



STARCH AND PECTIN BASED BIODEGRADABLE FILM -A REVIEW

¹Kaviya Sri K, ¹Suchitra P, ²Aarthi P

¹Student, ²Student, ³Assistant professor,

¹Department of Food Technology,

¹K. S. Rangasamy College of Technology, Tiruchengode, Tamil Nadu, India..

Abstract : The growing concern over the pollution of the natural environment by non-biodegradable polymers has intensified studies being conducted to create recyclable materials for packaging. Biodegradable films made from renewable materials like starch and pectin have attracted a lot of interest because of their promising qualities and eco-friendliness. This review comprehensively summarizes recent advancements in the synthesis, properties, and applications of biodegradable films based on starch and pectin. The methods for the extraction and processing of starch and pectin, including chemical modification techniques to enhance their film-forming capabilities, are discussed. An overview is also given of the various mixing techniques and additives used to enhance the mechanical, obstacle, and thermal properties of these films. A comprehensive study was conducted into the impact of processing factors on the properties of films, particularly temperature, pH, and plasticizers.

IndexTerms - Packaging, mechanical, barrier, biodegradable, eco-friendly, starch, and pectin

INTRODUCTION

Packages act as marketing tools for reaching out to customers, shielding goods from environmental factors, holding a variety of products in different sizes and shapes, and providing convenience and time-saving features to the user (Otlés & Yalcin, 2008). Food packaging provides a physical barrier between the food items and the external environment, maintaining sanitation and increasing the shelf life of perishable foods, particularly those that are subject to oxidative and microbiological deterioration (Gomez-Guillen et al., 2009). Plastic, paper, glass, aluminum, fiberboard, and steel are the materials most frequently used to package food. Plastics made from petroleum are extensively used because they are more durable, resilient, and lighter than substitutes for packaging. But since they produce large amounts of non-biodegradable trash, they cause significant ecological issues (Siracusa, Rocculi, Romani, & Rosa, 2008). Utilizing novel biodegradable films made of biopolymers is essential to minimizing the harm that non-biodegradable plastic waste causes to the environment (Soo and Sarbon, 2018).

One of the food elements that is frequently used in the food processing sector is starch. The inexpensive cost and the availability of starch in nature are the reasons for its wide application (Kaur, M. et al., 2004). Starches are utilized in the food packaging business for a number of reasons, more than only functional food components, because of their water-soluble nature and capacity to form films, such as the creation of edible coatings or films (Sadeghizadeh-Yazdi et al., 2019). Previous studies have extensively documented the potential use of starches derived from conventional sources, including but not limited to wheat, corn, potatoes, cassava, and the like, in the packaging of fresh produce and animal items (Ghanbarzadeh et al., 2011). For the purpose of creating film that is edible for use in food packaging, starches from unconventional sources, such as the processing of fruit waste, might thus be studied (Kringel et al., 2020). Edible films may be made from a polymer called starch. Due to its affordability, renewable nature, and suitable physical qualities, starch is widely used in the food sector as a sustainable film substitute for plastic polymers (Bourtoom, T. 2007). Biopolymers like starch and its primary constituents, amylose and amylopectin, make them appealing raw materials for packaging material preservation. Starch is a common ingredient in industrial foods.

The production of biodegradable films to replace plastic polymers has been made possible by their low cost, renewable nature, and advantageous mechanical characteristics (Xu et al., 2005). Although a starch membrane is commonly used, its mechanical properties and ability to protect against low-polar compounds make it ineffective (Azeredo et al., 2000).

Pectin is an acidic heteropolysaccharide of plant origin consisting of β -(1-4)-linked d-galacturonic acid and other saccharides such as galactose, arabinose, and rhamnose (Roy, S. et al., 2021). Due to its properties of stabilizing, emulsifying, and thickening, pectin is commonly utilized as a thickener, coating, and encapsulating agent (Ahn, Halake, & Lee, 2017). Pectin can be used as a packaging material to enhance the sensory experience and extend the shelf life of specific foods, thanks to its ability to form films (Bermudez-Oria, A. et al., 2017).

The plasticizer had an impact on the rheological characteristics of the films used. The plasticizer effectively improved the properties of mixed films (Sun et al., 2020). The functional properties of biopolymer films are altered by the addition of plasticizers, which are low-volatility molecules that enhance their extensibility, spread ability, and flexibility (Hanani et al., 2014a, 2014b).

The use of starch, pectin, and plasticizer for biodegradable packaging materials is the primary focus of this paper.

STARCH BASED BIODEGRADABLE PACKAGING

The primary source of starch for the worldwide starch industry has been determined to be maize (about 65%), followed by sweet potato (about 13%) and cassava (about 11%) (Sarka and Dvoracek 2017). So far, corn starch is the main biodegradable material that has been used as a film-forming component. Due to the molecular structures of amylose and amylopectin and their excellent physio-chemical properties, the production of corn starch has a large share in the entire corn processing industry (Singh, Langyan, and Yadava 2014). The microstructure of cornstarch-based films can be studied for food applications on a large scale. A scanning electron microscope (SEM) was employed to measure the microstructure of cornstarch-based films (Jiang et al. 2020). The mechanical properties and mechanical values of the maize starch-based films were similar to those of the LDPE-based films that are currently used in food packaging.

It has been demonstrated through a comparison of the mechanical characteristics of PVC and LDPE commercial films with corn starch-based films that the mechanical properties of the LDPE film are very similar to those of the maize starch-based film. The choice of starch source has a significant impact on the film's functional, chemical, and physical properties.

The starch source's microstructure, particle size, and roughness all had an impact on the texture and viscosity of the film-forming suspensions, which encouraged the drying process to modify the filmogenic matrix (Luchese CL et al., 2017). The use of cornstarch films can be utilized to create reusable pouches for processed vegetables that require heat-sealing ability. The film properties are highly desirable for biodegradable packaging, particularly for organic products, as they are preferred by consumers (Bof MJ et al., 2021). Additionally, the disadvantages of cornstarch-based membrane usage, such as suppleness, reduced mechanical properties, and inadequate water resistance, have hindered their adoption as biomaterials. The aim of this research was to improve the functional properties of corn starch. The mechanical and physical properties of the maize material were also tested. The tensile strength, brittleness, density, moisture, and water absorption of cornstarch-based film were studied to reduce the disadvantages of cornstarch-based film and maximize efficiency (Harussani MM et al., 2021).

The properties of sweet potato starch (SPS) are similar to those of regular potato flour, with a dry starchy content between 58 and 62%. When compared to conventional potato starch, SPS is rich in fibers and minerals, along with vitamins and antibodies. Consider this. Polyphenols, anthocyanins, ascorbic acid, tocopherol, and β -carotene. Using films made using SPS in food packaging can measure these nutrients, which would enhance the quality of packaged food and increase nutritional value. Biodegradable nanocomposite packaging (SPS) film may be produced without allergenic ingredients, as it has not been reported to be allergen-free. This is a potential source of biodegraded starch for packaging (Issa A. et al., 2016). SPS-based films have been shown to possess antioxidant properties. The results showed that natural anthocyanin in purple sweet potatoes has higher antioxidant activity compared to BHA (10 mg/l) in white-fleshed potatoes. Reduction of the synthetic antioxidant can be achieved by using natural antioxidants in the films (Ishak I et al., 2015). Sweet potato starch films are softened with glycerol and sorbitol to serve as packaging and coating materials for food. Overall, the water solubility, elongation, and water vapor permeability of the membranes subjected to testing were positively affected by the plasticizer's presence in suspension (Ballesteros-Márquez L et al., 2020).

Rice starch is an excellent source of ingredients for biodegradable film production since it has a high amylose content. When both types of films are created using glycerol, the permeability to water vapor of the rice-starch-based film is twice that of the starch-based film.

Glycerol-containing films are additionally plasticized and have worse tear barrier properties than sorbitol-containing films, which are less water transparent and stronger (Dias AB et al., 2010). By adding chitosan, the mechanical strength of rice starch films was greatly enhanced. Rice starch-chitosan mixture films were found to improve the crystallized peak structure of the starchy film by X-ray diffraction and FTIR analysis; however, the separation of starches and other underlying cellular phases was hampered by an excessive chitosan concentration (Bourtoom T et al., 2008).

PECTIN BASED BIODEGRADABLE PACKAGING

Pectin is a polymer that can be synthesized as dietary supplements, thickening, and serving as an additive in food packaging. It is considered one of the most promising polymers for future development. Even so, due to the poor mechanical and barrier properties of pure pectin-based films, their use in food packaging is very limited (Gouveia TI et al., 2019). The insolubility of pectin films to water vapor and the migration of water vapor make them highly reactive towards polyvalent cations. Among the cations tested, calcium treatment best improves the physicochemical properties, competing with commercial non-biodegradable membranes. Although the exact results of remote biodegradation tests are not yet available, it is safe to assume that ionic cross-linking does not significantly alter biodegradability. Worst of all, although these films are insoluble in water, the buried film slowly turns to pectin when washed away (Pavlati AE et al., 1999).

The physical characteristics of orange waste biofilms are identical to those of raw materials; drying provided a smoother surface but had no impact on physical or thermal qualities. Anaerobic conditions allowed for the biodegradable nature of these membranes. The constituents of biofilms, such as pectin and cellulose fiber optic cables, indicate an application where biodegradability is equally significant to durability, like short-acting packaging. The properties are promising, but they need to be characterized and improved to achieve the desired outcomes, which may involve less visible or highly detailed hygroscopic features.

In summary, the generation of biofilms from citrus waste has opportunities for the creation of environmentally friendly polymers and might possibly solve problems connected to the disposal of orange waste (Batori V et al., 2017). The incorporation of orange peel pectin into fish gelatin-based edible films enhances their physicochemical properties, such as mechanical strength and barrier properties.

The resulting films exhibit notable antioxidant activity, attributed to the presence of antioxidants in orange peel pectin. Additionally, these films demonstrate antibacterial properties, contributing to their potential as antimicrobial packaging materials. The synergistic effects of fish gelatin and orange peel pectin make these films promising for wrapping applications in the food industry. The improved characteristics not only extend the shelf life of packaged products but also offer a sustainable alternative to conventional packaging materials. Further research and development in this area could explore different ratios of gelatin to pectin, optimize processing conditions, and assess the films performance with various food products to fully realize their potential in practical applications (Jridi M et al., 2020).

Edible film is a type of active food packaging that enhances the quality of food products by providing biodegradability and edible coatings. These films protect food from deterioration, reduce particle clustering, and enhance visual and tactile features. They also serve as barriers against gas, vapor, oil, and carriers of active substances like flavors, antimicrobials, antioxidants, and colors (Dash KK et al., 2019).

PLASTICIZERS

The plasticizer had an impact on the rheological properties of the film-forming solution. Plasticizer worked well to improve the properties of the blended film. The chitosan/zein film demonstrated remarkable properties with PEG-400 (Sun et al., 2020). Polyols are effective plasticizers for products containing proteins, such as gelatin films. The beneficial elements of a plasticized gelatin film can be used to package food so that it breaks down organically. It was discovered that sorbitol and glycerol had a significant plasticizing effect on gelatin-based films (Suderman et al., 2018). Starch films have exceptional O₂ hindrance properties because of their strongly pressed, systematic H₂-linked groups and low dissolvability (Dos Santos Caetano et al., 2018). However, one disadvantage of starch films is that they break easily (Vu et al., 2016).

According to Souza et al. (2012), the plasticizer effect in the film exhibits a significant rate of water vapor transmission and high solubility. Edible films made of gelatin that have been plasticized by sorbitol based on the thickness, drying conditions, and/or plasticizer concentration. In a more recent study, Simon-Lukasik and Ludescher (2004) investigated how the relative humidity of conditioning affected the diffusion of oxygen in gelatin films. The study conducted by Bertan, Tanada-Palmu, Siani, and Grosso (2005) examined the microstructural and physical characteristics of edible films that were created by blending gelatin and starches and then plasticized using triacetin. These materials' characteristics can be broadly regarded as typical of edible films. Gelatin forms into a three-dimensional network consisting of intermolecular microcrystalline connection zones; dehydration of this system could result in brittle films (Vanin, Sobral, Menegalli, Carvalho, & Habitante, 2005). Therefore, adding a plasticizer is required to increase toughness, improve flow and flexibility, overcome the brittleness of the films, raise the impact resistance of the film coating, and keep the films from breaking during packing and transit (Aydinli and Tutas, 2000; Barreto et al., 2003). Various plasticizers, such as water, oligosaccharides, polyols, and lipids, are frequently utilized in hydrocolloid-based films (Suyatma, Tighzert, & Copinet, 2005).

Glycerine and sorbitol concentrations increased as the films' stickiness and softness increased. With 35% (w/w) glycerine and 45% (w/w) sorbitol (optimum solubility), the plasticized films showed greater solubility in water than the unplasticized films. In the high concentration range of 20–45% (w/w) plasticizer/rice starch film, the tensile strength of the films reduced significantly (Natta Laohakunjit et al., 2004).

Due to its plasticizing effect and ability to increase the ductility of biodegradable packaging, glycerine is vital to the food packaging industry. The starch film that has been plasticized with glycerine is flexible and processable, but its water and gaseous barrier qualities have been compromised, making it too fragile to handle when it is in its natural unplasticized state (Benet et al., 2022). According to Nordine et al. (2020), glycerine had a greater effect on the tensile strength of maize starch films than thymol alone. The elongation of the films rose and their tensile strength dropped as the plasticizer level increased. The starch-glycerine phase separation phenomenon may have caused some of the fissures that were observed in the dry films at high glycerine concentrations. The elongation and tensile strength of the films decreased as the plasticizer level rose.

When the glycerine content was high, some fissures were observed in the dried films; these cracks might have been caused by the starch-glycerine phase separation phenomenon. Given that the ability of the polymer chain to undergo rearrangement is connected with film crystallinity, the relative film crystallinity should increase with plasticizer content (glycerine and water).

Since starch films are hydrophilic, it has been found that the amount of water present greatly affects their mechanical properties. Moisture sorption had an impact on tensile strength in a manner akin to that of glycerine plasticization (Bertuzzi et al., 2012). Many plasticizers are added to starch films to change their characteristics. Commonly, glycerine and water are employed as plasticizers. In this study, we employ glycerine derivatives as a contemporary plasticizer for starch films made from potato starch using the tape casting technique, resulting in films that are 20 cm long and have a constant thickness. Investigations were conducted into the effects of different plasticizer ratios on mechanical qualities and surface-free energy. These plasticizers included glycerine, pentaerythritol ethoxylate, glycerine ethoxylate, and Poligliceryn-3. Our choice of plasticizers is distinguished by the abundance of functional hydroxyl groups. When a combination of plasticizers is used instead of a single plasticizer, the starch films exhibit improved mechanical and usable qualities (Zuzanna et al., 2018).

CONCLUSION

Starch, as a widely available and inexpensive natural polymer, serves as an excellent matrix for biodegradable films. Its compatibility with various additives and blending agents enables the modification of film properties to meet specific application requirements. Furthermore, the renewable nature of starch ensures sustainability in production processes, reducing dependence on non-renewable resources. Pectin, derived from plant sources such as citrus fruits and apples, offers distinct advantages in film formation due to its gel-forming properties. This enables the creation of films with tailored characteristics, including enhanced flexibility and moisture resistance. Moreover, pectin-based films exhibit good biodegradability, contributing to the reduction of environmental pollution.

REFERENCES

- Otles, S., & Yalcin, B. (2008). Intelligent food packaging. *LogForum*, 4(4), 3.
- Gomez-Guillen, M. C., Perez-Mateos, M., Gomez-Estaca, J., Lopez-Caballero, E., Gimenez, B., & Montero, P. (2009). Fish gelatin: A renewable material for developing active biodegradable films. *Trends in Food Science & Technology*, 20(1), 3–16.
- Siracusa, V., Rocculi, P., Romani, S., & Rosa, M. D. (2008). Biodegradable polymers for food packaging: A review. *Trends in Food Science & Technology*, 19(12), 634–643.

4. Soo, P. Y., & Sarbon, N. M. (2018). Preparation and characterization of edible chicken skin gelatin film incorporated with rice flour. *Food Packaging and Shelf Life*, 1–8.
5. Kaur, M.; Singh, N.; Sandhu, K. S.; Guraya, H. S. Physicochemical, Morphological, Thermal and Rheological Properties of Starches Separated from Kernels of Some Indian Mango Cultivars (*Mangifera Indica* L.). *Food Chem.* 2004, 85(1), 131–140. DOI: 10.1016/j.foodchem.2003.06.013.
6. Sadeghizadeh-Yazdi, J.; Habibi, M.; Kamali, A. A.; Banaei, M. Application of Edible and Biodegradable Starch-based Films in Food Packaging: A Systematic Review and Meta-analysis. *Curr. Res. Nutr. Food Sci.* 2019, 7(3), 624–637. DOI: 10.12944/CRNFSJ.7.3.03.
7. Ghanbarzadeh, B.; Almasi, H.; Entezami, A. A. Improving the Barrier and Mechanical Properties of Corn Starch-based Edible Films: Effect of Citric Acid and Carboxymethyl Cellulose. *Ind. Crops Prod.* 2011, 33(1), 229–235. DOI: 10.1016/j.indcrop.2010.10.016.
8. Kringel, D. H.; Dias, A. R. G.; Zavareze, E. D. R.; Gandra, E. A. Fruit Wastes as Promising Sources of Starch: Extraction, Properties, and Applications. *Staerke*. 2020, 72(3–4), 1900200. DOI: 10.1002/star.201900200.
9. Bourtoom, T. 2007. Effect of Some Process Parameters on The Properties of Edible Film Prepared from Starch. Songkhla: Department of Material Product Technology Prince of Songkla University Hat Yai.
10. Xu, X.Y., Kim, K.M., Hana, M.A. and Nag, D. 2005. Chitosan starch composite film: preparation and characterization. *Ind.Crops. And Prods.*, 21: 185-192.
11. Azeredo, H. M. C., Faria, J. A. F. & Azeredo, A. M. C. 2000. Embalagens ativas para alimentos. *Cienciae Tecno-logia de Alimentos*, 20: 337-341.
12. Roy, S.; Rhim, J.-W. Fabrication of Pectin/Agar Blended Functional Film: Effect of Reinforcement of Melanin Nanoparticles and Grapefruit Seed Extract. *Food Hydrocoll.* 2021, 118, 106823.
13. Ahn, S., Halake, K., & Lee, J. (2017). Antioxidant and ion-induced gelation functions of pectins enabled by polyphenol conjugation. *International Journal of Biological Macromolecules*, 101, 776–782.
14. Bermudez-Oria, A., Rodriguez-Gutierrez, G., Vioque, B., Rubio-Senent, F., & Fernandez-Bolanos, J. (2017). Physical and functional properties of pectin-fish gelatin films containing the olive phenols hydroxytyrosol and 3,4-dihydroxyphenylglycol. *Carbohydrate Polymers*, 178, 368–377.
15. 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. *International journal of biological macromolecules*. 2020 Jan 15;143:334-40.
16. Hanani, Z. N., Ross, Y. H., & Kerry, J. P. (2014a). Use and application of gelatin as potential biodegradable packaging materials for food packaging. *International Journal of Biological Macromolecules*, 71(2014), 94–102.
17. Hanani, Z. N., O'Mahony, J. A., Roos, Y. H., Oliveira, P. M., & Kerry, J. P. (2014b). Extrusion of gelatin-based composite films: Effects of processing temperature and pH of film forming solution on mechanical and barrier properties of manufactured films. *Food Packaging and Shelf Life*, 2(2), 91–101.
18. Sarka, E., and V. Dvoracek. 2017. New processing and applications of waxy starch (a review). *Journal of Food Engineering* 206:77–87. doi:10.1016/j.jfoodeng.2017.03.006.
19. Singh, I., S. Langyan, and P. Yadava. 2014. Sweet corn and corn-based sweeteners. *Sugar Tech* 16 (2):144–9. doi: 10.1007/s12355-014-0305-6.
20. Jiang, T., Q. Duan, J. Zhu, H. Liu, and L. Yu. 2020. Starch-based biodegradable materials: Challenges and opportunities. *Advanced Industrial and Engineering Polymer Research* 3 (1):8–18. doi: 10.1016/j.aiepr.2019.11.003.
21. Luchese CL, Spada JC, Tessaro IC. Starch content affects physicochemical properties of corn and cassava starch-based films. *Industrial Crops and Products*. 2017 Dec 15;109:619-26.
22. Bof MJ, Locaso DE, García MA. Corn starch-chitosan proportion affects biodegradable film performance for food packaging purposes. *Starch-Stärke*. 2021 May;73(5-6):2000104.
23. Harussani MM, Sapuan SM, Firdaus AH, El-Badry YA, Hussein EE, El-Bahy ZM. Determination of the tensile properties and biodegradability of cornstarch-based biopolymers plasticized with sorbitol and glycerol. *Polymers*. 2021 Oct 27;13(21):3709.
24. Issa A, Ibrahim SA, Tahergorabi R. Sweet potato starch/clay nanocomposite film: new material for emerging biodegradable food packaging. *MOJ Food Process. Technol.* 2016;3:313-5.
25. Ishak I, Muhamad II, Marsin AM, Iqbal T. Development of purple sweet potato starch base biodegradable film. *J. Teknol.* 2015 Jan 1;77:75-8.
26. Ballesteros-Martínez L, Pérez-Cervera C, Andrade-Pizarro R. Effect of glycerol and sorbitol concentrations on mechanical, optical, and barrier properties of sweet potato starch film. *NFS journal*. 2020 Aug 1;20:1-9.
27. Dias AB, Müller CM, Larotonda FD, Laurindo JB. Biodegradable films based on rice starch and rice flour. *Journal of cereal science*. 2010 Mar 1;51(2):213-9.
28. Bourtoom T, Chinnam MS. Preparation and properties of rice starch–chitosan blend biodegradable film. *LWT-Food science and Technology*. 2008 Nov 1;41(9):1633-41.
29. Gouveia TI, Biernacki K, Castro MC, Gonçalves MP, Souza HK. A new approach to develop biodegradable films based on thermoplastic pectin. *Food Hydrocolloids*. 2019 Dec 1;97:105175.
30. Pavlath AE, Voisin A, Robertson GH. Pectin-based biodegradable water insoluble films. In *Macromolecular Symposia* 1999 May (Vol. 140, No. 1, pp. 107-113). Weinheim, Germany: WILEY-VCH Verlag GmbH & Co. KGaA.
31. Batori V, Jabbari M, Akesson D, Lennartsson PR, Taherzadeh MJ, Zamani A. Production of pectin-cellulose biofilms: a new approach for citrus waste recycling. *International Journal of Polymer Science*. 2017 Jan 1;2017.
32. Jridi M, Abdelhedi O, Salem A, Kechaou H, Nasri M, Menchari Y. Physicochemical, antioxidant and antibacterial properties of fish gelatin-based edible films enriched with orange peel pectin: Wrapping application. *Food Hydrocolloids*. 2020 Jun 1;103:105688.
33. Dash KK, Ali NA, Das D, Mohanta D. Thorough evaluation of sweet potato starch and lemon-waste pectin based-edible films with nano-titania inclusions for food packaging applications. *International journal of biological macromolecules*. 2019 Oct 15;139:449-58.

34. Suderman N, Isa Mi, Sarbon Nm. The effect of plasticizers on the functional properties of biodegradable gelatin-based film: A review. *Food bioscience*. 2018 aug 1;24:111-9.
35. Dos santos caetano, k., almeida lopes, n., haas costa, t.m., brandelli, a., rodrigues, e., hickmann flôres, s., cladera-olivera, f., 2018. Characterization of active biodegradable films based on cassava starch and natural compounds. *Food packag. Shelf life*. 16, 138–147. <http://dx.doi.org/10.1016/j.fpsl.2018.03.006>.
36. Vu, nguyen., h.p, lumdubwong, n., 2016. Starch behaviors and mechanical properties of starch blend films with different plasticizers. *Carbohydr.polym*. 154, 1–36. <http://dx.doi.org/10.1016/j.carbpol.2016.08.034>.
37. Souza, a.c., benze, r., ferrão, e.s., ditchfield, c., coelho, a.c.v., tadini, c.c., 2012. Cassava starch biodegradable films: Influence of glycerol and clay nanoparticles content on tensile and barrier properties and glass transition temperature. *Lwt - food sci. Technol*. 46, 110–117.
38. F.M. Vanin a, P.J.A. Sobral a, F.C. Menegalli b, R.A. Carvalho a, A.M.Q.B. Habitante ., 2005. Effects of plasticizers and their concentrations on thermal and functional properties of gelatin-based films. *Food Hydrocolloids* 19, 899-907 <https://doi.org/10.1016/j.foodhyd.2004.12.003>.
39. Ben zy, samsudin h, yhaya mf. Glycerol: Its properties, polymer synthesis, and applications in starch based films. *European pol journal*. 2022 jun 23;111377.
40. Nordin n, othman sh, rashid sa, basha rk. Effects of glycerol and thymol on physical, mechanical, and thermal properties of corn starch films. *Food hydrocolloids*. 2020 sep 1;106:105884.
41. Bertuzzi ma, gottifredi jc, armada m. Mechanical properties of a high amylose content corn starch based film, gelatinized at low temperature. *Brazilian journal of food technology*. 2012;15:219-27
42. Zuzanna Żolek-Tryznowska, Łukasz Cichy Warsaw University of Technology, Faculty of Production Engineering, Mechanics and Printing Institute, Warsaw, Poland. Glycerol derivatives as a modern plasticizers for starch films. Original scientific paper. <https://doi.org/10.24867/GRID-2018-p27>.
43. Natta Laohakunjit, Athapol Noomhorm School of Environment, Resources and Development Asian Institute of Technology, Pathumthani, Thailand. Effect of Plasticizers on Mechanical and Barrier Properties of Rice Starch Film. 6 (2004) 348–356. DOI 10.1002/star.200300249.

