stronger and effective than neat and multi-layer edible films.
- Continuous film forming and fast drying are essential for industrial scale-up.
- Nanotechnology offers competitive film properties but needs more research.
- Lack of biodegradability and edibility tests questions film consumer's safety.
- Marketing strategies and low cost production increase consumer acceptance.

1. INTRODUCTION:

Edible packaging is a kind of packaging suitable for human consumption. By definition, edible packaging is a thin layer either formed directly on food surface or formed separately as thin sheet/ film and wrapped over the food surface later. The former is called as edible coating, and the later is called as edible film. Edible packaging is made from human consumable ingredients having ability to form a continuous and cohesive network, and as it can be eaten along with the contained food/ beverage, the waste disposal problem is almost zero. Even if it is not eaten, it degrades faster compared to both synthetic as well as biodegradable packaging materials, and it can reduce the requirement of landfills greatly. As the packaging materials are safe for human consumption, transmission of packaging molecules into food does not create any health issues. Due to these advantages, undoubtedly, the edible packaging has drawn much attention to replace synthetic and biodegradable plastic packaging in food packaging applications (Shit & Shah, 2014; Guilbert, Gontard & Cuq, 1995). Polysaccharides, proteins and lipids are the traditional polymers used for the preparation of edible films and coatings. The edible films produced from polysaccharides are good gas barriers but they show poor resistance to water vapors and poor mechanical strength. The films produced from proteins also show poor resistance to water vapors, but they show good mechanical strength. Lipids, on the other hand, are show good resistance to water vapors, but are not capable of making self-supporting structures, and they cannot be used for making edible films. Lipids are therefore used for edible coating applications or as an additive along with polysaccharide and/ or protein films in order to make the edible composite films (Jeevahan et al., 2017; Jeevahan & Chandrasekaran, 2019a).

A good edible film should meet some requirements, such as excellent sensory qualities, high barrier properties, high mechanical strength, high microbial stability, free of toxics, safe for health, simple to produce, non-polluting and low cost. The production of edible films is still in laboratory scale. There are many issues yet to be overcome for the commercial success of edible films. When compared to synthetic plastics, edible films suffer from mechanical strength (especially poor elongation), poor resistance to gases and liquids, lack of evaluation on edibility and biodegradability, processing scale up difficulties, etc. It is therefore essential to overcome these difficulties in order to make the edible films commercially successful (Debeaufort, Quezada-Gallo & Voilley, 1998; Otani et al., 2017). Reviews in this regard are very rare in literature. Some reviews on edible films and coatings, has discussions about the commercialization aspects, but in a very brief manner. A review, by Werner, Koontz & Goddard (2017), explained some aspects of commercialization related problems for active food packaging technologies. However, there is no dedicated article covering the challenges confronted to scaled up production and commercial success of edible films, in particular. Thus, this review article on commercial aspects of edible films is very important to the research community. In this article, the scaling up and commercialization aspects are divided into six sections, namely, (a) functional properties, (b) film making and drying methods, (c) nanotechnology on edible films, (d) lack of knowledge, and (e) consumer acceptance, each covering the research progress, confronting problems, and research opportunities ahead for the commercial success for edible films in food packaging applications.

2. FUNCTIONAL PROPERTIES:

The performance of edible films is typically evaluated by some important film characteristics, such as mechanical strength (TS - tensile strength, YM - Young's modulus, and EAB - elongation at break), water vapor transmission rate (WVTR) and film color. Mechanical strength is essential for protecting the contained food from the external loads. Barrier properties are essential for preventing transmission of liquids/ gases between the contained food and the environment. Film color is essential for improving

the acceptability of consumers. Table 1 shows the film characteristics of few edible films produced from polysaccharides and proteins reported in literature. Most of the unplasticized edible films are clear and transparent, which makes them more acceptable. Mechanical strength and barrier properties to water vapour and gases (oxygen and carbon dioxide, mainly) of unplasticized edible films are inferior to petroleum derived plastics. Edible films generally shows higher resistance to gases, but poor resistance to water vapours, as compared to plastic films, for example LDPE. While TS and YM of most edible films are comparable, EAB is very low compared to petroleum derived plastics. Hence, edible films are highly brittle, leading to poor flexibility. As most of the edible polymers are hydrophilic, edible films are sensitive to water vapors, causing water absorption and dimensional instability.

Plasticizers are added in the film forming solution to improve the film flexibility. The plasticizer molecules break the polymer-polymer interactions, and create the polymer-plasticizer interactions. As a result, the addition of plasticizer makes the edible film soft and flexible. In order to make the edible films, different kinds of food-grade polyols, glycols, sugars, and lipids are used as plasticizers. Table 2 shows the effects of different plasticizers on film properties of some edible films reported in literature. It is noted that the addition of plasticizer increased the film flexibility of edible films significantly. As the concentration of plasticizer increases, EAB increases with decreased TS and YM of the films and increased WVTR. Plasticizers are generally clear and odorless, and the addition of plasticizer, therefore, does not change the film color significantly. Even though the literature show that the type of plasticizer affects the film properties significantly, in fact, mixed results are found in literature. While polyols (such as glycerol and sorbitol) plasticized films produced soft, smooth, clear and homogeneous surface with good mechanical strength, glycol plasticized films produced hard, opaque and rough surface with relatively poor mechanical strength (Laohakunjit & Noomhorm, 2004). Sugars plasticized films showed higher crystallinity, higher mechanical strength and higher elongations, as compared to polyols and glycols (Edhirej et al., 2016; Zhang and Han, 2006; Saberi et al., 2017; Ploypetchara & Gohtani, 2018). On the other hand, there was no significant change in film properties were observed in the work of Galdeano et al. (2009). In addition to the mixed results, it should be noted that most research works were carried out with glycerol as plasticizer to make the edible films. However, other polyols, for example, sorbitol (Balqis et al., 2017;), glycols (El-Miri et al., 2018), sugars (Edhirej et al., 2016; Zhang and Han 2006; Saberi et al., 2017) were found to produce stronger and more stretchable edible films as compared to glycerol plasticized films. Therefore the effects of plasticizer type should be evaluated in order to understand their effects on film properties.

The mechanical and barrier properties of the unplasticized edible films can be improved by making the composite films in order to obtain the complementary benefits of each other. Table 3 shows the effects of composite films on the film properties. Composite films can be obtained as either emulsions or multi-layers. Multi-layer composite films usually consist of two or more layers of edible polymers. Studies shows that the production of multilayer edible films requires long production time, high energy consumption and high cost as two casting processes and two drying processes are required. The multilayer films, also, tend to delaminate over the time, causing problems like pinholes, cracks, surface non-uniformity, and reduced cohesion. These problems make the multilayer edible films less popular inspite of providing good WVTR. On the other hand, emulsion composite films consist of a lipid dispersed in a hydrocolloid matrix so that the structural integrity of the hydrophilic matrix and hydrophobic behavior of the lipid could be complemented in order to improve the functional properties of the resulting films than the neat hydrocolloid films.

Heat sealing is another important property required for a food packaging materials. In heat sealing operation, two films are brought between the heated dies, and, for the heat and pressure applied, the film surfaces melt and join surfaces in order to seal the adjoining pieces of the edible films. To evaluate the seal quality, the seal strength is used as an indicator (Lacroix, 2009). Table 4 shows heat sealability of some of the edible films. The findings show that the optimum heating temperature of edible films varies depending on the film composition, and the type of film forming materials, plasticizer and additives. The optimum heating temperature was approximately close to its onset temperature. All edible films were able to seal the films without decomposition near optimum heating temperature. However, if the heating is lower than the optimum heating temperature, the films delaminated. If higher, the films deform (Kim & Ustunol, 2001).

Apart from the comparable mechanical strength, heat sealability, and easy processing of edible films, the consumer acceptability also depends the sensory properties, such as film appearance, texture, taste, odour etc. Descriptive analysis is usually carried out to evaluate the sensory properties of edible films. A group of trained/ untrained people are given the edible films, the qualitative information on sensory properties are collected in a multi-point scale, and are then converted to determine the score/ rating for each sensory property. Table 4 shows some of the findings of sensory properties of edible films. Most of the findings shows that the sensory properties were affected by the edible films. As the edible films can be regarded as eatable along with the contained food, the sensory properties, of edible films as well as the interactions of edible films with the contained food/ the food additives, should be evaluated. As only limited research is found in this area, much attention is required to evaluate and assure the sensory properties in order to evaluate the consumer acceptability and commercial success of the edible films.

3. FILM MAKING AND DRYING METHODS:

Table 5 shows some of the research works carried out with different fabrication methods for making films. The casting method is generally used for producing films in the laboratory scale. Cast films contain significant amount of water that needs to be evaporated, which is regarded as high energy-consuming process. Dry methods do not require evaporation step. Hence, drying methods could save considerable time needed for drying (Thunwall et al., 2008). However, the film properties of such films are greatly affected by process parameters, such as barrel temperature, pressure at the die, screw speed, energy input, moisture content and die diameter. The post-extrusion methods, such as film blowing, injection molding and thermocompression, are also required in order to form specific film characteristics (Zhang, Remel & Liu, 2014; Thunwall et al., 2008; Fakhouri et al., 2013). Further investigation is required in order to understand the mechanism of film forming and to optimize the process conditions to make the industrial production of edible films.

Inability of making large sized films (>25 cm), long drying times (2-3 days) and inaccurate thickness control (local variations in thickness) make the current laboratory scale film makings methods unsuitable for scaling-up to industrial production. In order to make scaled-up production of edible films, there must be a need to develop continuous film making with less production time and high production rates (Zhang, Rempel & Liu, 2014). A continuous film making was fabricated by Moraes et al. (2013) using tape casting method, which is a variant of casting method. In this method, the film forming solution is spread onto a continuously moving support, and dried with the help of various drying modes (conduction by supports and/ or convection by circulation of hot air and infrared rays). The film properties of the resulting films were highly influenced by the drying methods and drying rates. Further

investigation is required to investigate and optimize the various parameters in order to make industrial scaled-up production of edible films.

According to All4pack report (2018), 63% of the packaging machines are owned by food and beverages industry. For the commercial making of edible films, the edible film making processes should use the existing machines and processes. However, the fabrication processes of edible films are different from those of synthetic plastics. For example, the gelatinization, spreading and drying processes of edible films are different from the synthetic plastic making processes, which use melting, spreading and curing processes. As a result, the film forming machinery and the processes are currently different from the existing infrastructure. Furthermore, complete replacement or major changes in machinery and equipments may not be encouraged by the packaging industry (Krochta & Mulder-Johnston, 1997). Special attention is required to develop the fabrication methods, which requires no or only minor changes in the existing infrastructure or machineries.

Table 6 shows the effects of drying methods investigated by researchers on edible films. Most of the lab-scale edible films are dried in evaporation mode using hot air drying, which is a very slow process (2-3 days). But, fairly rapid drying process should be developed in order to scale-up to industrial-scale. From the table, it is observed that depending on the temperature of hot air, the conventional evaporation method usually takes more time for drying (from 12h to 54 h). The microwave drying could produce edible films in 5 min with no significant difference in WVP (Kaya & Kaya, 2000). Vacuum drying, conduction, infrared drying and low-pressure superheated steam drying produced films in less than two hours (Mayachiew & Devahastin, 2008; De Moraes and Laurindo, 2017; Ortiz et al., 2017). Another problem is the continuous production of edible films. In the work of Munhoz et al. (2018), a continuous film fabrication was proposed where a wet layer of film forming solution was first spread in a conveyor and dried using an IR pre-dryer and hot air drying. The total drying time was 7 min and productivity was 0.03 m^2 film/min. However, research on similar work requires immediate attention, and production of low cost and high productivity fabrication methods need to be established for the industrial scale production of edible films.

4. NANOTECHNOLOGY ON EDIBLE FILMS:

Nanotechnology is the current trend of research in almost all fields. The unique properties of nanomaterials could be used in food packaging as well. The food and beverage industry has already started investing and researching the applicability of nano-materials in food packaging (Jeevahan & Chandrasekaran, 2019a). Table 7 shows some of the works showing the effects of nanomaterials loaded on edible films. The results suggested that the addition of nanofillers improved the mechanical strength with improved transparency and reduced WVTR.

Most of the research works used nanomaterials as reinforcement in macroscale edible materials to produce nano edible films. Only limited research was carried out to find the effects of nanomaterials as both matrix and fillers to make the complete nano edible films. Taniguchi and Okamura (1998) produced complete nanocellulose films from cellulose nanofibrils that showed 2-3 times higher mechanical strength than LDPE films. Leitner et al. (2007) produced nanocellulose based complete edible films that exhibited TS of 104 MPa and YM of 9 GPa, respectively. However, these kinds of research with all nano-scaled edible polymer films are rarely found in literature. Future investigation is required to produce and investigate the complete nanomaterials based edible films.

The right selection of isolation method and making up of the homogenous dispersion of nanomaterials in matrix are a bit of challenges for making the efficient edible films. Despite the addition of nanomaterials is considered to show the environmental benefits, isolation process of nanomaterials uses high energy consumption and costly chemicals, which affect the economic and environmental values of nanocomposite edible films. In addition, the effects of surface modifications and edibility after surface modifications should also be evaluated in order to ensure the safety of the films (Siqueira, Bras & Dufresne, 2010; Solans & Sole, 2012; Khalil et al., 2014). Most of the nanocomposite edible films are currently produced in laboratory scale. In order to make the transition into industrial scale production, the development of new or improved fabrication methods to reduce the use of toxic chemicals, production cost, drying time, pretreatments, post treatments, surface modifications, energy utilization, and the overall preparation time of the nanocomposite edible films.

The addition of nanomaterials substantially improved the functional properties of the edible films. Since nanomaterials can easily penetrate human body, it can impart the toxicological effects and health risks on human body (Magnson, Jonaitis & Card, 2011). According to the Institute of Food Science and Technology (IFST), United Kingdom, the nanomaterials should be treated as potentially harmful unless clear evidence on safety are available. Hence, a good understanding of the toxicological effects, and adequate evidences on human health and environment are necessary, before nano-based edible films are used in food packaging.

5. LACK OF KNOWLEDGE:

Most of the research work on edible films investigated the effects of different biopolymer sources, plasticizer concentration and relative humidity on film properties. However, structure of edible polymers, their orientation, acid and base concentration, crystallinity index, degree of cohesion and adhesion, temperature and pressure, free volume, additives, film thickness etc. might influence the properties of edible films (Miller & Krochta, 1997). Very limited researchers have investigated the effects of some of these factors, and the effects of most of these factors are yet to be explored. In addition, only few works have carried out process optimization for batch production (Sharma & Singh, 2016; Sandhu et al., 2020). There is a need to optimize the process conditions for the continuous production of edible films which should also be established in near future. Barrier properties of edible films are commonly determined for its ability to resist water vapors, oxygen, and carbon dioxide. However, the permeability of food ingredients, such as flavors and oil permeability, are also very important for the food packaging applications, but the research on this area has very less attention (Han, 2014; Valencia-Chamorro et al., 2011). Most materials exhibit different material properties and behavior at different scales and hierarchical structures, and the understanding of the relationship among the material structure, properties and process are very important for designing edible packaging films with multi-functionalities (Mkandawire & Aryee, 2018). The future edible films and coatings can be multifunctional. In order to be used more effectively in food applications, the current and future edible films should serve several functions, such as heat-proof, water-proof, air-proof, anti-corrosive, oil-resistant, insect preventer, disease-resistant, etc. (Zhang et al., 2014).

Talking about mechanical strength of edible, not only tensile strength, but also the puncture strength, seal strength, tear strength, scratch resistance and light degradation etc. should be considered (Avena-Bustillos et al., 2017). However, most research works focused only on tensile strength indicating TS, YM and EAB of edible films. The film properties must be stable enough with respect to time to protect the contained food and offer long shelf life. But the edible films generally suffer during aging

(Mojumdar et al., 2011). There are only rare studies available in literature to study the impact of aging on film properties. It is, therefore, essential to explore the mechanisms that govern the time-dependent changes in film properties.

While storage temperature and processing temperature of food packaging vary from 20°C to 60°C, the most permeability data reported in literature were measured at room temperature, say 25°C. Therefore, the permeability given at ambient temperature cannot be considered for food packaging maintained at different storage/processing temperatures (Siracusa, 2012). Not only permeability of water vapors and gases, but also migration of residual monomers, plasticizers, food additives, printed inks, etc. may also affect the textural, nutritional and sensory properties of the contained food. Hence, other permeability data, such as oil permeability, aroma permeability, permeability of other additives and food components need to be measured (Kim-Kang, 1990; Li et al., 2015).

Beverage packaging is another important food packaging sector requiring high amount of packaging materials. Research on applicability of edible films for beverage packaging is not found in literature, except the one investigated by Rodríguez-Castellanos et al. (2015). In their work, the hydrolyzed corn starch–gelatin pellets with or without cellulose were first extruded to form the parison, and blow molded to form a 500 mL bottle. Blow-molded films showed the more uniform internal surface, while the external surface showed more porosity. The films were not so strong and are suspicious to show good barrier properties in the humid environment. Further research is required to produce edible films for beverages packaging.

Edible films should also be compatible to modern day packaging technologies. Food packaging generally acts as a barrier between food and environment. However, active food packaging, intelligent food packaging and smart packaging are some of the recent technologies adapted for food packaging. Active packaging allows some interactions between food and environment. (Ozdemir & Floros, 2004; Suppakul et al., 2003). Intelligent packaging monitors the food condition and provide information (Dainelli et al., 2008; Restuccia et al., 2010). Smart packaging, not only monitors, but also allows the user to track the food, monitor its condition, and control its environment. They use different sensors, indicators and radio frequency identification (RFID). However, integrating such thin film electronic devices onto edible films and inegrating these devices to communications systems are the big challenging areas and need further research (Schaefer & Cheung, 2018).

6. CONSUMER ACCEPTANCE

Consumers accept edible films only if they feel it as safe. Although researchers claim that edible films can be eaten along with the contained food, only limited investigations were supported with clear evidence on biodegradability and edibility of edible films (Janjarasskul & Krochta, 2010). Recent studies show that the film forming mechanism, film forming materials, type of plasticizer, additives, structural properties, composition, chain length, molecular arrangement, and crystallinity index can significantly affect the digestibility and digestion rates (Hubbe et al., 2017). Hernandez, Emaldi, & Tovar (2008) investigated the digestibility test and found the resistance to enzyme digestion of three starches and the edible films produced from them. The results showed that the edible films showed completely different digestibility rate from the native starches. Essential oils, which are generally regarded as safe (GRAS), are generally used in edible films to improve the antimicrobial properties. While low concentration of essential oils is beneficial, higher concentration of essential oils may cause serious toxicological effects and allergic reactions (Sanchez-Gonzalez et al., 2011). Research on

evaluating the biodegradability and edibility and assuring the safety is rarely found in literature, and extensive investigations are required to evaluate these properties.

The customer acceptability of edible films not only depends on the functional properties, but also other factors, such as film appearance, organoleptic properties, marketing, cost etc. Edible films should not affect the sensory properties and nutritional values of the contained food. They should appear transparent, colorless, odorless, tasteless, glossy, etc., and help food coloring, flavor, and concentrations of spices, acid, sweetener or salt (Han, 2014). However, much attention is required in order to improve the organoleptic properties. Lack of awareness and fear about edible films can reduce its acceptance. Marketing strategies, such as conducting awareness programs, price discounts, attractive offers and advertisements, might be helpful to attract consumers (Falguera et al., 2011; Janjarasskul & Krochta, 2010). The animal derived edible films may not be accepted by vegetarians and the people from religions that do not allow consumption of animal derived products. People, who wish to avoid the animal derived food products, may also have concerns to use edible films. Furthermore, if edible films contain any kinds of allergens, they may cause allergic reactions. The people may not accept the edible films fearing for the presence of such allergens. Proper labeling of any such known allergens could help improve the customer acceptance of the edible films. Thus, the regulatory bodies should emphasize food producers to label the required information about allergens and the presence of animal derived materials (Dhall, 2013). Consumers look onto the film properties from the personal point, and they are unlikely to look on the environmental or industrial benefits. Hence, instead of highlighting the environmental benefits, marketing and product development should understand the edible films from the consumers' point of view, and should improve the film properties in order to make the edible films to be adopted (Cheek & Wansink, 2016).

Different countries follow different regulations on food packaging materials. These variations can significantly affect the amount of data required for determining whether or not a substance can be cleared for food packaging use. European Directive and US regulations classify edible films and coatings as food products, food ingredients, food additives, food contact substances, or food packaging materials. Because edible films is considered as the integral part of the contained food, they must adhere to the regulations related to food products. Hence, for example, all ingredients used for making an edible film must attain Generally Recognized As Safe (GRAS) status, as per Food and Drug Administration (FDA) regulations (Dhall, 2013; Raybaudi-Massilia et al., 2016). According to EU regulation (EC) No. 1935/2004, all food contact materials and articles should meet the following four basic requirements: (a) they shall not endanger human health, (b) they shall not change the composition of the food in an unacceptable way, (c) they shall not change taste, odor, or texture of the food, and (d) thay shall be manufactured according to good manufacturing practice. According to this regulation, a materials will be authorized for food packaging only if no risk to human health is evidenced. However, safety evaluation on the inclusion of nanomaterials in food packaging and their toxicological effects are not mentioned clearly (EC/1935/2004; Restuccia et al., 2010). In United States, the USFDA provides list of food ingredients and food contact substances, and recommends that manufacturers to study and prepare a toxicological profile for each container with nanomaterials (USFDA 2014). It should also be noted that the term nanotechnology is defined in few countries like Australia/New Zealand, Canada, China and the EU only (Magnuson et al., 2013). There is a need of stating the regulations needed for the incorporation of nanomaterials. In addition, each country may have different list of approved materials suitable for edible film making. The material used in one country may not be approved in other countries. Hence, the food manufacturers supplying to another countries should consider the regulations of the other countries

and the film should be formed with the materials listed in the country's approved list of food materials. When food manufacturers produce the edible films, they should include all the ingredients used for the film formation on the labels of their food products. However, if they use edible film produced by another suppliers, the edible film suppliers should obtain clearance (no objection certificate) from the authorizing agencies before using them for packaging with proper labeling of materials, nutritional information and possible allergenicity (Han, 2014).

Last but not the least, cost is an important driving factor for the customer acceptance of edible films. Currently, the cost of edible films is as high as 10-50 times higher than the petroleum derived plastic films. However, as the production of edible films is in the development phase, and less quantities are produced, the high cost of edible films cannot be taken as a negative point at this moment (Debeaufort, Quezada-Gallo & Voilley, 1998). The total cost of the packaging should be less than 10% of the product cost. Proper cost-benefit analyses should be performed to justify the adaptation of edible films. The cost of the edible films should be lower than or equal to the petroleum derived plastics in order to attract the customers (Mihindukulasuriya & Lim, 2014).

SUMMARY AND FUTURE PERSPECTIVES:

In this article, industrial scaling up difficulties and commercialization related issues for the successful acceptability of edible films for food packaging were reviewed. The major findings are summarized as follows.

- Unplasticized edible films are brittle, and show inferior film properties than petroleum derived plastics. However, heat sealability and gas barrier properties are comparable to those of plastics. While incorporation of a plasticizer improves the film flexibility, production of multilayers, composites, and nanocomposite films improves the film properties. Further research is still required to bring superior film properties.
- Current laboratory scale production of edible films is unsuitable for scaling up to industrial scale due to problems such as inability of making continuous films, long drying time and inaccurate thickness control, high energy consumption and high cost. Future research must address these issues to scaling up production.
- Application of nanotechnology appears to improve the functional properties, but research on nanocomposite edible films is in its early stage. More research is required to investigate the application of nanomaterials and their toxicological effects.
- Most research focused on only few of the film properties, and many other properties were not investigated. Future edible film would be multifunctional and compatible to the modern packaging technologies. However, an extensive research is required on the fundamental research of the ignored factors and film properties.
- Lack of evidence on edibility and biodegradability, organoleptic aspects, insufficient legal aspects, fear of toxicological and health effects, inadequate marketing, public awareness and cultural issues, etc. can affect the consumer acceptance of edible films. Future research on edible films should also consider these aspects to improve the commercialization success.

From the above observations, future research seems to be directed to address all these problems from the view of industrial scaling up and commercial aspects in order to make the industrially viable and commercially successful edible films.

REFERENCES:

1. Abdorreza, M. N., Cheng, L. H., & Karim, A. A. (2011). Effects of plasticizers on thermal properties and heat sealability of sago starch films. Food Hydrocolloids, 25(1), 56–60. doi:10.1016/j.foodhyd.2010.05.005
2. Acevedo-Fani, A., Salvia-Trujillo, L., Rojas-Graü, M. A., & Martín-Belloso, O. (2015). Edible films from essential-oil-loaded nanoemulsions: Physicochemical characterization and antimicrobial properties. Food Hydrocolloids, 47, 168–177. doi:10.1016/j.foodhyd.2015.01.032
3. All4pack. (2018). Market key figures, challenges and perspecives of worldwide packaging, www.all4pack.com, accessed on 27 Nov 2019, 1-10.
4. Avena-Bustillos, C.G., R.J., Azeredo, H.M.C., Lorevice, M.V., Moura, M.R., Mattoso, L.H.C., & McHugh, T.H. (2017). Recent Advances on Edible Films Based on Fruits and Vegetables—A Review. Comprehensive Reviews in Food Science and Food Safety, 1-19.
5. Balqis, A. M. I., Nor Khaizura, M. A. R., Russly, A. R., & Nur Hanani, Z. A. (2017). Effects of plasticizers on the physicochemical properties of kappa-carrageenan films extracted from Eucheuma cottonii. International Journal of Biological Macromolecules, 103, 721–732. doi:10.1016/j.ijbiomac.2017.05.105
6. Basiak, E., Galus, S., & Lenart, A. (2014). Characterisation of composite edible films based on wheat starch and whey-protein isolate. International Journal of Food Science & Technology, 50(2), 372–380. doi:10.1111/ijfs.12628
7. Basiak, E., Lenart, A., & Debeaufort, F. (2017). Effect of starch type on the physico-chemical properties of edible films. International journal of biological macromolecules, 98, 348-356.
8. Carbone, M., Donia, D. T., Sabbatella, G., & Antiochia, R. (2016). Silver nanoparticles in polymeric matrices for fresh food packaging. Journal of King Saud University - Science, 28(4), 273–279. doi:10.1016/j.jksus.2016.05.004
9. Cárdenas, G., Díaz, J., Meléndrez, M. F., & Cruzat, C. (2008). Physicochemical properties of edible films from chitosan composites obtained by microwave heating. Polymer Bulletin, 61(6), 737–748. doi:10.1007/s00289-008-0994-7
10. Cheek, K.A., & Wansink, B. (2016). Making It Part of the Package: Edible Packaging Is More Acceptable to Young Consumers When It Is Integrated With Food. Journal of Food Products Marketing, 23(6), 723–732. doi:10.1080/10454446.2017.1244793
11. Chen, X., Cui, F., Zi, H., Zhou, Y., Liu, H., & Xiao, J. (2019). Development and characterization of a hydroxypropyl starch/zein bilayer edible film. International Journal of Biological Macromolecules. doi:10.1016/j.ijbiomac.2019.08.240
12. Cho, S. Y., Lee, S. Y., & Rhee, C. (2010). Edible oxygen barrier bilayer film pouches from corn zein and soy protein isolate for olive oil packaging. LWT - Food Science and Technology, 43(8), 1234–1239. doi:10.1016/j.lwt.2010.03.014
13. Chick, J., & Hernandez, R. J. (2002). Physical, Thermal, and Barrier Characterization of Casein-Wax-Based Edible Films. Journal of Food Science, 67(3), 1073–1079. doi:10.1111/j.1365-2621.2002.tb09455.x
14. Cho, S. Y., & Rhee, C. (2004). Mechanical properties and water vapor permeability of edible films made from fractionated soy proteins with ultrafiltration. LWT - Food Science and Technology, 37(8), 833–839. doi:10.1016/j.lwt.2004.03.009
15. Condés, M. C., Añón, M. C., Mauri, A. N., & Dufresne, A. (2015). Amaranth protein films reinforced with maize starch nanocrystals. Food Hydrocolloids, 47, 146–157. doi:10.1016/j.foodhyd.2015.01.026

16. Dai, L., Qiu, C., Xiong, L., & Sun, Q. (2015). Characterisation of corn starch-based films reinforced with taro starch nanoparticles. Food Chemistry, 174, 82–88. doi:10.1016/j.foodchem.2014.11.005
17. Dainelli, D., Gontard, N., Spyropoulos, D., Beuken, E.Z.D. and Tobback, P. (2008). Active and intelligent food packaging: legal aspects and safety concerns, Trends in Food Science & Technology, 19, S103-S112.
18. Das, M., & Chowdhury, T. (2016). Heat sealing property of starch based self-supporting edible films. Food Packaging and Shelf Life, 9, 64–68. doi:10.1016/j.fpsl.2016.05.002
19. De Moraes, J. O., & Laurindo, J. B. (2017). Properties of starch–cellulose fiber films produced by tape casting coupled with infrared radiation. Drying Technology, 36(7), 830–840. doi:10.1080/07373937.2017.1357568
20. Debeaufort, F., Quezada-Gallo, J.A., & Voilley, A. (1998). Edible Films and Coatings: Tomorrow's Packagings: A Review. Critical Reviews in Food Science and Nutrition, 38(4), 299-313.
21. Dhall, R.K. (2013). Advances in Edible Coatings for Fresh Fruits and Vegetables: A Review. Critical Reviews in Food Science and Nutrition, 53(5), 435-450
22. Du, W. X., Olsen, C. W., Avena-Bustillos, R. J., McHugh, T. H., Levin, C. E., & Friedman, M. (2008). Storage Stability and Antibacterial Activity against Escherichia coli O157:H7 of Carvacrol in Edible Apple Films Made by Two Different Casting Methods. Journal of Agricultural and Food Chemistry, 56(9), 3082–3088. doi:10.1021/jf703629s
23. EC/1935/2004 of the European Parliament and of the Council of 27.10.2004 on materials and articles intended to come into contact with food and repealing Directives 80/590/ EEC and 9/109/EEC. OJ L338, 13.11.2004
24. Edhirej, A., Sapuan, S. M., Jawaid, M., & Zahari, N. I. (2016). Effect of various plasticizers and concentration on the physical, thermal, mechanical, and structural properties of cassava-starch-based films. Starch - Stärke, 69(1-2), 1500366. doi:10.1002/star.201500366
25. Escamilla-García, M., Calderón-Domínguez, G., Chanona-Pérez, J., Mendoza-Madrigal, A., Di Pierro, P., García-Almendárez, B., … Regalado-González, C. (2017). Physical, Structural, Barrier, and Antifungal Characterization of Chitosan–Zein Edible Films with Added Essential Oils. International Journal of Molecular Sciences, 18(11), 2370. doi:10.3390/ijms18112370
26. Fakhouri, F.M., Costa, D., Yamashita, F., Martelli, S.M., Jesus, R.C., Alganer, K., Collares-Queiroz, F.P., & Innocentini-Mei, L.H. (2013). Comparative study of processing methods for starch/gelatin films. Carbohydrate Polymers, 95(2), 681-689.
27. Falguera, V., Quintero, J.P., Jimenez, A., Munoz, J.A., & Ibarz, A. (2011).Edible films and coatings: Structures, active functions and trends in their use. Trends in Food Science & Technology, 22, 292-303.
28. Fan, J.M., Ma, W., Liu, G.Q., Yin, S.W., Tang, C.-H., & Yang, X.-Q. (2014). Preparation and characterization of kidney bean protein isolate (KPI)–chitosan (CH) composite films prepared by ultrasonic pretreatment. Food Hydrocolloids, 36, 60–69. doi:10.1016/j.foodhyd.2013.08.024
29. Farhan, A., & Hani, N. M. (2017). Characterization of edible packaging films based on semi-refined kappa-carrageenan plasticized with glycerol and sorbitol. Food Hydrocolloids, 64, 48–58. doi:10.1016/j.foodhyd.2016.10.034
30. Galdeano, M. C., Mali, S., Grossmann, M. V. E., Yamashita, F., & García, M. A. (2009). Effects of plasticizers on the properties of oat starch films. Materials Science and Engineering: C, 29(2), 532–538. doi:10.1016/j.msec.2008.09.034

31. George, J., & Siddaramaiah. (2012). High performance edible nanocomposite films containing bacterial cellulose nanocrystals. Carbohydrate Polymers, 87(3), 2031–2037. doi:10.1016/j.carbpol.2011.10.019
32. Gheribi, R., Puchot, L., Verge, P., Jaoued-Grayaa, N., Mezni, M., Habibi, Y., & Khwaldia, K. (2018). Development of plasticized edible films from Opuntia ficus-indica mucilage: A comparative study of various polyol plasticizers. Carbohydrate Polymers, 190, 204–211. doi:10.1016/j.carbpol.2018.02.085
33. González-Seligra, P., Guz, L., Yepes, O.O., Goyanes, S., Fama, L. (2017). Influence of extrusion process conditions on starch film morphology. LWT - Food Science and Technology, doi: 10.1016/j.lwt.2017.06.027.
34. Guerrero, P., Retegi, A., Gabilondo, N., & de la Caba, K. (2010). Mechanical and thermal properties of soy protein films processed by casting and compression. Journal of Food Engineering, 100(1), 145–151. doi:10.1016/j.jfoodeng.2010.03.039
35. Guilbert, S., Gontard, N., & Cuq, B. (1995). Technology and Applications of Edible Protective Films. Packaging Technology and Science, 8, 339-346.
36. Han, J. H. (2014). Edible Films and Coatings. Innovations in Food Packaging, 213–255. doi:10.1016/b978-0-12-394601-0.00009-6
37. Hernandez, O., Emaldi, U., & Tovar, J. (2008). In vitro digestibility of edible films from various starch sources. Carbohydrate Polymers, 71, 648–655.
38. Hosseini, S. F., Rezaei, M., Zandi, M., & Farahmandghavi, F. (2015). Fabrication of bio-nanocomposite films based on fish gelatin reinforced with chitosan nanoparticles. Food Hydrocolloids, 44, 172–182. doi:10.1016/j.foodhyd.2014.09.004
39. Hubbe, M. A., Ferrer, A., Tyagi, P., Yin, Y., Salas, C., Pal, L., & Rojas, O. J. (2017). Nanocellulose in Thin Films, Coatings, and Plies for Packaging Applications: A Review. BioResources, 12(1). doi:10.15376/biores.12.1.2143-2233
40. Janjarasskul, T., & Krochta, J.M. (2010). Edible Packaging Materials. The Annual Review of Food Science and Technology, 1, 415–48.
41. Jeevahan, J., & Chandrasekaran, M. (2019a). Nanoedible films for food packaging: a review. Journal of Material Science, 54, 12290. https://doi.org/10.1007/s10853-019-03742-y
42. Jeevahan, J., & Chandrasekaran, M. (2019b). Influence of Nanocellulose Additive on the Film Properties of Native Rice Starch-based Edible Films for Food Packaging. Recent patents on nanotechnology, 13(3), 222-233.
43. Jeevahan, J., & Chandrasekaran, M. (2018). Effect of olive oil concentrations on film properties of edible composite films prepared from corn starch and olive oil. Research Journal of Pharmacy an Technology, 11:4934–4938.
44. Jeevahan, J., Chandrasekaran, M., Durairaj, R.B., Mageshwaran, G., Joseph, G.B. (2017). A brief review on edible packing materials. Journal of Global Engineering Problems and Soluttions 1, 9–19.
45. Kanmani, P., & Lim, S. T. (2013). Development and characterization of novel probiotic-residing pullulan/starch edible films. Food Chemistry, 141(2), 1041–1049. doi:10.1016/j.foodchem.2013.03.103
46. Kaya, S., & Kaya, A. (2000). Microwave drying effects on properties of whey protein isolate edible films. Journal of Food Engineering, 43(2), 91–96. doi:10.1016/s0260-8774(99)00136-3
47. Khalil, H. P. S.A, Davoudpour, Y., Islam, M. N., Mustapha, A., Sudesh, K., Dungani, R., & Jawaid, M. (2014). Production and modification of nanofibrillated cellulose using various

mechanical processes: A review. Carbohydrate Polymers, 99, 649–665. doi:10.1016/j.carbpol.2013.08.069
48. Kim-Kang, H. (1990). Volatiles in packaging materials, Critical Reviews in Food Science and Nutrition, 29(4), 255-271.
49. Kim, K. W., Ko, C. J., & Park, H. J. (2002). Mechanical Properties, Water Vapor Permeabilities and Solubilities of Highly Carboxymethylated Starch-Based Edible Films. Journal of Food Science, 67(1), 218–222. doi:10.1111/j.1365-2621.2002.tb11387.x
50. Kim, S.J., & Ustunol, Z. (2001a). Sensory Attributes of Whey Protein Isolate and Candelilla Wax Emulsion Edible Films. Journal of Food Science, 66(6), 909–911. doi:10.1111/j.1365-2621.2001.tb15195.x
51. Kim, S.J., & Ustunol, Z. (2001b). Thermal Properties, Heat Sealability and Seal Attributes of Whey Protein Isolate/ Lipid Emulsion Edible Films. Journal of Food Science, 66(7), 985–990. doi:10.1111/j.1365-2621.2001.tb08223.x
52. Krochta, J.M. and Mulder-Johnston, C.D. (1997). Edible and Biodegradable Polymer Films: Challenges and Opportunities, Food Technology, 51(2), 61-74.
53. Küçüközet, A. O., & Uslu, M. K. (2018). Cooking loss, tenderness, and sensory evaluation of chicken meat roasted after wrapping with edible films. Food Science and Technology International, 108201321877654. doi:10.1177/1082013218776540
54. Lacroix, M. (2009). Mechanical and Permeability Properties of Edible Films and Coatings for Food and Pharmaceutical Applications. Edible Films and Coatings for Food Applications, 347–366. doi:10.1007/978-0-387-92824-1_13
55. Laohakunjit, N., & Noomhorm, A. (2004). Effect of Plasticizers on Mechanical and Barrier Properties of Rice Starch Film. Starch - Stärke, 56(8), 348–356. doi:10.1002/star.200300249
56. Leitner, J., Hinterstoisser, B., Wastyn, M., Keckes, J., & Gindl, W. (2007). Sugar beet cellulose nanofibril-reinforced composites. Cellulose, 14(5), 419–425. doi:10.1007/s10570-007-9131-2
57. Leuangsukrerk, M., Phupoksakul, T., Tananuwong, K., Borompichaichartkul, C., & Janjarasskul, T. (2014). Properties of konjac glucomannan–whey protein isolate blend films. LWT - Food Science and Technology, 59(1), 94–100. doi:10.1016/j.lwt.2014.05.029
58. Li, J., Ye, F., Liu, J., & Zhao, G. (2015). Effects of octenylsuccination on physical, mechanical and moisture-proof properties of stretchable sweet potato starch film. Food Hydrocolloids, 46, 226–232. doi:10.1016/j.foodhyd.2014.12.017
59. Li, M., Liu, P., Zou, W., Xie, F., Yu, L., Pu, H., Liu, H., & Chen, L. (2011). Extrusion processing and characterization of edible starch films with different amylose contents. Journal of Food Engineering, 106(1), 95-101.
60. Li, X., Qiu, C., Ji, N., Sun, C., Xiong, L., & Sun, Q. (2015). Mechanical, barrier and morphological properties of starch nanocrystals-reinforced pea starch films. Carbohydrate Polymers, 121, 155–162. doi:10.1016/j.carbpol.2014.12.040
61. Magnuson, B., Munro, I., Abbot, P., Baldwin, N., Lopez-Garcia, R., Ly, K., ... & Socolovsky, S. (2013). Review of the regulation and safety assessment of food substances in various countries and jurisdictions. Food additives & contaminants: Part A, 30(7), 1147-1220.
62. Magnuson, B. A., Jonaitis, T. S., & Card, J. W. (2011). A brief review of the occurrence, use, and safety of food-related nanomaterials. Journal of food science, 76(6), R126-R133.
63. Mali, S., Grossmann, M. V. E., García, M. A., Martino, M. N., & Zaritzky, N. E. (2006). Effects of controlled storage on thermal, mechanical and barrier properties of plasticized films from different starch sources. Journal of Food Engineering, 75(4), 453–460. doi:10.1016/j.jfoodeng.2005.04.031

64. Martelli, M. R., Barros, T. T., de Moura, M. R., Mattoso, L. H. C., & Assis, O. B. G. (2012). Effect of Chitosan Nanoparticles and Pectin Content on Mechanical Properties and Water Vapor Permeability of Banana Puree Films. Journal of Food Science, 78(1), N98–N104. doi:10.1111/j.1750-3841.2012.03006.x
65. Mayachiew, P., & Devahastin, S. (2008). Comparative Evaluation of Physical Properties of Edible Chitosan Films Prepared by Different Drying Methods. Drying Technology, 26(2), 176–185. doi:10.1080/07373930701831309
66. Meenatchisundaram, S., Chandrasekar, C. M., Udayasoorian, L. P., Kavindapadi Rajasekaran, R., Kesavan, R. K., Srinivasan, B., & Muthusamy, S. (2016). Effect of spice□incorporated starch edible film wrapping on shelf life of white shrimps stored at different temperatures. Journal of the Science of Food and Agriculture, 96(12), 4268-4275.
67. Mihindukulasuriya, S. D. F., & Lim, L.-T. (2014). Nanotechnology development in food packaging: A review. Trends in Food Science & Technology, 40(2), 149–167. doi:10.1016/j.tifs.2014.09.009
68. Miller, K.S., & Krochta, J.M. (1997). Oxygen and Aroma Barrier Properties of Edible Films: A Review. Trends in Food Science & Technology, 8, 228-237.
69. Mkandawire, M., & Aryee, A. N. (2018). Resurfacing and modernization of edible packaging material technology. Current Opinion in Food Science, 19, 104–112. doi:10.1016/j.cofs.2018.03.010
70. Mohammadi, R., Mohammadifar, M. A., Rouhi, M., Kariminejad, M., Mortazavian, A. M., Sadeghi, E., & Hasanvand, S. (2018). Physico-mechanical and structural properties of eggshell membrane gelatin- chitosan blend edible films. International Journal of Biological Macromolecules, 107, 406–412. doi:10.1016/j.ijbiomac.2017.09.003
71. Mojumdar, S. C., Moresoli, C., Simon, L. C., & Legge, R. L. (2011). Edible wheat gluten (WG) protein films. Journal of Thermal Analysis and Calorimetry, 104(3), 929–936. doi:10.1007/s10973-011-1491-z
72. Moraes, J.O.d., Scheibe, A.S., Sereno, A., & Laurindo, J.B. (2013). Scale-up of the production of cassava starch based films using Tape-casting, Journal of Food Engineering, 119(4), 800-808.
73. Mościcki, L., Mitrus, M., Wójtowicz, A., Oniszczuk, T., Rejak, A., & Janssen, L. (2012). Application of extrusion-cooking for processing of thermoplastic starch (TPS). Food Research International, 47, 291–299.
74. Munhoz, D. R., Moreira, F. K. V., Bresolin, J. D., Bernardo, M. P., De Sousa, C. P., & Mattoso, L. H. C. (2018). Sustainable Production and In vitro Biodegradability of Edible Films from Yellow Passion Fruit Coproducts via Continuous Casting. ACS Sustainable Chemistry & Engineering, 6(8), 9883–9892. doi:10.1021/acssuschemeng.8b01101
75. Nagar, M., Sharanagat, V. S., Kumar, Y., & Singh, L. (2019). Development and characterization of elephant foot yam starch–hydrocolloids based edible packaging film: physical, optical, thermal and barrier properties. Journal of Food Science and Technology, 1-11.
76. Nilsuwan, K., Benjakul, S., & Prodpran, T. (2017). Properties, Microstructure and Heat Seal Ability of Bilayer Films Based on Fish Gelatin and Emulsified Gelatin Films. Food Biophysics, 12(2), 234–243. doi:10.1007/s11483-017-9479-2
77. Ortiz, C. M., de Moraes, J. O., Vicente, A. R., Laurindo, J. B., & Mauri, A. N. (2017). Scale-up of the production of soy (Glycine max L.) protein films using tape casting: Formulation of film-forming suspension and drying conditions. Food Hydrocolloids, 66, 110–117. doi:10.1016/j.foodhyd.2016.12.029

78. Otoni, C. G., Avena-Bustillos, R. J., Azeredo, H. M. C., Lorevice, M. V., Moura, M. R., Mattoso, L. H. C., & McHugh, T. H. (2017). Recent Advances on Edible Films Based on Fruits and Vegetables-A Review. Comprehensive Reviews in Food Science and Food Safety, 16(5), 1151–1169. doi:10.1111/1541-4337.12281.
79. Ozdemir, M., & Floros, J.D. (2004). Active Food Packaging Technologies. Critical Reviews in Food Science and Nutrition, 44(3), 185-193.
80. Ozdemir, M., & Floros, J. D. (2008). Optimization of edible whey protein films containing preservatives for water vapor permeability, water solubility and sensory characteristics. Journal of Food Engineering, 86(2), 215–224. doi:10.1016/j.jfoodeng.2007.09.028
81. Pereda, M., Amica, G., & Marcovich, N. E. (2012). Development and characterization of edible chitosan/olive oil emulsion films. Carbohydrate polymers, 87(2), 1318-1325.
82. Ploypetchara, T., & Gohtani, S. (2018). Effect of sugar on starch edible film properties: plasticized effect. Journal of Food Science and Technology, 55(9), 3757–3766. doi:10.1007/s13197-018-3307-7
83. Qin, Y., Zhang, S., Yu, J., Yang, J., Xiong, L., & Sun, Q. (2016). Effects of chitin nano-whiskers on the antibacterial and physicochemical properties of maize starch films. Carbohydrate Polymers, 147, 372–378. doi:10.1016/j.carbpol.2016.03.095
84. Rao, M. S., Kanatt, S. R., Chawla, S. P., & Sharma, A. (2010). Chitosan and guar gum composite films: Preparation, physical, mechanical and antimicrobial properties. Carbohydrate Polymers, 82(4), 1243–1247. doi:10.1016/j.carbpol.2010.06.058
85. Raybaudi-Massilia, R., Mosqueda-Melgar, J., Soliva-Fortuny, R., & Martín-Belloso, O. (2016). Combinational Edible Antimicrobial Films and Coatings. Antimicrobial Food Packaging, 633–646. doi:10.1016/b978-0-12-800723-5.00052-8
86. Restuccia, D., Spizzirri, U.G., Parisi, O.I., Cirillo, G., Curcio, M., Iemma, F., Puoci, F., Vinci, G., & Picci, N. (2010). New EU regulation aspects and global market of active and intelligent packaging for food industry applications. Food Control, 21, 1425–1435.
87. Rodríguez-Castellanos, W., Martínez-Bustos, F., Denis Rodrigue, D., & Trujillo-Barragán, M. (2015). Extrusion blow molding of a starch–gelatin polymer matrix reinforced with cellulose. European Polymer Journal, 73, 335–343.
88. Rompothi, O., Pradipasena, P., Tananuwong, K., Somwangthanaroj, A., & Janjarasskul, T. (2017). Development of non-water soluble, ductile mung bean starch based edible film with oxygen barrier and heat sealability. Carbohydrate Polymers, 157, 748–756. doi:10.1016/j.carbpol.2016.09.007.
89. Rosa, R.C.R.S., & Andrade, C.T. (2004). Effect of Chitin Addition on Injection-Molded Thermoplastic Corn Starch. Journal of Applied Polymer Science, 92, 2706–2713.
90. Saberi, B., Chockchaisawasdee, S., Golding, J. B., Scarlett, C. J., & Stathopoulos, C. E. (2017). Physical and mechanical properties of a new edible film made of pea starch and guar gum as affected by glycols, sugars and polyols. International Journal of Biological Macromolecules, 104, 345–359. doi:10.1016/j.ijbiomac.2017.06.051
91. Sablani, S. S., Dasse, F., Bastarrachea, L., Dhawan, S., Hendrix, K. M., & Min, S. C. (2009). Apple Peel-Based Edible Film Development Using a High-Pressure Homogenization. Journal of Food Science, 74(7), E372–E381. doi:10.1111/j.1750-3841.2009.01273.x
92. Salgado, P. R., López-Caballero, M. E., Gómez-Guillén, M. C., Mauri, A. N., & Montero, M. P. (2013). Sunflower protein films incorporated with clove essential oil have potential application for the preservation of fish patties. Food Hydrocolloids, 33(1), 74–84. doi:10.1016/j.foodhyd.2013.02.008

93. Sanchez-Gonzalez, L., Vargas, M., Gonzalez-Martınez, C., Chiralt, A., & Chafer, M. (2011). Use of Essential Oils in Bioactive Edible Coatings. Food Eng. Rev., 3, 1–16.
94. Sangroniz, A., Zhu, J.-B., Tang, X., Etxeberria, A., Chen, E. Y.-X., & Sardon, H. (2019). Packaging materials with desired mechanical and barrier properties and full chemical recyclability. Nature Communications, 10(1). doi:10.1038/s41467-019-11525-x
95. Sandhu, K. S., Sharma, L., Kaur, M., & Kaur, R. (2020). Physical, structural and thermal properties of composite edible films prepared from pearl millet starch and carrageenan gum: Process optimization using response surface methodology. International Journal of Biological Macromolecules, 143, 704-713.
96. Schaefer, D., & Cheung, W. M. (2018). Smart Packaging: Opportunities and Challenges. Procedia CIRP, 72, 1022–1027. doi:10.1016/j.procir.2018.03.240
97. Shankar, S., & Rhim, J.-W. (2016). Preparation of nanocellulose from micro-crystalline cellulose: The effect on the performance and properties of agar-based composite films. Carbohydrate Polymers, 135, 18–26. doi:10.1016/j.carbpol.2015.08.082
98. Sharma, L., Sharma, H. K., & Saini, C. S. (2017). Edible films developed from carboxylic acid cross-linked sesame protein isolate: barrier, mechanical, thermal, crystalline and morphological properties. Journal of Food Science and Technology, 55(2), 532–539. doi:10.1007/s13197-017-2962-4.
99. Sharma, L., & Singh, C. (2016). Composite film developed from the blends of sesame protein isolate and gum rosin and their properties thereof. Polymer Composites, 39(5), 1480–1487. doi:10.1002/pc.24088.
100. Sharma, L., & Singh, C. (2016). Sesame protein based edible films: Development and characterization. Food Hydrocolloids, 61, 139-147.
101. Shit, S.C., & Shah, P.M. (2014). Edible Polymers: Challenges and Opportunities. J of Polymers, Article ID 427259, 13 pages.
102. Siqueira, G., Bras, J., & Dufresne, A. (2010). Cellulosic Bionanocomposites: A Review of Preparation, Properties and Applications. Polymers, 2(4), 728–765. doi:10.3390/polym2040728
103. Siracusa, V. (2012). Food Packaging Permeability Behaviour: A Report, Int J. of Polymer Science, 2012, Article ID 302029, 11 Pages.
104. Solans, C., & Solé, I. (2012). Nano-emulsions: Formation by low-energy methods. Current Opinion in Colloid & Interface Science, 17(5), 246–254.doi:10.1016/j.cocis.2012.07.003
105. Soni, A., Gurunathan, K., Mendiratta, S. K., Talukder, S., Jaiswal, R. K., & Sharma, H. (2018). Effect of essential oils incorporated edible film on quality and storage stability of chicken patties at refrigeration temperature (4 ± 1 °C). Journal of Food Science and Technology, 55(9), 3538–3546. doi:10.1007/s13197-018-3279-7
106. Sun, Q., Sun, C., & Xiong, L. (2013). Mechanical, barrier and morphological properties of pea starch and peanut protein isolate blend films. Carbohydrate Polymers, 98(1), 630–637. doi:10.1016/j.carbpol.2013.06.040
107. Suppakul, P., Miltz, J., Sonneveld, K., & Bigger, S.W. (2003). Active Packaging Technologies with an Emphasis on Antimicrobial Packaging and its Applications. Journal of Food Science, 68(2), 408-420.
108. Tabari, M. (2018). Characterization of a new biodegradable edible film based on Sago Starch loaded with Carboxymethyl Cellulose nanoparticles. Nanomedicine Research Journal, 3(1), 25-30.
109. Talja, R. A., Helén, H., Roos, Y. H., & Jouppila, K. (2008). Effect of type and content of binary polyol mixtures on physical and mechanical properties of starch-based edible films. Carbohydrate Polymers, 71(2), 269–276. doi:10.1016/j.carbpol.2007.05.037.

110. Taniguchi, T., & Okamura, K. (1998). New films produced from microfibrillated natural fibres. Polymer International, 47(3), 291–294. doi:10.1002/(sici)1097-0126(199811)47:3<291::aid-pi11>3.0.co;2-1
111. Thunwall, M., Boldizar, A., & Rigdahl, M. (2006). Compression Molding and Tensile Properties of Thermoplastic Potato Starch Materials. Biomacromolecules, 7, 981-986.
112. Thunwall, M., Kuthanova, V., Boldizar, A., & Rigdahl, M. (2008). Film blowing of thermoplastic starch. Carbohydrate Polymers, 71, 583-590.
113. Tian, H., Xu, G., Yang, B., & Guo, G. (2011). Microstructure and mechanical properties of soy protein/agar blend films: Effect of composition and processing methods. Journal of Food Engineering, 107(1), 21–26. doi:10.1016/j.jfoodeng.2011.06.008
114. Valencia-Chamorro, S. A., Palou, L., del Río, M. A., & Pérez-Gago, M. B. (2011). Antimicrobial Edible Films and Coatings for Fresh and Minimally Processed Fruits and Vegetables: A Review. Critical Reviews in Food Science and Nutrition, 51(9), 872–900. doi:10.1080/10408398.2010.485705
115. Wan, V. C.H., Kim, M. S., & Lee, S.Y. (2006). Water Vapor Permeability and Mechanical Properties of Soy Protein Isolate Edible Films Composed of Different Plasticizer Combinations. Journal of Food Science, 70(6), e387–e391. doi:10.1111/j.1365-2621.2005.tb11443.x
116. Wang, X., Sun, X., Liu, H., Li, M., & Ma, Z. (2011). Barrier and mechanical properties of carrot puree films. Food and Bioproducts Processing, 89(2), 149–156. doi:10.1016/j.fbp.2010.03.012
117. Werner, B. G., Koontz, J. L., & Goddard, J. M. (2017). Hurdles to commercial translation of next generation active food packaging technologies. Current Opinion in Food Science, 16, 40–48. doi:10.1016/j.cofs.2017.07.007
118. Zhang, S., Gu, W., Cheng, Z., Ying Li, Y., & Gu, W. (2014). Development of Edible Packaging Materials. Advanced Materials Research, 904, 189-191.
119. Zhang, Y., & Han, J. H. (2006). Mechanical and Thermal Characteristics of Pea Starch Films Plasticized with Monosaccharides and Polyols. Journal of Food Science, 71(2), E109–E118. doi:10.1111/j.1365-2621.2006.tb08891.x
120. Zhang, Y., Rempel, C., & Liu, Q. (2014). Thermoplastic Starch Processing and Characteristics—A Review. Critical Reviews in Food Science and Nutrition, 54(10), 1353-1370.
121. Zuo, G., Song, X., Chen, F., & Shen, Z. (2017). Physical and structural characterization of edible bilayer films made with zein and corn-wheat starch. Journal of the Saudi Society of Agricultural Sciences. doi:10.1016/j.jssas.2017.09.005

FUNDING:
This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

DECLARATIONS OF INTEREST:
None.

SUBMISSION DECLARATION:
I declare that the content of this review article is complete and genuine, and is solely to submitted to this journal only. It is neither submitted nor under consideration in any other journal.

Table 1: Film properties of unplasticized edible films

Film Composition	Test Conditions	WVTR ($g.mm/m^2.day$)	O_2P (Barrer)	CO_2P (Barrer)	TS (MPa)	YM (MPa)	EAB (%)	L	a	b	Reference
PET	NA	1.49 ± 0.11	0.09 ± 0.0	0.5	45	610	335	NA	NA	NA	Sangroniz et al., 2019
LPDE		0.71 ± 0.12	5.42 ± 0.18	6.3	12 ± 0.4	88.4 ± 5.7	510 ± 30				
PHB		0.5 ± 0.08	0.01 ± 0.003	NA	37 ± 5.0	5460 ± 340	0.7 ± 0.0				
PLA		5.7 ± 0.50	0.26 ± 0.01	1.2	54.2 ± 4.0	3520 ± 270	3.6 ± 0.5				
Pea starch	0.104 mm, 25°C, 0/100% RH	15.37 ± 0.15	NA	NA	5.76 ± 0.02	21.15 ± 0.25	29.23 ± 0.56	86.93 ± 0.15	1.15 ± 0.01	2.10 ± 0.02	Li et al., 2015
Elephant Foot Yam Starch	0.163 mm, 25°C, 0/75% RH	389.03	NA	NA	15.81 ± 0.90	54.08 ± 4.16	23.96 ± 3.87	35.12 ± 0.90	0.36 ± 0.28	-2.49 ± 0.15	Nagar et al., 2019
κ-carrageenan	0.057 ± 0.001 mm	12.4 ± 0.23	1.82 ± 0.10	NA	40.30 ± 3.95	NA	1.77 ± 0.33	93.88 ± 0.13	−0.23 ± 0.01	4.00 ± 0.18	Farhan & Hani, 2017
Sesame protein isolate	0.15 mm, 25°C	1.58 ± 0.04	NA	NA	3.56 ± 0.08	0.147 ± 0.001	5.00 ± 0.25	NA	NA	NA	Sharma, Sharma & Saini, 2017; Sharma & Singh, 2016
Basil seed gum	0.058 mm, 25°C, 0/75% RH	1.69 ± 0.06	NA	NA	31.69 ± 0.43	NA	18.55 ± 2.44	64.34 ± 0.60	−0.57 ± 0.02	3.07 ± 0.19	Khazaei et al., 2014
Wheat Starch	0.087 mm, 25°C, 0/30% RH	72.3 ± 11	2.72 ± 0.68	NA	2.29 ± 0.33	NA	10.22 ± 0.81	95.62 ± 0.40	-0.20 ± 0.05	2.90 ± 0.16	Basiak, Galus & Lenart, 2014; Basiak, Lenart & Debeaufort, 2017
Whey protein	0.089 mm, 25°C, 0/30% RH	96.2 ± 4.77	3.03 ± 0.40	13.10 ± 0.70	8.90 ± 1.01	NA	13.12 ± 1.42	95.39 ± 0.25	0.15 ± 0.05	3.92 ± 0.35	
Corn Starch	0.08 mm, 25°C, 0/75% RH	70.3 ± 6.98	NA	NA	48 ± 4	1229 ± 390	2 ± 0.6	NA	NA	NA	Mali et al., 2006
Cassava Starch		76.6 ± 1.22	NA	NA	39 ± 2	868 ± 200	3 ± 1				
Yam Starch		71.9 ± 7.94	NA	NA	60 ± 5	1280 ± 50	2 ± 0.1				
Tapioca Starch	0.040 mm, 25°C, 0/84.5% RH	0.44 ± 0.00	NA	NA	3.58	NA	3.92	93.84 ± 0.07	-0.90 ± 0.03	3.22 ± 0.17	Kanmani & Lim, 2013
Gelatin	0.083 mm, 25°C, 0% RH	4.019 ± 0.16	NA	NA	32.521 ± 0.99		3.52 ± 0.74	NA	NA	NA	Mohammadi et al., 2018
Chitosan	0.035 mm, 25°C, 0/50% RH	144 ± 0.00	1.84 ± 0.4	NA	NA	NA	NA	47.90 ± 0.77	-2.37 ± 1.15	4.91 ± 0.32	Rao et al., 2010
Soy protein isolate	0.067 mm, 25°C, 0/50% RH	152.38 ± 1.10	NA	NA	3.2 ± 0.2		110.9 ± 6.2	88.22 ± 1.21	-0.68 ± 0.06	13.06 ± 0.09	Cho & Rhee, 2004
Peanut protein isolate	0.071 mm, 25°C, 67/1000% RH	4.132 ± 0.14	NA	NA	~1	NA	~27	81.82 ± 0.09	4.48 ± 0.02	11.8 ± 0.43	Sun, Sun & Xiong, 2013
Sunflower protein concentrate	0.070 mm, 20°C, 0/75% RH	20.75 ± 1.84	NA	NA	2.3 ± 0.4	0.22 ± 0.04	32.3 ± 3.9	30.85 ± 1.68	-2.64 ± 0.99	4.97 ± 1.04	Salgado et al., 2013
Banana puree	0.12 mm	115.26	NA	NA	2.7 ± 0.9	37 ± 6	13 ± 4	NA	NA	NA	Martelli et al., 2012
Carrot puree	~0.001mm, 25°C, 0/83% RH	298.67 ± 2.05	NA	NA	5.06 ± 0.26	NA	8.64 ± 0.56	43.61 ± 0.04	34.72 ± 0.07	43.65 ± 0.13	Wang et al., 2011

WVTR - Water vapour transmission rate, O_2P - Oxygen permeability, CO_2P - Carbon dioxide permeability, TS - Tensile strength, YM - Young's modulus, EAB - Elongation at break, PET - Polyethylene terephthalate, LDPE - Low-density polyethylene, PHB - Polyhydroxybutyrate, PLA - Polylactic acid, RH - Relative humidity, L - Whiteness colour parameter, a - Greenness-redness colour parameter, b - Blueness-yellowness colour parameter, NA - Data not available.

Table 2: Effects of plasticizers on edible films

Film Composition	Plasticizer	Effects on film properties	Reference
Effect of single plasticizer			
oat starch	glycerol, sorbitol, urea and sucrose	The film properties were not significantly affected by the plasticizer type.	Galdeano et al., 2009
pea starch cum guar gum	glycols (ethylene glycol, Propylene glycol, and polyethylene glycol 400), sugars (fructose, galactose, glucose and sucrose), and polyols (glycerol, sorbitol, mannitol, xylitol and maltitol)	All plasticized films were smooth, transparent and homogeneous, except the one formed with polyethylene glycol 400. Glycerol plasticized films produced better flexibility among other films. However, monosaccharides were suggested to have better film properties based on the optical, mechanical and barrier characteristics.	Saberi et al., 2017
pea starch	monosaccharides (mannose, glucose and fructose) and polyols (glycerol and sorbitol)	The monosaccharides produced stronger (high tensile strength) and highly stretchable films with lower WVP than the polyols.	Zhang & Han, 2006
cassava starch	fructose, triethylene glycol, urea and triethanolamine	Fructose plasticized films exhibited smooth surfaces with free of pores with high water resistance and high density compared to other plasicized films.	Edhirej et al., 2016
kappa-carrageenan	glycerol, sorbitol and polyethylene glycol 300	Glycerol plasticized films had higher thickness and higher moisture content compared to sorbitol plasticized films. Sorbital plasticized films showed better mechanical strength and better water barrier properties than glycerol plasticized films.	Balqis et al., 2017
native corn, waxy corn, native rice and waxy rice	sucrose, maltose and D-allulose	Sugars improved the crystallinity and homogenity of the edible films. However, the all sugar plasticized films showed the reduced breaking stress as compared to that of the films without plasticizers.	Ploypetchara & Gohtani, 2018
cellulose nanocrystals reinforced alginate	glycerol, diethylene glycol and polyethylene glycol	Glycerol plasticized alginate film showed lower mechanical strength, lower thermal properties and higher water sensitivity as compared to those of diethylene glycol and polyethylene glycol plasticized films.	El-Miri et al., 2018
Mucilage polysaccharide	glycerol, sorbitol and polyethylene glycol (200 and 400)	Sorbitol plasticized films were three times lower WVP than those of other films, whereas both sorbital plasticized films as well as polyethylene glycol plasticized films showed two times higher tensile strength than the glycerol plasticized films.	Gheribi et al., 2018
Effect of mixture of plasticizers			
Highly carboxymethylated starch (95g/5mlH_2O) + plasticizer (0.3g/100ml solution)	Glycerol, sorbitol, mannitol, xylitol (50:50, 33:33:33, 25:25:25:25)	While xylitol plasticized starch films showed the highest mechanical strength with moderate flexibility (TS: 13.0±5.0 MPa; EAB: 5.6±2.6 %), glycerol plasticized films showed moderate strength with highest flexibility (TS: 9.7±3.6 MPa; EAB: 7.7±1.9 %). The xylitol-glycerol (50:50) plasticized films showed the overall highest mechanical strength (TS: 19.1±3.7 MPa; EAB: 5.0±1.2 5%) in two plasticizer composition. Mannitol-xylitol-glycerol (33:33:33) plasticized films showed relatively higher mechanical strength (TS: 18.5±3.3 MPa; EAB: 8.8±2.7 %) in three plasticizer composition. Glycerol-sorbitol-mannitol-xylitol (25:25:25:25) plasticized films produced relatively lower mechanical strength (TS: 14.1±4.1 MPa; EAB: 3.9±1.0 %), but higher than single plasticizer.	Kim, Ko & Park, 2002
Pullulan + plasticizer (0.3g/100ml solution)		Sorbitol plasticized pullulan films showed the higher mechanical strength with lower flexibility (TS: 29.2±3.7 MPa; EAB: 2.6±0.8 %), but xylitol plasticized films showed lower mechanical strength with higher flexibility (TS: 15.7±2.9; EAB: 9.5±1.4 %). The addition of glycerol in either films increased the mechanical strength as well as film flexibility. The highest mechanical strength (TS: 36.3±6.7; EAB: 7.6±0.8 %) was observed in sorbitol-glycerol-xylitol (33:33:33) plasticizer composition.	
Potato starch + plasticizer	Glycerol–Xylitol (1:1) Glycerol–Sorbitol (1:1) Xylitol–Sorbitol (1:1)	Xylitol–Sorbitol plasticized films showed lower WVTR and higher mechanical properties (WVTR: 0.19 ± 0.03 g.mm/m^2.day) than unplasticized films (WVTR: 1.06 ± 0.18 g.mm/m^2.day), while the other two films showed higher WVTR than unplasticized films..	Talja et al., 2008
Soy protein isolate + plasticizer	Glycerol + propylene glycol/ polyethylene glycol/ sorbitol/ sucrose (0:100: 25:75, 50:50, and 75:25)	Glycerol-sorbitol (50:50) plasticized films showed comparatively low WVTR and relatively mechanical strength and high flexibility than the remaining films. Due to incompatibility, glycerol-polyethylene glycol plasticized film exhibited surface migration of polyethylene glycol from the film matrix.	Wan, Kim, & Lee, 2006

Table 3: Multi-layers and emulsion based composite films

Matrix	Filler/ Laminate	Properties without filler/ multilayer	Properties with filler/ multilayer	Reference
Composites:				
Lactic Casein (50%) + Sorbitol (35%)	Candelilla wax (30%)	TS: 6.2 ± 2.2; EAB: 156 ± 6; WVTR: 2.71 ± 0.72	TS: 7.9 ± 0.4; EAB: 31 ± 5; WVTR: 1.31 ± 0.00	Chick & Hernandez, 2002
	Carnauba wax (30%)		TS: 8.3 ± 2.5; EAB: 37 ± 12; WVTR: 0.83 ± 0.19	
Chitosan: Zein (1:1) + Glycerol (30%)	Cinnamon oil (250 ppm)	Tr: 88.4 ± 0.7; WVTR: 98.5 ± 5.4; YM: 66 ± 6	Tr: 69.3 ± 1.1; WVTR: 51.6 ± 6.74; YM: 24 ± 3	Escamilla-García et al., 2017
	Anise oil (250 ppm)		Tr: 72.6 ± 1.4; WVTR: 40.8 ± 3.37; YM: 22 ± 3	
	Orange oil (250 ppm)		Tr: 71.6 ± 1.1; WVTR: 54.6 ± 0.67; YM: 20 ± 2	
Chitosan (78.13%) + Glycerol (21.87%)	Olive oil (15 wt% Chitosan)	TS: 8.41±0.79; YM: 76.2±3.9; EAB: 19.55±3.38; WVTR: 163.8 ± 80.1	TS: 14.69±1.24; YM: 139.6±31.2; EAB: 32.90±4.13; WVTR: 125.0 ± 43.7	Pereda, Amica & Marcovich, 2012
Kidney bean protein isolate (5wt%)	Chitosan (40%)	TS: 2.96 ± 0.50; YM: 120.2 ± 8.8; EAB: 5.68 ± 1.20	TS: 3.96 ± 0.69; YM: 39.6 ± 2.8; EAB: 75.65 ± 11.64	Fan et al., 2014
Multilayers:				
Soy protein isolate	Corn zein	TS: 2.5 ± 0.5; EAB: 178.6 ± 19.7; WVTR: 128.7 ± 8.22	TS: 5.9 ± 0.4; EAB: 7.3 ± 2.0; WVTR: 83.54 ± 6.85	Chen et al., 2019
Corn-wheat starch	Corn zein	Whiteness: 93.92 ± 0.09; Opacity: 89.73 ± 0.06; TS: ~18 MPa;	Whiteness: 82.93 ± 0.27; Opacity: 88.13 ± 0.06; TS: ~9 MPa;	Zuo et al., 2017
Fish Gelatin	Gelatin emulsion	TS: 26.93 ± 3.05; EAB: 33.87 ± 4.57; WVTR: 1.94 ± 0.04	TS: 31.95 ± 1.11; EAB: 16.44 ± 1.84; WVTR: 1.34 ± 0.00	Nilsuwan, Benjakul & Prodpran, 2017

WVTR - Water vapour transmission rate in g.mm/m^2.day, Tr - Transparency in %, TS - Tensile strength in MPa, YM - Young's modulus in MPa, EAB - Elongation at break in %

Table 4: Other Functional Properties

Film Composition	Test Conditions	Effects on film properties	Reference
Sensory/ organoleptic Properties:			
Whey protein isolate + Sorbitol/ Glycerol + Candelilla wax	Film evaluation. 7.62 cm x 2.54 cm strips evaluated by sensory panel using 9 point scale	The films without candelilla wax were found to be clear and transparent, whereas candelilla wax containing films were opaque, slightly sweet, adhesive, and no distinctive milk odor.	Kim & Ustunol, 2001a.
Whey protein + Beewax + potassium sorbate + sorbitol	Film evaluation. Descriptive analysis with 150 mm line scale by sensory panels.	While the incorporation of beewax affected the stickiness and appearance strongly, the addition of potassium sorbate and sorbitol too affected them to a lesser extent	Ozdemir & Floros, 2008.
Clove and cinnamon-assimilated starch edible films	Food evaluation. Wrapped white shrimps stored at 10 and 4 °C at 5, 10, 15 and 20 days of storage using sensory panels. 9 & 5 point scales were used.	Edible film-wrapped shrimps stored at 4 °C showed good odour, taste and colour scores showing high acceptability of such films. However, they showed low texture and mouthfeel scores showing borderline acceptance.	Meenatchisundaram et al., 2016.
Carrageenan + oregano oil + thyme oil	Food evaluation. Wrapped chicken patties stored at 4 °C at 5, 10, 15, 20, 25 and 30 days of storage using sensory panels. 8 point scale was used. Served hot at 40-60 °C.	The essential oils incorporated films showed poor sensory properties as they are spoiled at the storage conditions. However, the control films without essential oils showed good scores up to 25 days in terms of appearance, colour, flavour, binding, texture, juiciness, and the overall acceptability.	Soni et al., 2018.
Sodium caseinate + potato starch + oleoresins (cumin and oregano oleoresin mixture)	Sensory evaluation of chicken thigh meat wrapped with edible films using pairwise ranking test. Stored at 4 °C for four days, and roasted at 200 °C for 30 min.	Wrapped meat samples were found to be tenderer and tastier than the control films. In addition, the meat samples wrapped with oleoresin incorporated edible films were ranked as most delicious.	Küçüközet & Uslu, 2018.
Heat Sealability:			
Mung bean starch + Glycerol/ Sorbitol	Impulse heating (with temperature of 68-85ºC and dwell time of 1 or 3 sec), Specimen size of 2.54x7.62 cm^2 using ASTM E88-07a	Optimum heat sealing was done at 70 °C with seal strength of up to 422.36+7.93 N/m.	Rompothi et al., 2017.
Whey protein isolate + sorbitol or glycerol + butterfat or candelilla wax	Impulse heating with temperature (110, 120 or 130 °C), pressure (296 or 445 kPa), and dwell time (1 or 3 s)	Optimum heat sealing temperature was found to be 130 °C for sorbitol plasticized films, and 110 °C for glycerol plasticized films. The seal strength of sorbitol plasticized films ranged from 105 to 301 N/m, whereas the glycerol plasticized films ranged from 141 to 323 N/m.	Kim & Ustunol, 2001b.
Sago starch + sorbitol-glycerol + carboxymethyl cellulose nanoparticles	ASTM F-88- 09 in a texture analyzer	Seal strength of the cast films without nanoparticles was found to be 321±33.5 N/m, and the addition 0.01g/g nanoparticles increased the seal strength up to 395±29.1 N/m.	Tabari, 2018.
Sago starch + sorbitol and/ or glycerol	Impulse heating (dwell time of 1 s, heat seal pressure of 1.8 x 105 Pa, and temperature of 110±10 °C), 7.62 x 2.5 cm strips with clamp distance of 2.5 cm were tested using ASTM F-88 with a texture analyzer.	Optimum sealing temperature is around 110±10 °C. The sorbitol plasticized films showed better heat sealability than glycerol plasticized films. The sorbitol/glycerol (3:1) exhibited the highest seal strength.	Abdorreza, Cheng & Karim, 2011.
Corn zein laminated on soy protein isolate + glycerol-sorbitol (1:1)	Impulse heating (size of 10 mm x 25 mm, under a pressure of 3 atm for dwell time of 3 s at temperatures of 85-155 °C), followed by texture analyzer at crosshead speed of 500 mm/min.	The resulting bilayer films were heat sealable at optimum temperatures of 120-130 °C, and produced a seal strength up to 300 N/m.	Cho, Lee & Rhee, 2010
Amylose, methylcellulose, and hydroxypropylmethylcellulose	Impulse heating (85-166 °C)	Amylose, methylcellulose, and hydroxypropylmethylcellulose edible films showed the maximum seal strength, at 166 °C, of 0.396, 0.211, and 0.385 N/mm, respectively.	Das & Chowdhury, 2016.
konjac glucomannan + whey protein isolate + glycerol	Heat sealed at an area of 2.54 x 1.5 cm (at 175 °C with heating time of 2.7 s and 5 s). ASTM F88 for seal strength.	The resulting edible films could be optimally heat sealed at 175 °C.	Leuangsukrerk et al., 2014

Table 5: Effects of film forming methods on edible films

Film Composition	Fabrication Method & Description	Effects of Fabrication Method	Reference
SPI + Glycerol (30%)	Casting (gelatinization at 80 °C for 30 min + room evaporation 48 h)	Freeze-dried films produced higher mechanical strength (TS: 7.7 ± 0.6 MPa, YM: 120.5 ± 5.3 MPa, EAB: 140.6 ± 13.3 %), as compared to compressed films (TS: 7.8 ± 0.5 MPa, YM: 114.2 ± 6.3 MPa, EAB: 132.4 ± 15.7) as well as cast films (TS: 4.1 ± 0.4 MPa, YM: 112.4 ± 5.3 MPa, EAB: 105.4 ± 13.3 %). However, when fabrication duration is concerned, the compression method was found to produce the optimum film properties with less time.	Guerrero et al., 2010
	Compression (at 150 °C and 12 MPa for 2 min), followed by cooling for 2 min.		
	Freeze-drying (to make powder) + Compression		
SPI + agar + glycerol (33%)	Casting (gelatinization at 95 °C for 30 min + Oven evaporation at 50 °C for 24 h)	The solution cast films produced more homogeneous films with higher TS (~10 Mpa for neat agar film) as compared to those of thermo-molded films (~25 MPa for neat agar film).	Tian et al., 2011
	Thermo-molding (gelatinization at 95 °C for 30 min + thermo-molding at 140 °C, 20 MPa for 10 min)		
Apple peel + Glycerol (30%)	Homogenization (Prehomogenization at 22,000 rpm for 5 min, stirring for 1-2 h, and high pressure homogenization at 138, 172 & 207 MPa) + casting (geletanization at 90°C for 30 min, followed by room evaporation at 23°C for 32 h)	The films produced at homogenizer pressure of 207 MPa were found to be more stretchable (TS: 4.63 MPa, YM: 71.41 MPa, EAB: 14.21%), while the films produced at homogenizer pressure of 138 MPa (TS: 9.18 MPa, YM: 149.76 MPa, EAB: 11.34 %) and 172 MPa (TS: 5.94 MPa, YM: 122.79 MPa, EAB: 10.89 %) produced strong films.	Sablani et al., 2009
Corn Starch (waxy corn starch of 4.3% amylose, regular corn of 29.0% amylose, Gelose 50 of 61.5% amylose and Gelose 80 of 77.4% amylose)	Extrusion (feeding starch and water, either separately or premixed, at a rate of 1.2–2.4 kg/h through a twin-extruder with screw speed of 30-120 rpm and different temperature zones)	The premixed composition requires lower torque and die pressure to produce the films, which are soft and produce homogeneous films than the separately fed films. The films produced from higher amylose starch showed better mechanical and thermal properties as compared to that of lower amylose starch.	Li et al., 2011
Potato starch and glycerol (80/20, 78/22,and 75/25)	Pellets extrusion (at 75-145°C and screw rotation of 60-100 rpm) + Injection molding (70–90 mm/s injection speed, 3s injection time, 100-180 °C) + Molding	Both injection molded and blown films showed good mechanical strength, for 22% glycerol.	Mościcki et al., 2012
	Pellets extrusion (at 75-145°C and screw rotation of 60-100 rpm) + Film blowing (with the compression ratio of 3, screw rotation of 90 rpm, 70–155 °C.		
cassava starch (amylose 18% and amylopectin 82%) and glycerol	Extrusion (twin-screw extruder, equipped with a cylindrical die of 4 mm, at 6-15 g/min feedrate, 0.5 mm gap, at 90-120°C and three screw rotations of 40 rpm, 80 rpm and 120 rpm) + Compression (140 °C and 56 kPa for 15 min)	While 80 rpm screw speed produced the homogeneous structures, the 120 rpm speed produced amorphous films with high mechanical strength (TS: 1.4 MPa, YM: 21 MPa, EAB: 65%).	González-Seligra et al., 2017
High-amylose potato starch and normal potato starch	Compression molding (temperature and pressure of 140 °C and 9 MPa, respectively, for 5 min)	films produced from high-amylose potato starch were found to exhibit higher tensile strength and elastic modulus as compared to that of normal potato starch. High-amylose potato starch also produced a higher melt viscosity requiring higher processing temperatures for improving the processibility.	Thunwall, Boldizar & Rigdahl, 2006
Corn starch, glycerol, water and chitin	Injection molding (pressure of 113 bar was heated electrically (three heating zones, to temperatures of 130, 130, and 145°C respectively) from feed zone to die end) + Cooling (with a closed refrigeration system maintained at 1275 bar)	The composite films having 30% chitin addition exhibited high mechanical strength (~6.1 MPa, YM: 1500 MPa, EAB: 3.5%).	Rosa & Andrade, 2004

WVTR - Water vapour transmission rate in g.mm/m^2.day, TS - Tensile strength in MPa, YM - Young's modulus in MPa, EAB - Elongation at break in %

Table 6: Effects of drying methods on edible films

Film Composition	Drying Method & Description	Effects of Drying Method	Reference
Chitosan + Glycerol (25%)	Casting (gelatinization and centrifugation + room evaporation at 30°C for 54 h)	The low pressure saturated steam dried films were more strong (TS: 69.1 ± 3.9 MPa; EAB: 24.7 ± 4.6%; WVTR: 26.02 ± 1.37 g.mm/m^2.day) and resistant to water vapors, compared to the vacuum dried films (TS: 32.8 ± 2.6; EAB: 19.2 ± 2; WVTR: 27.39 ± 4.11 g.mm/m^2.day), hot air dried films (TS: 36.5 ± 2.5; EAB: 23.1 ± 2.3; WVTR: 26.02 ± 2.74 g.mm/m^2.day) and cast films (TS: 40.2 ± 3.2; EAB: 23.5 ± 1.6; WVTR: 28.76 ± 1.37 g.mm/m^2.day).	Mayachiew & Devahastin, 2008
	Casting (gelatinization and centrifugation + hot air drying at 40°C for 54 h)		
	Gelatinization and centrifugation + Vacuum drying at 70°C and 10 kPa for 85 min)		
	Gelatinization and centrifugation + Low pressure superheated steam drying at 70°C and 10 kPa for 130 min)		
Chitosan + Acetic acid + Sorbitol (0.5%)	Casting (gelatinization at 75 °C for 30 min + air oven drying for 12 h at 35°C)	The cast films were good barriers to water vapors (WVTR: 3.23 ± 0.00 g.mm/m^2.day), as compared to microwave heat-dried films (WVTR: 2.97 ± 0.00 g.mm/m^2.day). However, this difference is not significant. Microwave heating is faster (about 6 times) than the air heating. Moreover, microwave heating exhibited the smooth surface and improved UV-vis light barrier properties.	Cárdenas et al., 2008
	Casting (gelatinization at 75 °C for 30 min + microwave heating for 10 min at 2450 MHz) + Air drying (for 2 h)		
WPI (10wt%/v) + Glycerol (50wt/wt%)	Casting (gelatinization at 90 °C for 15 min + Oven drying (at 20°C and 40% RH for 12h)	The microwave dried films showed better mechanical strength (TS: 2.43 ± 0.1 MPa, YM: 20.17±7 MPa, EAB: 35.9 ± 4.3), same water barrier properties (WVTR:41.84 ± 2.66 g.mm/m^2.day) and appearance (gloss: 96 ± 2), as compared to the oven dried films (TS: 2.28 ± 0.3 MPa, YM: 18.91± 5.3 MPa, EAB: 26.5 ± 3.1%, WVTR: 41.84 ± 2.66 g.mm/m^2.day, gloss: 87).	Kaya & Kaya, 2000
	Casting (gelatinization at 90 C for 15 min + Microwave heating (at 700 W and 2450 MHz for 5 min)		
SPI + Glycerol (30%)	Tape casting (Spreading at 1.8 cm/s and 2 mm thick, and heating through water circulating system at 60 °C) + hot air drying (at 60°C)	The infrared radiated films produced films with clear (opacity: 0.6±0.02 UA/mm), but slightly lower mechanical strength (TS: ~6 MPa, YM: ~60 MPa, EAB: ~2.2%) and water resistance (WVTR: 22.05 ± 9.31 g.mm/m^2.day), as compared to hot air dried films (opacity: 1.1 ± 0.001 UA/mm , TS: ~7.5 MPa, YM: ~45 MPa, EAB: ~4.2%, WVTR: 13.01 ± 2.88 g.mm/m^2.day).	Ortiz et al., 2017
	Tape casting (Spreading at 1.8 cm/s and 2 mm thick, and heating through water circulating system at 60 °C) + infrared radiation (at 60°C with eight 150 W lamps producing 42.3 W/m^2 heat flux for 200 V)		
Apple puree + glycerol + methoxyl pectin + ascorbic and citric acids	Continuous casting (spreading the solution at 1.04 mm thick on a Mylar coated conveyor moving at a speed of 0.11 m/min + infrared heater + hot air dryer (flowing air at 132 °C and a velocity of 1500 m/min)	The bench cast films exhibited better performance (TS: 1.45±0.13 MPa, EAB: 45.94 ± 2.54 %, WVTR: 167.0 ± 7.6 g.mm/m^2.day) as compared to continuous films (TS: 1.25 ± 0.14 MPa, EAB: 38.1 ± 2.4 %, WVTR: 167.0 ± 16.74 g.mm/m^2.day). However, the scaling-up possibility of continuous casting is regarded as advantageous.	Du et al., 2008
	Batch casting (spreading the solution at 1.04 mm thick on a flat Mylar sheet placed in a bench + room air drying (at 20–25 °C for 12 h)		

WVTR - Water vapour transmission rate in g.mm/m^2.day, TS - Tensile strength in MPa, YM - Young's modulus in MPa, EAB - Elongation at break in %

Table 7: Effects of nanofillers on the film properties of the edible films

Material	Nanofiller	Properties without nanofiller	Properties with nanofiller	Reference
Gelatin (10g/100ml H_2O)	Bacterial Cellulose (4 wt%)	TS: 83.7±3.2; YM: 2189.5±50; EAB: 3.7±1.6	TS:108.6±5.1; YM: 2350.4±65; EAB: 23.4±1.8	George & Siddaramaiah, 2012
Alginate (3 wt%/v) + Tween 80 (3wt%/v) + Glycerol (2%v/v)	Thyme oil nanoemulsion (1%v/v)	Opacity: 6.7±0.4; WVTR: 28.65 ± 2.55; EAB: 38±7	Opacity: 7.4±0.5; WVTR: 26.46 ± 2.79; EAB: 41±12	Acevedo-Fani et al., 2015
	Lemongrass oil nanoemulsion (1%v/v)		Opacity: 9.7±1.9; WVTR: 25.74 ± 2.91; EAB: 32±9	
	Sage oil nanoemulsion (1%v/v)		Opacity: 5.69±0.25; WVTR: 23.06 ± 4.85; EAB: 78±5	
Maize Starch (7wt%/v) + Glycerol (3 wt%/v)	Chitin nano-whiskers (1wt%)	TS: 1.64±0.11; EAB: 175±7.07; WVTR: 0.644± 0.003; Opacity: 1.16±0.05	TS: 3.69±0.07; EAB: 179±7.07; WVTR: 0.433 ± 0.002; Opacity: 1.98±0.11	Qin et al., 2016
Pea Starch (5wt%/v) + Glycerol (1.5wt%/v)	Waxy maize starch nanocrystals (5wt%)	Opacity: 2.23±0.09; TS: 5.76±0.02; YM: 21.15±0.25; EAB: 29.23±0.56; WVTR: 7.69 ± 0.69	Opacity: 2.44±0.13; TS: 9.96±0.02; YM: 85.72±0.98; EAB: 12.58±0.66; WVTR: 4.61 ± 0.06	Li et al., 2015
Corn starch (7.5wt%/v) + Glycerol (3wt%/v)	Taro starch nanoparticles (10 wt%)	Opacity: 1.15 ± 0.02; WVTR: 10.42 ± 0.23; TS: 1.20	Opacity: 2.34 ± 0.08; WVTR: 4.56 ± 0.00; TS: 2.87 Mpa	Dai et al., 2015
Soy Protein Isolate (0.25g/30ml H_2O) + Glycerol (50 wt% Protein)	Corn starch nanocrystals (40%)	Opacity: 1.293±0.112; TS: 1.10±0.20; YM: 26.89±11.21; EAB: 65.95±17.76; WVTR: 58.88 ± 2.74	Opacity: 2.680±0.125; TS: 5.08±0.48; YM: 10.34±21.55; EAB: 1.35±10.54; WVTR: 48.88 ± 1.10	Ganzalez & Igarzabal, 2015
Amarnath Protein Isolate (5wt%/v) + Glycerol (1.25wt%/v)	Normal maize starch nanocrystals (12%)	Opacity: 2.6±0.7; WVTR: 4.11 ± 0.27	Opacity: 2.2±0.8; WVTR: 2.61 ± 0.27	Condes et al., 2015
	Waxy maize starch nanocrystals (129%)		Opacity: 2.1±0.2; WVTR: 4.52 ± 1.09	
Agar (3g/150ml H_2O) + Glycerol (0.9g/150ml H_2O)	Nanocellulose (3%)	TS: 6.7±3.7; YM: 1.34±0.09 GPa; EAB: 15.7±2.2; WVTR: 180.08 ± 8.22	TS: 52.8±3.3; YM: 1.39±0.10 GPa; EAB: 15.8±2.5; WVTR: 132.84 ± 4.11	Shankar & Rhim, 2016
Fish gelatin (4g/100ml H_2O) + Glycerol (0.3g/1g Gelatin)	Chitason nanoparticle (8%)	TS: 7.44±0.17; YM: 287.03±14.25; EAB: 102.04±28.38; WVTR: 54.06 ± 3.31	TS: 11.28±1.02; YM: 467.2±49.63; EAB: 32.73±7.38; WVTR: 33.63 ± 4.83	Hosseini et al., 2015
Rice starch (5g/100ml H_2O) + Glycerol (0.3g/1g Rice Starch)	Nanocellulose (10%)	TS: 2.15 ± 0.31; YM: 21.22 ± 1.79; EAB: 59.32 ± 2.94; WVTR: 143.14 ± 12.45	TS: 6.41 ± 0.66; YM: 234.92 ± 11.53; EAB: 27.34 ± 3.74; WVTR: 52.3 ± 3.15	Jeevahan et al., 2019b

WVTR - Water vapour transmission rate in g.mm/m^2.day, TS - Tensile strength in MPa, YM - Young's modulus in MPa, EAB - Elongation at break in %