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Starch Based Biodegradable Film Materials for Smart Packaging

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ABSTRACT:

Food ingredients or products are vulnerable to external contamination or damage from the farm to the table, primarily from oxidation and pathogenic bacteria, which lowers their quality. Approximately 40% of the 300 million tons of plastic produced annually worldwide are used as packaging materials. However, the majority of plastic packaging pollutes the environment and is not biodegradable. Because they are abundant, inexpensive, and biodegradable, starch-based edible packaging films have become a viable substitute for traditional plastics. These bioplastics, which are made from natural starch sources like corn, potatoes, and wheat, are an essential component of sustainable packaging initiatives since they are biodegradable and decompose more readily than traditional plastics. By adding bioactive ingredients like anthocyanins or essential oils that can change color in reaction to pH changes, which serve as markers for spoiling, or by releasing antioxidants and antimicrobials, starch-based packaging keeps an eye on the quality of food. Food can be preserved by using starch-based films, which can extend shelf life and prevent the formation of bacteria and mold. To visually indicate freshness, films can be made to change color in response to pH variations or the presence of gases created during spoiling. Cassava: Mugbean (50: 50), wheat corn potato (50:50) etc. starch-based degradable films having excellent mechanical properties can be used to an impressive advantage in traditional packaging. Three phases are involved in the development of starch-based biodegradable materials: the stage of starch-filled plastics, the stage of blended starch plastics, and the stage of all-starch plastics. A lack of uniformity and stability in the final product can arise from a variety of factors affecting starch-based biodegradable products, including starch type, preparation methods, storage conditions, and other preparation-related issues. Nowadays, the majority of studies on food packaging uses are carried out in lab settings. The commercialization of starch-based films has also been constrained by industrial manufacturing, safety standards, environmental concerns, and customer acceptance.

Keywords: Starch based biodegradable film, biodegradable, traditional plastics, shelf life, anthocyanins, antioxidants.

INTRODUCTION:

Approximately 40% of the 300 million tons of plastic produced annually worldwide are used as packaging materials [1]. However, the majority of plastic packaging pollutes the environment and is not biodegradable. As a result, there has been a growing interest in researching and creating environmentally friendly food packaging alternatives to plastic packaging [2]. The main form of carbohydrate storage in plant tubers and seed endosperm is starch, which is typically present in grains, maize, potatoes, and cassava. Amylose and amylopectin are the two types of starch [3]. A non-branching helical helix made up of α-1,4-glycosidic linkages joined end to end makes up the former. The latter produces highly branched polymers with 24 to 30 glucose residues and is composed of α-1,4- and α-1,6-glycosidic linkages. The amount of amylose in various plant sources varies [4-6]. The use of natural starch in the business is limited by the properties of organic starch itself, including its insolubility in cold water, hygrometry, poor structure, deterioration, etc. Conversely, the pure starch-based film's mechanical qualities are far worse than those of regular, everyday plastics. Furthermore, starch molecules have a lot of hydroxyl groups, which makes them extremely hydrophilic. This leads to poor mechanical properties in wet conditions as well as low water resistance and hydrophobicity[7-10]. As a result, packing materials based on starch must have their mechanical and barrier qualities strengthened. The main solutions for the aforementioned issues involve altering or combining starch with other substances [11-13]. Food must have a lengthy shelf life and retain its freshness due to the widespread use of integrated technologies in food manufacturing, transportation, and storage [14]. Additionally, there is a comparatively greater necessity for food packaging. Food manufacturers, merchants, and consumers can all benefit from the new active, intelligent food packaging that can increase food shelf life, guarantee food safety, and display information about food and its current position in the food supply chain.In order to prolong the shelf life of food and preserve its quality, safety, and sensory qualities, active packaging refers to a packaging system that contains specific active substances (such as organic acids, enzymes, bacteriocins, natural plant extracts, etc.) that can be released into the packaged food or the surrounding environment [15-18]. A system that can track the storage condition or cycle of packed food or notify consumers about the food's quality is known as intelligent packaging. Examples of such systems include pH indicators, time or temperature sensors, and more. These clever packaging materials can be directly formed into films or widely pasted as labels [19-20].

Development of starch based packaging materials:

Research and development on starch-based biodegradable packaging started in the 1980s and grew quickly during that time. Only the starch component of those so-called degradable films could be broken down after around ten years of development; the other film elements simply shattered into shards that remained in soil and water and continued to harm the environment. As a result, at that time, fully deteriorated materials were introduced [21]. Three phases are involved in the development of starch-based biodegradable materials: the production of starch-filled plastics, blended starch plastics, and all-starch plastics. The development of starch-based polymers has coincided with an increase in starch content. The development of starch-based polymers is centered on several plastics, all of which are fully biodegradable, have a wide supply of raw materials, and are reasonably priced [22].

1. Polyethylene or other thermoplastics are combined with a tiny amount of original or modified starch, together with other suitable additives, to create starch-filled plastics. Its goal is to make conventional starch materials derived from petroleum more biodegradable. However, it takes years to fully decay and cannot be completely broken down [23].

2. Synthetic resin or other natural polymer ingredients are combined with starch to create blended starch plastics. They are typically mixtures of synthetic biodegradable polymers, which can be fully biodegradable and environmentally benign, and starch or modified starch (30–60%). The mixtures offer superior mechanical qualities and deteriorate more rapidly than pure synthetic polymers. However, prolonged exposure to or contact with water will significantly deteriorate the plastic's qualities because the additional synthetic resins or other natural polymer ingredients are mainly polar compounds with hydrophilicity. Furthermore, there are issues with the compatibility of starch with additions like natural polymers or synthetic resins [24-25].

3. All starch plastics, sometimes referred to as thermoplastic starch plastic, are biodegradable natural polymers. Through procedures including extrusion, injection molding, blow molding, and calendaring, which produce a "disordered" arrangement of starch molecules, they are made by adding degradable plasticizers and other chemicals. All starch-based polymers include more than 90% starch, and the few additives that are added are harmless and fully biodegradable. As a result, every starchy plastic is truly and fully biodegradable. Furthermore, nearly every plastic processing technique is applicable to all starch-based plastics [26-27].

Factors effecting and their remedy on starch based packaging:

Water vapor barrier:

The water vapor barrier is essential for maintaining or increasing food shelf life, because food spoilage is directly correlated with ambient humidity. The needs of a water vapor barrier vary depending on the cuisine. Fresh foods should not be dehydrated; however bread or cooked items should not be exposed to water vapor [28]. When starch is mixed with glycerol, the network's growth retains a significant amount of water because starch is hydrophilic and rich in hydroxyl groups, making the starch-based material vulnerable to water [29]. This expansion limits the film's range of applications, compromises the structural integrity of the matrix, results in subpar barrier performance, and makes it impossible to package protective items. To improve the hydrophobic qualities of starch-based packaging materials, researchers have modified starch to add hydrophobic groups. In order to decrease the quantity of hydrophilic hydroxyl groups in starch and increase its hydrophobic qualities, these groups are esterified, etherified, crosslinked, and grafted with other materials. By extrusion blending protostars (NS), acetylated starch (AS), octenyl succinate starch (OS), and hydroxypropyl starch (HS), Wongphan and Panrong created a blended film using polybutylene adipate terephthalate (PBAT). The findings demonstrated that the hydrophobic starch significantly enhanced the barrier performance (82–89%) and enhanced compatibility and interaction with PBAT. However, altering starch by itself is not enough to strengthen material qualities [30,33].

Oxygen Barrier

Researchers have altered starch by adding hydrophobic groups to enhance the hydrophobic properties of starch-based packaging materials. Hydrophilic hydroxyl groups in starch are esterified, etherified, crosslinked, and grafted with other substances to increase their hydrophobic properties and decrease their number [31,34]. Wongphan and Panrong used polybutylene adipate terephthalate (PBAT) to extrude a blended film consisting of protostars (NS), acetylated starch (AS), octenyl succinate starch (OS), and hydroxypropyl starch (HS). The results showed that the hydrophobic starch improved compatibility and interaction with PBAT and greatly improved barrier efficacy (82–89%). However, strengthening material properties requires more than just changing starch [32, 35].

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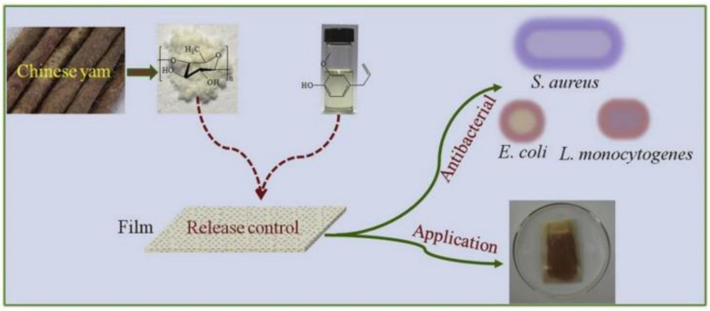
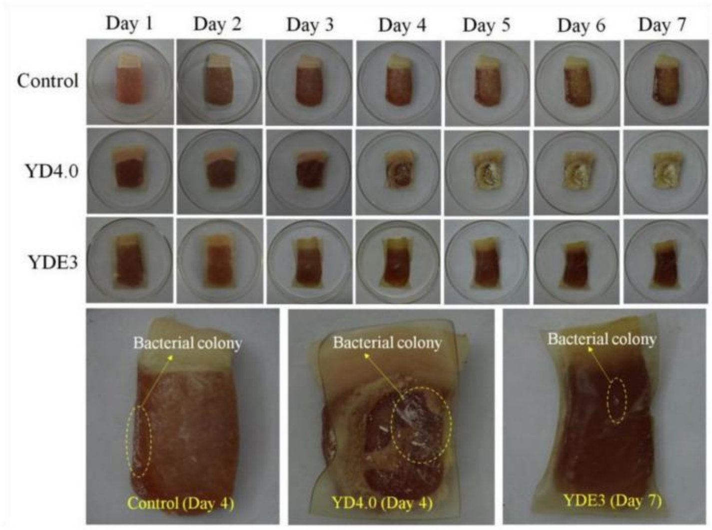
Starch based various packaging:

Active Packaging:

Food shelf life can be increased by using starch-based active film in food packaging, which effectively inhibits lipid oxidation and microorganism development. The film's antibacterial and antioxidant agent action is primarily responsible for this impact [36]. When the film is used to package food, its active ingredients can diffuse their way to the food's surface or the upper part of the container, preventing the meal's quality from declining. In the end, how active ingredients interact with food determines its preservation mechanism [37]. The use of starch-based active film in food preservation is currently the subject of an increasing amount of research. Cheng and Wang used eugenol (YDE) and yam starch as a matrix to create the starch-based antibacterial film for pig preservation (Figure 1A) [41]. The findings demonstrated that YDE's antibacterial efficacy against E. coli outperformed that of S. aureus and Listeria monocytogenes. Pork's shelf life might be increased by over 50% because to the superior antibacterial activity of YDE3 film (Figure 1B). The hydrophobic active ingredient in EO has been demonstrated in studies to adhere to the surface of microorganisms' cells and penetrate through plasma, plasma-binding enzymes, and other targets, causing cell wall rupture and intracellular material release [38]. By embedding EOs in a starch-based film, active packaging extends the time that food is transported and stored by allowing the bacteriostatic active component to be released from the container for a longer period of time. In order to preserve strawberries, thermoplastic starch/montmorillonite films containing EO components—such as thymol and carvacrol—were made and put in PET containers. The EO was then released as water vapor [39,40].



(A)

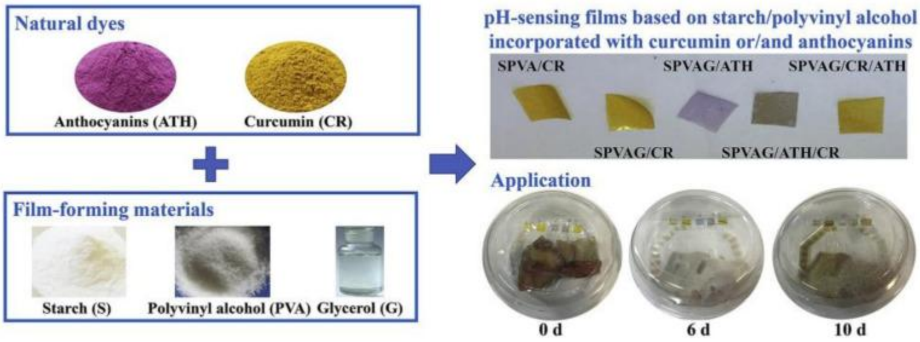


(B)

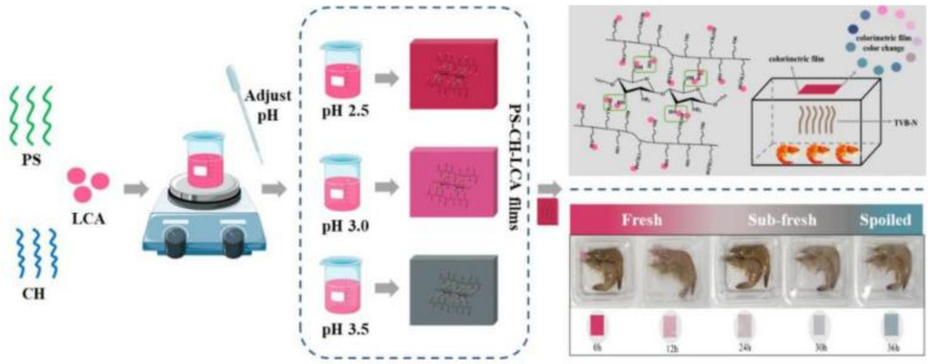
Figure-1: Application of active starch-based film (**A**) Active packaging film based on yam starch with eugenol (**B**) application of antibacterial films to pork preservation [41].

Intelligent Packaging:

Scholars have created intelligent packaging film materials based on starch in addition to conducting applied research on active packaging. Currently, their primary focus is on materials for indication intelligent packaging [42]. Through exterior color changes, indicative intelligent packaging informs consumers by fusing regular packaging technology with intelligent functions. Using (CR) and (ATH) as packaging indication labels, Chen and Zhang created visual pH-sensitive films that allow for the non-destructive, real-time assessment of fish freshness (Figure 2A) [43]. According to the findings, three distinct colors—which represent freshness, medium freshness, and deterioration of packaged fish—could be produced by combining starch film with CR and ATH. By adjusting the pH of the film-forming solution, pH and NH3 response coloristic film (PS-CH-LCA) was created using potato starch (PS), chitosan (CH), and floss lonicera anthocyanins (LCA) as raw ingredients. This film was then used for real-time shrimp freshness monitoring (Figure 2B). The findings demonstrated that PS-CH-LCA (pH = 2.5) film was highly connected with spoilage indicators and sensitive to color changes, suggesting that the film could accurately represent the degree of shrimp spoilage, freshness, and sub-freshness [44].



(A)



(B)

Figur-2: Application of Intelligent starch-based film (**A**) novel pH-sensitive films containing curcumin and anthocyanins to monitor fish freshness. (**B**) preparation and application of chitosan/starch based colorimetric film for sub-freshness monitoring [42,43,44]

Conclusion:

Starch-based biodegradable materials may play an important role in the future development of sustainable food packaging materials, reducing the energy and environmental stress of petroleum-based packaging materials. The current limitation is mainly due to the poor mechanical properties and barrier properties of starch-based packaging materials due to the properties of starch itself. Researchers can solve this problem by physically or chemically modifying starch or mixing it with other biopolymers and functional additives. After meeting the basic conditions of food packaging, starch-based active packaging can be prepared by adding antioxidant or anti-bacterial substances, which can extend the shelf life of food and reduce food waste. Starch time and temperature indicator films can detect food freshness in real-time by the color reaction. Starch-based films are widely used in food packaging and have a good protective effect on fresh food. In the future, it will be possible to prepare active or smart packaging using starch-based materials.

Conflict of interest:

There is no conflict of interest.

REFERENCES:

1. Ellen, P.; Jacob, H.; Karl, H.; Dan, N.T. Narrating plastics governance: Policy narratives in the European plastics strategy. Environ. Politics 2022, 31, 365–385.
2. Biron, M. Thermoplastics and Thermoplastic Composites; William Andrew: Norwich, NY, USA, 2018.
3. Williams, K.S. Plastic Packaging: Not a Throw-away Resource. In Issues in Environmental Science and Technology: Waste as a Resource; The Royal Society for Chemistry: Cambridge, UK, 2013; pp. 83–109.
4. Robertson, G.L. Definitions, Functions, Attributes and Environments of Food Packaging. In Reference Module in Food Science; Elsevier: Amsterdam, The Netherlands, 2018.
5. Shen, M.; Song, B.; Zeng, G.; Zhang, Y.; Huang, W.; Wen, X.; Tang, W. Are biodegradable plastics a promising solution to solve the global plastic pollution? Environ. Pollut. 2020, 263 Pt A, 114469.
6. Guo, B.; Wang, Y.; Pang, M.; Wu, J.; Hu, X.; Huang, Z.; Wang, H.; Xu, S.; Luo, S.; Liu, C. Annealing treatment of amylose and amylopectin extracted from rice starch. Int. J. Biol. Macromol. 2020, 164, 3496–3500.
7. Ettelaie, R.; Holmes, M.; Chen, J.; Farshchi, A. Steric stabilising properties of hydrophobically modified starch: Amylose vs. amylopectin. Food Hydrocoll. 2016, 58, 364–377.
8. Punia, B.S.; Omodunbi, A.A.; Arashdeep, S.; Vandana, C.; Scott,W.W. Enzymatic modification of starch: A green approach for starch applications. Carbohydr. Polym. 2022, 287, 119265.
9. Khan, B.; Niazi, M.B.K.; Samin, G.; Jahan, Z. Thermoplastic Starch: A Possible Biodegradable Food Packaging Material—A Review. J. Food Process Eng. 2017, 40, e12447.
10. Liu, P.; Li, Y.; Shang, X.; Xie, F. Starch–zinc complex and its reinforcement effect on starch-based materials. Carbohydr. Polym. 2018, 206, 528–538.
11. Congli, C.; Na, J.; Yanfei,W.; Liu, X.; Qingjie, S. Bioactive and intelligent starch-based films: A review. Trends Food Sci. Technol. 2021, 116, 854–869.
12. Weerapoprasit, C.; Prachayawarakorn, J. Effects of Polymethacrylamide-Grafted Branch on Mechanical Performances, Hydrophilicity, and Biodegradability of Thermoplastic Starch Film. Starch-Stärke 2019, 71, 11–12.
13. Kwa´sniewska, A.; Chocyk, D.; Gładyszewski, G.; Borc, J.; ´Swietlicki, M.; Gładyszewska, B. The Influence of Kaolin Clay on the Mechanical Properties and Structure of Thermoplastic Starch Films. Polymers 2020, 12, 73.
14. Alizadeh, S.M.; Maryam, A.; Milad, T.; Keyhan, M.; Julian, M.D. Recent Advances in the Development of Smart and Active Biodegradable Packaging Materials. Nanomaterials 2021, 11, 1331.
15. Vilas, C.; Mauricio-Iglesias, M.; García, M.R. Model-based design of smart active packaging systems with antimicrobial activity. Food Packag. Shelf Life 2020, 24, 100446.
16. Kanatt, S.R. Development of active/intelligent food packaging film containing Amaranthus leaf extract for shelf life extension of chicken/fish during chilled storage. Food Packag. Shelf Life 2020, 24, 100506.
17. Tarsila, R.A.; Patrícia, C.B.; Allan, R.F.e.M.; Nilda, d.F.F.S. Natural bioactives in perspective: The future of active packaging based on essential oils and plant extracts themselves and those complexed by cyclodextrins. Food Res. Int. 2022, 156, 111160.
18. Menzel, C.; González-Martínez, C.; Vilaplana, F.; Diretto, G.; Chiralt, A. Incorporation of natural antioxidants from rice straw into renewable starch films. Int. J. Biol. Macromol. 2020, 146, 976–986.
19. Meng, C.; Yingjun, C.; Xiaoran, Y.; Rongfei, Z.; Juan, W.; Xiangyou, W. Effect of dual-modified cassava starches on intelligent packaging films containing red cabbage extracts. Food Hydrocoll. 2022, 124, 107225.
20. Luman, Z.; Liming, L.; Jiahao, Y.; Ping, S. Novel trends and applications of natural pH-responsive indicator film in food packaging for improved quality monitoring. Food Control 2022, 134, 108769.
21. Zuzanna, Z˙ .; Alicja, K. The Influence of Starch Origin on the Properties of Starch Films: Packaging Performance. Materials 2021, 14, 1146.
22. Abioye, A.A.; Obuekwe, C.C. Investigation of the biodegradation of low-density polyethylene-starch Bi-polymer blends. Results Eng. 2020, 5, 100090. [CrossRef]
23. Dammak, M.; Fourati, Y.; Tarrés, Q.; Delgado-Aguilar, M.; Mutjé, P.; Boufi, S. Blends of PBAT with plasticized starch for packaging applications: Mechanical properties, rheological behaviour and biodegradability. Ind. Crops Prod. 2020, 144, 112061. [CrossRef]
24. Castaño, J.; Rodríguez-Llamazares, S.; Sepúlveda, E.; Giraldo, D.; Bouza, R.; Pozo, C. Morphological and structural changes of starch during processing by melt blending. Starch-Stärke 2017, 69, 9–10. [CrossRef]
25. Huan, H.; Ang, X.; Dianfeng, Z.; Weiyi, Z.; Shaoxian, P.; Xipo, Z. High-Toughness Poly(Lactic Acid)/Starch Blends Prepared through Reactive Blending Plasticization and Compatibilization. Molecules 2020, 25, 5951.
26. Hirpara, N.J.; Dabhi,M.N. Development of Potato Starch Based Biodegradable Packaging Film. J. Food Process. Technol. 2021, 12, 529–541.

27. Gülay, B.; Faik, D. Investigation and preparation of biodegradable starch-based nanofilms for potential use of curcumin and garlic in food packaging applications. J. Biomater. Sci. Polym. Ed. 2020, 31, 1127–1143.
28. Siracusa, V.; Rocculi, P.; Romani, S.; Rosa, M.D. Biodegradable polymers for food packaging: A review. Trends Food Sci. Technol. 2008, 19, 634–643.
29. Perdomo, J.; Cova, A.; Sandoval, A.J.; García, L.; Laredo, E.; Müller, A.J. Glass transition temperatures and water sorption isotherms of cassava starch. Carbohydr. Polym. 2009, 76, 305–313.
30. Chenglong, L.; Bin, Y.; Haiteng, T.; Pengfei, L.; Haibo, Z.; Congping, T.; Bo, C. Effects of soy protein isolate on mechanical and hydrophobic properties of oxidized corn starch film. LWT 2021, 147, 111529.
31. Frida, I.; Krister, H.; Romain, B. Surface Treatment by Hydrophobic Particles: Influence of Starch and Ionic Strength. ACS Sustain. Chem. Eng. 2017, 5, 6107–6115.
32. Phanwipa,W.; Theeraphorn, P.; Nathdanai, H. Effect of different modified starches on physical, morphological, thermomechanical, barrier and biodegradation properties of cassava starch and polybutylene adipate terephthalate blend film. Food Packag. Shelf Life
2022, 32, 100844.
33. Milani, M.J.; Nemati, A. Lipid-Based Edible Films and Coatings: A Review of Recent Advances and Applications. J. Packag. Technol. Res. 2022, 6, 11–22.
34. Bourtoom, T. Improvement of Water Barrier Property of Rice Starch-chitosan Composite Film Incorporated with Lipids. Food Sci. Technol. Int. 2009, 15, 149–158.
35. Tavares, K.M.; de Campos, A.; Mitsuyuki, M.C.; Luchesi, B.R.; Marconcini, J.M. Corn and cassava starch with carboxymethyl cellulose films and its mechanical and hydrophobic properties. Carbohydr. Polym. 2019, 223, 115055.
36. Goudar, H.V.D.; Gasti, N.; Khanapure, T.; Vanjeri, S.; Sataraddi, V.N.; D'souza, S.; Oshin, V.J.; Kumar, S.; Saraswati, M.P.; Malabadi, R.B.; et al. Exploration of Multifunctional Properties of Piper betel Leaves Extract Incorporated Polyvinyl Alcohol-Oxidized Maize Starch Blend Films for Active Packaging Applications. J. Polym. Environ. 2022, 30, 1314–1329.
37. Zhikun, M.; Yanfei, Z.; Panfang, L. Novel active starch films incorporating tea polyphenols-loaded porous starch as food packaging materials. Int. J. Biol. Macromol. 2021, 192, 1123–1133.
38. Shi, C.; Zhang, X.; Guo, N. The antimicrobial activities and action-mechanism of tea tree oil against food-borne bacteria in fresh cucumber juice. Microb. Pathog. 2018, 125, 262–271.
39. Quintavalla, S.; Vicini, L. Antimicrobial food packaging in meat industry. Meat Sci. 2002, 62, 373–380.
40. Campos-Requena, V.H.; Rivas, B.L.; Pérez, M.A.; Figueroa, C.R.; Sanfuentes, E.A. The synergistic antimicrobial effect of carvacrol and thymol in clay/polymer nanocomposite films over strawberry gray mold. LWT-Food Sci. Technol. 2015, 64, 390–396.
41.Cheng, J.;Wang, H.; Kang, S.; Xia, L.; Jiang, S.; Chen, M.; Jiang, S. An active packaging film based on yam starch with eugenol and its application for pork preservation. Food Hydrocoll. 2019, 96, 546.0–554.0.
42. Bin, L.; Yiwen, B.; Jiaxin, L.; Jinfeng, B.; Qinqin, C.; Huijun, C.; Yuxuan, W.; Jinlong, T.; Chi, S.; Yuehua, W.; et al. A sub-freshness monitoring chitosan/starch-based colorimetric film for improving color recognition accuracy via controlling the pH value of the film-forming solution. Food Chem. 2022, 388, 132975.
43. Chen, H.; Zhang, M.; Bhandari, B.; Yang, C. Novel pH-sensitive films containing curcumin and anthocyanins to monitor fish freshness. Food Hydrocoll. 2020, 100, 105438.
44. Mohammadalinejhad, S.; Almasi, H.; Moradi, M. Immobilization of Echium amoenum anthocyanins into bacterial cellulose film: A novel colorimetric pH indicator for freshness/spoilage monitoring of shrimp. Food Control 2020, 113, 107169.

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