PENGEMBANGAN FILM GELATIN DENGAN FIKOSIANIN *Spirulina plantesis* YANG DIPERKAYA MINYAK ESENSIAL KAYU MANIS SEBAGAI *SMART PACKAGING*

TESIS

diajukan untuk memenuhi sebagian dari syarat memperoleh gelar magister sains di bidang kimia

Oleh

Ni Putu Yunika Arindita

2208545

PROGRAM STUDI MAGISTER KIMIA

FAKULTAS PENDIDIKAN MATEMATIKA DAN ILMU PENGETAHUAN ALAM

UNIVERSITAS PENDIDIKAN INDONESIA

BANDUNG

2024

PENGEMBANGAN FILM GELATIN DENGAN FIKOSIANIN *Spirulina plantesis* YANG DIPERKAYA MINYAK ESENSIAL KAYU MANIS SEBAGAI *SMART PACKAGING*

Oleh
Ni Putu Yunika Arindita

Universitas Pendidikan Indonesia, 2024

Sebuah Tesis yang diajukan untuk memenuhi salah satu syarat memperoleh gelar Magister Sains (M.Si.) pada Program Studi Kimia Fakultas Pendidikan Matematika dan Ilmu Pengethauan Alam

HALAMAN PENGESAHAN

NI PUTU YUNIKA ARINDITA

2208545

PENGEMBANGAN FILM GELATIN DENGAN FIKOSIANIN *Spirulina plantesis* YANG DIPERKAYA MINYAK ESENSIAL KAYU MANIS SEBAGAI *SMART PACKAGING*

Disetujui dan disahkan oleh:

Pembimbing I,

<u>Dr. Heli Siti Halimatul Munawaroh, M.Si.</u>

NIP. 197907302001122000 2

Pembimbing II,

<u>Dr. Siti Aisyah, M.Si.</u>

NIP. 197509302001122001

Ketua Program Studi Kimia FPMIPA UPI

<u>Prof Fitri Khoerunnisa, Ph.D</u>

NIP. 197806282001122001

ABSTRAK

Keterbatasan kemasan konvensional dalam menjaga kualitas dan masa simpan produk pangan mendorong pengembangan teknologi kemasan inovatif. Tujuan penelitian ini adalah untuk mengembangkan film berbasis ekstrak gelatin kulit ikan nila yang diperkaya minyak esensial kayu manis dan menggunakan indikator fikosianin yang diekstrak dari *Spirulina plantesis* sebagai kemasan pintar (*smart packaging)* pada produk pangan fillet ikan. Ekstraks gelatin diperoleh melalui hidrolisis basa (NaOH) dan asam sitrat. Ekstraksi fikosianin diperoleh melalui metode freeze-thawing yang dilanjutkan dengan pemurnian menggunakan amonium sulfat. Sintesis film dilakukan melalui pemanasan dan sonikasi. Berdasarkan hasil penelitian diperoleh yield ekstrak gelatin berkisar antara 7,66 - 8,37% dan ekstrak fikosianin dengan tingkat kemurnian pada rasio A260/280 yaitu 1,83 yang termasuk ke dalam kategori *food grade.* Karakterisasi film dengan FTIR menunjukkan adanya pergeseran, perubahan intensitas, dan pembentukan puncak serapan baru dari vibrasi ikatan O-H, C=O karbonil, dan C=C cincin pirol. Hal ini mengindikasikan adanya pembentukan interaksi baru antara gekatin dengan fikosianin dan minyak kayu manis. Karakterisasi SEM menunjukkan bahwa penambahan fikosianin (GC-PC) menjadikan morfologi film lebih padat dan teratur, meningkatkan kelarutan film serta mengurangi laju transmisi uap air (WVP). Karakteristik mekanik film menunjukkan kualitas yang baik dan sesuai dengan standar JIS 1975, dengan nilai *tensile strength* (TS) berkisar antara 3,58 ± 0,77 hingga 4,44 ± 0,49 MPa, dan nilai *elongation at break* (EAB) berkisar antara 185,47 ± 37,15 hingga 312,15 ± 68,94%. Pengujian biokimia menunjukkan bahwa film yang disintesis memiliki aktivitas antioksidan dan mampu menghambat pertumbuhan bakteri umum pemicu pembusukkan. Pengaplikasian film menunjukkan bahwa proses pembusukkan fillet ikan nila berhasil dideteksi dengan baik oleh film dengan konsentrasi indikator fikosianin 6,25% yang ditujukkan dengan perubahan warna dari biru (pH ~6 untuk ikan segar) menjadi biru keabuan (pH ~9 untuk ikan busuk). Melalui penelitian ini diperoleh sumber alternatif biopolimer maupun indikator alami kemasan pintar dari sumber limbah kulit ikan dan mikroalga.

Kata kunci: gelatin ikan, *smart packaging*, fikosianin, minyak esensial kayu manis, kesegaran fillet ikan nila

ABSTRACT

The limitations of conventional packaging in preserving the quality and shelf life of food products have driven the development of innovative packaging technologies. The objective of this research is to develop a film based on gelatin extracted from tilapia fish skin, enriched with essential oil from cinnamon, and incorporating phycocyanin extracted from Spirulina plantesis as a smart packaging material for fish fillet products. Gelatin extraction was achieved through alkaline (NaOH) and citric acid hydrolysis, while phycocyanin extraction utilized the freeze-thawing method followed by purification using ammonium sulfate. Film synthesis involved heating and sonication. The research results showed that the gelatin extraction yield ranged from 7.66% to 8.37%, and the phycocyanin extract had a purity level (A260/280 ratio) of 1.83, falling within the food-grade category. FTIR characterization of the film revealed shifts, intensity changes, and the emergence of new absorption peaks from O-H bond vibrations, C=O carbonyl, and C=C pyrrole ring. This indicates the formation of new interactions between gelatin, phycocyanin, and cinnamon oil. SEM characterization demonstrated that the addition of phycocyanin (GC-PC) resulted in a denser and more organized film morphology, increasing film thickness and solubility, while reducing water vapor transmission rate (WVP). Mechanical film characteristics indicated good quality consistent with JIS 1975 standards, with tensile strength (TS) values ranging from 3.58 ± 0.77 to 4.44 ± 0.49 MPa, and elongation at break (EAB) values ranging from 185.47 ± 37.15 to 312.15 ± 68.94%. Biochemical testing showed that the synthesized film exhibited antioxidant activity and could inhibit the growth of common bacteria that cause decay. Film application demonstrated the successful detection of tilapia fish fillet decay by the film with a 6.25% phycocyanin concentration, as indicated by a color change from blue (pH ~6 for fresh fish) to bluish-gray (pH ~9 for spoiled fish). Through this research, alternative sources of biopolymers and natural indicators for smart packaging were obtained from waste tilapia skin and microalgae.

Keywords: fish gelatin, smart packaging, phycocyanin, cinnamon essential oil, tilapia fillet freshness

DAFTAR ISI

DAFTAR TABEL

DAFTAR GAMBAR

DAFTAR LAMPIRAN

DAFTAR PUSTAKA

Abdelhedi, O., Salem, A., Nasri, R., Nasri, M., & Jridi, M. (2022). Food applications of bioactive marine gelatin films. In *Current Opinion in Food Science*. https://doi.org/10.1016/j.cofs.2021.12.005

Acker, J. P., & McGann, L. E. (2003). Protective effect of intracellular ice during freezing? *Cryobiology*. https://doi.org/10.1016/S0011-2240(03)00025-7

Ahmad, M., & Benjakul, S. (2011). Characteristics of gelatin from the skin of unicorn leatherjacket (Aluterus monoceros) as influenced by acid pretreatment and extraction time. *Food Hydrocolloids*. https://doi.org/10.1016/j.foodhyd.2010.07.004

Ahmad, M., Bushra, R., Ritzoulis, C., Meigui, H., Jin, Y., & Xiao, H. (2024). Molecular characterisation, gelation kinetics and rheological enhancement of ultrasonically extracted triggerfish skin gelatine. *Journal of Molecular Structure*, *1296*(October 2023). https://doi.org/10.1016/j.molstruc.2023.136931

Ahmad, T., Ismail, A., Ahmad, S. A., Khalil, K. A., Kumar, Y., Adeyemi, K. D., & Sazili, A. Q. (2017). Recent advances on the role of process variables affecting gelatin yield and characteristics with special reference to enzymatic extraction: A review. In *Food Hydrocolloids* (Vol. 63). https://doi.org/10.1016/j.foodhyd.2016.08.007

Al-Hassan, A. A., & Norziah, M. H. (2012). Starch-gelatin edible films: Water vapor permeability and mechanical properties as affected by plasticizers. *Food Hydrocolloids*. https://doi.org/10.1016/j.foodhyd.2011.04.015

Alfaro, A. da T., Balbinot, E., Weber, C. I., Tonial, I. B., & Machado-Lunkes, A. (2015). Fish Gelatin: Characteristics, Functional Properties, Applications and

Future Potentials. In *Food Engineering Reviews* (Vol. 7, Issue 1). https://doi.org/10.1007/s12393-014-9096-5

Alizadeh-Sani, M., Mohammadian, E., & McClements, D. J. (2020). Eco-friendly active packaging consisting of nanostructured biopolymer matrix reinforced with TiO2 and essential oil: Application for preservation of refrigerated meat. *Food Chemistry*. https://doi.org/10.1016/j.foodchem.2020.126782

Amarante, M. C. A. de, Corrêa Júnior, L. C. S., Sala, L., & Kalil, S. J. (2020). Analytical grade C-phycocyanin obtained by a single-step purification process. *Process Biochemistry*. https://doi.org/10.1016/j.procbio.2019.11.020

Amaregouda, Y., Kamanna, K., & Gasti, T. (2022). Fabrication of intelligent/active films based on chitosan/polyvinyl alcohol matrices containing Jacaranda cuspidifolia anthocyanin for real-time monitoring of fish freshness. *International Journal of Biological Macromolecules*. https://doi.org/10.1016/j.ijbiomac.2022.07.174

Andrade, M. A., Barbosa, C. H., Souza, V. G. L., Coelhoso, I. M., Reboleira, J., Bernardino, S., Ganhão, R., Mendes, S., Fernando, A. L., Vilarinho, F., Silva, A. S., & Ramos, F. (2021). Novel active food packaging films based on whey protein incorporated with seaweed extract: Development, characterization, and application in fresh poultry meat. *Coatings*. https://doi.org/10.3390/coatings11020229

Arrieta, M. P., Peltzer, M. A., Garrigós, M. D. C., & Jiménez, A. (2013). Structure and mechanical properties of sodium and calcium caseinate edible active films with carvacrol. *Journal of Food Engineering*. https://doi.org/10.1016/j.jfoodeng.2012.09.002

Asadi, S., & Pirsa, S. (2020). Production of Biodegradable Film Based on Polylactic

Acid, Modified with Lycopene Pigment and TiO2 and Studying Its Physicochemical Properties. *Journal of Polymers and the Environment*. https://doi.org/10.1007/s10924-019-01618-5

Astuti, A. I., Soejoedono, R. D., Saepudin, E., Assaat, L. D., & Ivandini, T. A. (2020). Polyclonal antibodies production from porcine gelatin and its preliminary study for immunosensor applications. *IOP Conference Series: Materials Science and Engineering*. https://doi.org/10.1088/1757-899X/763/1/012007

Azlim, N. A., Mohammadi Nafchi, A., Oladzadabbasabadi, N., Ariffin, F., Ghalambor, P., Jafarzadeh, S., & Al-Hassan, A. A. (2022). Fabrication and characterization of a pH-sensitive intelligent film incorporating dragon fruit skin extract. *Food Science and Nutrition*. https://doi.org/10.1002/fsn3.2680

Badway, H., Abd El-Moniem, S., Soliman, A., & Rabie, M. (2019). PHYSICOCHEMICAL PROPERTIES OF GELATIN EXTRACTED FROM NILE TILAPIA (Oreochromis niloticus) AND NILE PERCH (Lates niloticus) FISH SKINS. *Zagazig Journal of Agricultural Research*. https://doi.org/10.21608/zjar.2019.48170

Baranwal, J., Barse, B., Fais, A., Delogu, G. L., & Kumar, A. (2022). Biopolymer: A Sustainable Material for Food and Medical Applications. In *Polymers*. https://doi.org/10.3390/polym14050983

Baya, G. M., Putri, N. Y., & Kamaliya, L. N. (2022). ACTIVE AND INTELLIGENT PACKAGING BASED ON CHITOSAN AND ANTOCYANIN FROM THE EXTRACT OF ROSELLA FLOWER (Hibiscus sabdariffa) WITH THE ADDITION OF CITRONELLA ESSENTIAL OIL (Cymbopogon citrratus). *Khazanah: Jurnal Mahasiswa*. https://doi.org/10.20885/khazanah.vol13.iss4.art23

Becerril, R., Nerín, C., & Silva, F. (2021). Bring some colour to your package: Freshness indicators based on anthocyanin extracts. In *Trends in Food Science and Technology*. https://doi.org/10.1016/j.tifs.2021.02.042

Bergo, P., & Sobral, P. J. A. (2007). Effects of plasticizer on physical properties of pigskin gelatin films. *Food Hydrocolloids*. https://doi.org/10.1016/j.foodhyd.2006.09.014

Bermejo, R., Felipe, M. A., Talavera, E. M., & Alvarez-Pez, J. M. (2006). Expanded bed adsorption chromatography for recovery of phycocyanins from the microalga Spirulina platensis. *Chromatographia*. https://doi.org/10.1365/s10337-005-0702-9

Biji, K. B., Ravishankar, C. N., Mohan, C. O., & Srinivasa Gopal, T. K. (2015). Smart packaging systems for food applications: a review. In *Journal of Food Science and Technology*. https://doi.org/10.1007/s13197-015-1766-7

Byrne, L., Lau, K. T., & Diamond, D. (2002). Monitoring of headspace total volatile basic nitrogen from selected fish species using reflectance spectroscopic measurements of pH sensitive films. *Analyst*. https://doi.org/10.1039/b206149j

Calogero, G., Yum, J. H., Sinopoli, A., Di Marco, G., Grätzel, M., & Nazeeruddin, M. K. (2012). Anthocyanins and betalains as light-harvesting pigments for dye-sensitized solar cells. *Solar Energy*. https://doi.org/10.1016/j.solener.2012.02.018

Chang, Y. K., Show, P. L., Lan, J. C. W., Tsai, J. C., & Huang, C. R. (2018). Isolation of C-phycocyanin from Spirulina platensis microalga using Ionic liquid based aqueous two-phase system. *Bioresource Technology*. https://doi.org/10.1016/j.biortech.2018.07.138

Chen, E., Wu, S., McClements, D. J., Li, B., & Li, Y. (2017). Influence of pH and cinnamaldehyde on the physical stability and lipolysis of whey protein isolate-stabilized emulsions. *Food Hydrocolloids*. https://doi.org/10.1016/j.foodhyd.2017.01.028

Chen, H. zhi, Zhang, M., Bhandari, B., & Yang, C. hui. (2020). Novel pH-sensitive films containing curcumin and anthocyanins to monitor fish freshness. *Food Hydrocolloids*. https://doi.org/10.1016/j.foodhyd.2019.105438

Chen, K., Li, J., Li, L., Wang, Y., Qin, Y., & Chen, H. (2023). A pH indicator film based on sodium alginate/gelatin and plum peel extract for monitoring the freshness of chicken. *Food Bioscience*. https://doi.org/10.1016/j.fbio.2023.102584

Chentir, I., Hamdi, M., Li, S., Doumandji, A., Markou, G., & Nasri, M. (2018). Stability, bio-functionality and bio-activity of crude phycocyanin from a two-phase cultured Saharian Arthrospira sp. strain. *Algal Research*. https://doi.org/10.1016/j.algal.2018.09.013

Chentir, I., Kchaou, H., Hamdi, M., Jridi, M., Li, S., Doumandji, A., & Nasri, M. (2019). Biofunctional gelatin-based films incorporated with food grade phycocyanin extracted from the Saharian cyanobacterium Arthrospira sp. *Food Hydrocolloids*. https://doi.org/10.1016/j.foodhyd.2018.11.034

Chi, W., Cao, L., Sun, G., Meng, F., Zhang, C., Li, J., & Wang, L. (2020). Developing a highly pH-sensitive κ-carrageenan-based intelligent film incorporating grape skin powder via a cleaner process. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2019.118862

Choi, I., Lee, J. Y., Lacroix, M., & Han, J. (2017). Intelligent pH indicator film composed of agar/potato starch and anthocyanin extracts from purple sweet potato. *Food Chemistry*. https://doi.org/10.1016/j.foodchem.2016.09.050

Chowdhury, E. U., & Morey, A. (2019). Intelligent Packaging for Poultry Industry. In *Journal of Applied Poultry Research*. https://doi.org/10.3382/japr/pfz098

da Silva e Silva, N., de Souza Farias, F., dos Santos Freitas, M. M., Pino Hernández, E. J. G., Dantas, V. V., Enê Chaves Oliveira, M., Joele, M. R. S. P., & de Fátima Henriques Lourenço, L. (2021). Artificial intelligence application for classification and selection of fish gelatin packaging film produced with incorporation of palm oil and plant essential oils. *Food Packaging and Shelf Life*. https://doi.org/10.1016/j.fpsl.2020.100611

Debreczeny, M., Gombos, Z., & Szalontai, B. (1992). Surface-enhanced resonance Raman spectroscopy of phycocyanin and allophycocyanin. *European Biophysics Journal*. https://doi.org/10.1007/BF00196763

Debreczeny, M. P., Sauer, K., Zhou, J., & Bryant, D. A. (1993). Monomeric C-phycocyanin at room temperature and 77 K: Resolution of the absorption and fluorescence spectra of the individual chromophores and the energy-transfer rate constants. *Journal of Physical Chemistry*. https://doi.org/10.1021/j100140a050

Dimić, G., Kocić-Tanackov, S., Mojović, L., & Pejin, J. (2015). Antifungal Activity of Lemon Essential Oil, Coriander and Cinnamon Extracts on Foodborne Molds in Direct Contact and the Vapor Phase. *Journal of Food Processing and Preservation*. https://doi.org/10.1111/jfpp.12410

Drago, E., Campardelli, R., Pettinato, M., & Perego, P. (2020). Innovations in smart packaging concepts for food: An extensive review. In *Foods*. https://doi.org/10.3390/foods9111628

Ezati, P., & Rhim, J. W. (2020). pH-responsive chitosan-based film incorporated with alizarin for intelligent packaging applications. *Food Hydrocolloids*. https://doi.org/10.1016/j.foodhyd.2019.105629

Ezati, P., Rhim, J. W., Moradi, M., Tajik, H., & Molaei, R. (2020). CMC and CNF-based alizarin incorporated reversible pH-responsive color indicator films. *Carbohydrate Polymers*. https://doi.org/10.1016/j.carbpol.2020.116614

Fadiji, T., Rashvand, M., Daramola, M. O., & Iwarere, S. A. (2023). A Review on Antimicrobial Packaging for Extending the Shelf Life of Food. In *Processes*. https://doi.org/10.3390/pr11020590

Faleiro M.L. (2011). The mode of antibacterial action of essential oils. *Science against Microbial Pathogens: Communicating Current Research and Technological Advances*.

Falkeborg, M. F., Roda-Serrat, M. C., Burnæs, K. L., & Nielsen, A. L. D. (2018). Stabilising phycocyanin by anionic micelles. *Food Chemistry*. https://doi.org/10.1016/j.foodchem.2017.07.007

Farhan, A., & Hani, N. M. (2017). Characterization of edible packaging films based on semi-refined kappa-carrageenan plasticized with glycerol and sorbitol. *Food Hydrocolloids*. https://doi.org/10.1016/j.foodhyd.2016.10.034

Fernández-Rojas, B., Hernández-Juárez, J., & Pedraza-Chaverri, J. (2014). Nutraceutical properties of phycocyanin. In *Journal of Functional Foods*. https://doi.org/10.1016/j.jff.2014.10.011

Francis, G. A., Gallone, A., Nychas, G. J., Sofos, J. N., Colelli, G., Amodio, M. L., & Spano, G. (2012). Factors Affecting Quality and Safety of Fresh-Cut Produce. *Critical Reviews in Food Science and Nutrition*. https://doi.org/10.1080/10408398.2010.503685

Gabr, G. A., El-Sayed, S. M., & Hikal, M. S. (2020). Antioxidant Activities of Phycocyanin: A Bioactive Compound from Spirulina platensis. *Journal of*

Pharmaceutical Research International. https://doi.org/10.9734/jpri/2020/v32i230407

Gantt, E. (1981). Phycobilisomes. *Annual Review of Plant Physiology*. https://doi.org/10.1146/annurev.pp.32.060181.001551

García, A. B., Longo, E., & Bermejo, R. (2021). The application of a phycocyanin extract obtained from Arthrospira platensis as a blue natural colorant in beverages. *Journal of Applied Phycology*. https://doi.org/10.1007/s10811-021-02522-z

Ghaani, M., Cozzolino, C. A., Castelli, G., & Farris, S. (2016). An overview of the intelligent packaging technologies in the food sector. In *Trends in Food Science and Technology*. https://doi.org/10.1016/j.tifs.2016.02.008

Giacomelli da Silva, C., Souza Rodrigues, A., Carolina Lima, A., de Oliveira Mello, R., Dal Pont Morisso, F., Cristina Prestes Dornelles, R., & Hashime Kubota, E. (2022). Gelatin extracted from jundiá skin (Rhamdia quelen): An alternative to the discarded by-product. *Food Research International*. https://doi.org/10.1016/j.foodres.2022.111829

Golmohammadi, A., Razavi, M. S., Tahmasebi, M., Carullo, D., & Farris, S. (2023). Cinnamon Essential-Oil-Loaded Fish Gelatin–Cellulose Nanocrystal Films Prepared under Acidic Conditions. *Coatings*. https://doi.org/10.3390/coatings13081360

Gómez-Guillén, M. C., Pérez-Mateos, M., Gómez-Estaca, J., López-Caballero, E., Giménez, B., & Montero, P. (2009). Fish gelatin: a renewable material for developing active biodegradable films. In *Trends in Food Science and Technology*. https://doi.org/10.1016/j.tifs.2008.10.002

Gudipati, V. (2013). Fish Gelatin: A Versatile Ingredient for the Food and

Pharmaceutical Industries. In *Marine Proteins and Peptides: Biological Activities and Applications*. https://doi.org/10.1002/9781118375082.ch13

Haghighi, H., De Leo, R., Bedin, E., Pfeifer, F., Siesler, H. W., & Pulvirenti, A. (2019). Comparative analysis of blend and bilayer films based on chitosan and gelatin enriched with LAE (lauroyl arginate ethyl) with antimicrobial activity for food packaging applications. *Food Packaging and Shelf Life*. https://doi.org/10.1016/j.fpsl.2018.11.015

Haug, I. J., Draget, K. I., & Smidsrød, O. (2004). Physical and rheological properties of fish gelatin compared to mammalian gelatin. *Food Hydrocolloids*. https://doi.org/10.1016/S0268-005X(03)00065-1

Hermanto, S., Sumarlin, L. O., & Fatimah, W. (2013). Differentiation of Bovine and Porcine Gelatin Based on Spectroscopic and Electrophoretic Analysis. *J.Food Pharm.Sci*.

Holley, R. A., & Patel, D. (2005). Improvement in shelf-life and safety of perishable foods by plant essential oils and smoke antimicrobials. In *Food Microbiology*. https://doi.org/10.1016/j.fm.2004.08.006

Hosseini, S. F., Ghaderi, J., & Gómez-Guillén, M. C. (2021). trans-Cinnamaldehyde-doped quadripartite biopolymeric films: Rheological behavior of film-forming solutions and biofunctional performance of films. *Food Hydrocolloids*. https://doi.org/10.1016/j.foodhyd.2020.106339

Huang, S., Xiong, Y., Zou, Y., Dong, Q., Ding, F., Liu, X., & Li, H. (2019). A novel colorimetric indicator based on agar incorporated with Arnebia euchroma root extracts for monitoring fish freshness. *Food Hydrocolloids*. https://doi.org/10.1016/j.foodhyd.2018.12.009

Japanese Industrial Standards – JIS. (1975). *Japanese Industrial Standard 21707*. Japanese Standards Association.

Kang, S., Wang, H., Xia, L., Chen, M., Li, L., Cheng, J., Li, X., & Jiang, S. (2020). Colorimetric film based on polyvinyl alcohol/okra mucilage polysaccharide incorporated with rose anthocyanins for shrimp freshness monitoring. *Carbohydrate Polymers*. https://doi.org/10.1016/j.carbpol.2019.115402

Kannaujiya, V. K., & Sinha, R. P. (2016). Thermokinetic stability of phycocyanin and phycoerythrin in food-grade preservatives. *Journal of Applied Phycology*. https://doi.org/10.1007/s10811-015-0638-x

Karim, A. A., & Bhat, R. (2009). Fish gelatin: properties, challenges, and prospects as an alternative to mammalian gelatins. In *Food Hydrocolloids* (Vol. 23, Issue 3). https://doi.org/10.1016/j.foodhyd.2008.07.002

Katari, J. K., Uz Zama Khan, M. R., Trivedi, V., & Das, D. (2023). Extraction, purification, characterization and bioactivity evaluation of high purity C-phycocyanin from Spirulina sp. NCIM 5143. *Process Biochemistry*. https://doi.org/10.1016/j.procbio.2023.04.022

Kilinc, D., Ocak, B., & Özdestan-Ocak, Ö. (2021). Preparation, characterization and antioxidant properties of gelatin films incorporated with Origanum onites L. essential oil. *Journal of Food Measurement and Characterization*. https://doi.org/10.1007/s11694-020-00683-y

Kim, H., Beak, S. E., & Song, K. Bin. (2018). Development of a hagfish skin gelatin film containing cinnamon bark essential oil. *LWT*. https://doi.org/10.1016/j.lwt.2018.06.016

Kim, S. K. (2013). Marine Proteins and Peptides: Biological Activities and

Applications. In *Marine Proteins and Peptides: Biological Activities and Applications*. https://doi.org/10.1002/9781118375082

Kong, I., Degraeve, P., & Pui, L. P. (2022). Polysaccharide-Based Edible Films Incorporated with Essential Oil Nanoemulsions: Physico-Chemical, Mechanical Properties and Its Application in Food Preservation—A Review. In *Foods*. https://doi.org/10.3390/foods11040555

Kossyvaki, D., Contardi, M., Athanassiou, A., & Fragouli, D. (2022). Colorimetric Indicators Based on Anthocyanin Polymer Composites: A Review. In *Polymers*. https://doi.org/10.3390/polym14194129

Kumar, D. P., Chandra, M. V., Elavarasan, K., & Shamasundar, B. A. (2018). Structural properties of gelatin extracted from croaker fish (Johnius sp) skin waste. *International Journal of Food Properties*, *20*, S2612–S2625. https://doi.org/10.1080/10942912.2017.1381702

Kumar, P., Elavarasan, K., & Shamasundar, B. (2017). Functional properties of gelatin obtained from croaker fish (Johnius sp) skin by rapid method of extraction. *Food Hydrocolloids*.

Kuswandi, B., & Jumina. (2019). Active and intelligent packaging, safety, and quality controls. In *Fresh-Cut Fruits and Vegetables: Technologies and Mechanisms for Safety Control*. https://doi.org/10.1016/B978-0-12-816184-5.00012-4

Ladokhin, A. S., Jayasinghe, S., & White, S. H. (2000). How to measure and analyze tryptophan fluorescence in membranes properly, and why bother? *Analytical Biochemistry*. https://doi.org/10.1006/abio.2000.4773

Lakshmi, C. (2014). Food Coloring: The Natural Way. *Research Journal of Chemical Sciences Res. J. Chem. Sci*.

Lee, S. Y., Lee, S. J., Choi, D. S., & Hur, S. J. (2015). Current topics in active and intelligent food packaging for preservation of fresh foods. In *Journal of the Science of Food and Agriculture*. https://doi.org/10.1002/jsfa.7218

Li, R., Wang, S., Feng, H., Zhuang, D., & Zhu, J. (2024). An intelligent chitosan/gelatin film via improving the anthocyanin-induced color recognition accuracy for beef sub-freshness differentiation monitoring. *Food Hydrocolloids*. https://doi.org/10.1016/j.foodhyd.2023.109219

Li, Y., Gillilan, R., & Abbaspourrad, A. (2021). Tuning C-Phycocyanin Photoactivity via pH-Mediated Assembly-Disassembly. *Biomacromolecules*. https://doi.org/10.1021/acs.biomac.1c01095

Liao, W., Zhu, Y., Lu, Y., Wang, Y., Dong, X., Xia, G., & Shen, X. (2021). Effect of extraction variables on the physical and functional properties of tilapia gelatin. *LWT*. https://doi.org/10.1016/j.lwt.2021.111514

Liu, C., Huang, J., Zheng, X., Liu, S., Lu, K., Tang, K., & Liu, J. (2020). Heat sealable soluble soybean polysaccharide/gelatin blend edible films for food packaging applications. *Food Packaging and Shelf Life*. https://doi.org/10.1016/j.fpsl.2020.100485

Liu, D., Nikoo, M., Boran, G., Zhou, P., & Regenstein, J. M. (2015). Collagen and gelatin. In *Annual Review of Food Science and Technology* (Vol. 6). https://doi.org/10.1146/annurev-food-031414-111800

Liu, J., Li, K., Chen, Y., Ding, H., Wu, H., Gao, Y., Huang, S., Wu, H., Kong, D., Yang, Z., & Hu, Y. (2022). Active and smart biomass film containing cinnamon oil and curcumin for meat preservation and freshness indicator. *Food Hydrocolloids*. https://doi.org/10.1016/j.foodhyd.2022.107979

Lu, M., Zhou, Q., Yu, H., Chen, X., & Yuan, G. (2022). Colorimetric indicator based on chitosan/gelatin with nano-ZnO and black peanut seed coat anthocyanins for application in intelligent packaging. *Food Research International*. https://doi.org/10.1016/j.foodres.2022.111664

Lucas-González, R., Yilmaz, B., Mousavi Khaneghah, A., Hano, C., Shariati, M. A., Bangar, S. P., Goksen, G., Dhama, K., & Lorenzo, J. M. (2023). Cinnamon: An antimicrobial ingredient for active packaging. In *Food Packaging and Shelf Life*. https://doi.org/10.1016/j.fpsl.2023.101026

Lukavský, J. (2000). Vonshak, A. (Ed.): Spirulina platensis (Arthrospira). Physiology, Cell Biology and Biotechnology. *Photosynthetica*. https://doi.org/10.1023/a:1012498515734

Luo, Q., Hossen, A., Sameen, D. E., Ahmed, S., Dai, J., Li, S., Qin, W., & Liu, Y. (2023). Recent advances in the fabrication of pH-sensitive indicators films and their application for food quality evaluation. In *Critical Reviews in Food Science and Nutrition*. https://doi.org/10.1080/10408398.2021.1959296

Lupatini, A. L., Colla, L. M., Canan, C., & Colla, E. (2017). Potential application of microalga Spirulina platensis as a protein source. In *Journal of the Science of Food and Agriculture*. https://doi.org/10.1002/jsfa.7987

Ma, Q., Liang, T., Cao, L., & Wang, L. (2018). Intelligent poly (vinyl alcohol)-chitosan nanoparticles-mulberry extracts films capable of monitoring pH variations. *International Journal of Biological Macromolecules*. https://doi.org/10.1016/j.ijbiomac.2017.12.049

Ma, Q., & Wang, L. (2016). Preparation of a visual pH-sensing film based on tara gum incorporating cellulose and extracts from grape skins. *Sensors and Actuators, B: Chemical*. https://doi.org/10.1016/j.snb.2016.05.107

Maity, S., & Mallick, N. (2023). Unraveling C-phycocyanin extraction by dark incubation from marine cyanobacterium Leptolyngbya valderiana. *Sustainable Chemistry and Pharmacy*. https://doi.org/10.1016/j.scp.2022.100929

Mali, S., Sakanaka, L. S., Yamashita, F., & Grossmann, M. V. E. (2005). Water sorption and mechanical properties of cassava starch films and their relation to plasticizing effect. *Carbohydrate Polymers*. https://doi.org/10.1016/j.carbpol.2005.01.003

Mariano-Torres, J. A., López-Marure, A., & Domiguez-Sánchez, M. Á. (2015). Synthesis and characterization of polymers based on citric acid and glycerol: Its application in non-biodegradable polymers. *DYNA*. https://doi.org/10.15446/dyna.v82n190.42718

Mendonca, A., Jackson-Davis, A., Moutiq, R., & Thomas-Popo, E. (2018). Use of Natural Antimicrobials of Plant Origin to Improve the Microbiological Safety of Foods. In *Food and Feed Safety Systems and Analysis*. https://doi.org/10.1016/B978-0-12-811835-1.00014-2

Moazami Goodarzi, M., Moradi, M., Tajik, H., Forough, M., Ezati, P., & Kuswandi, B. (2020). Development of an easy-to-use colorimetric pH label with starch and carrot anthocyanins for milk shelf life assessment. *International Journal of Biological Macromolecules*. https://doi.org/10.1016/j.ijbiomac.2020.03.014

Mogany, T., Kumari, S., Swalaha, F. M., & Bux, F. (2019). Extraction and characterisation of analytical grade C-phycocyanin from Euhalothece sp. *Journal of Applied Phycology*. https://doi.org/10.1007/s10811-018-1661-5

Moradi, M., Tajik, H., Almasi, H., Forough, M., & Ezati, P. (2019). A novel pH-sensing indicator based on bacterial cellulose nanofibers and black carrot anthocyanins for monitoring fish freshness. *Carbohydrate Polymers*.

https://doi.org/10.1016/j.carbpol.2019.115030

Moraes, C. C., Sala, L., Cerveira, G. P., & Kalil, S. J. (2011). C-Phycocyanin extraction from Spirulina platensis wet biomass. *Brazilian Journal of Chemical Engineering*. https://doi.org/10.1590/S0104-66322011000100006

Moreira, J. B., Terra, A. L. M., Costa, J. A. V., & Morais, M. G. de. (2018). Development of pH indicator from PLA/PEO ultrafine fibers containing pigment of microalgae origin. *International Journal of Biological Macromolecules*. https://doi.org/10.1016/j.ijbiomac.2018.07.028

Müller, P., & Schmid, M. (2019). Intelligent packaging in the food sector: A brief overview. In *Foods*. https://doi.org/10.3390/foods8010016

Munawaroh, H. S. H., Gumilar, G. G., Alifia, C. R., Marthania, M., Stellasary, B., Yuliani, G., Wulandari, A. P., Kurniawan, I., Hidayat, R., Ningrum, A., Koyande, A. K., & Show, P. L. (2020). Photostabilization of phycocyanin from Spirulina platensis modified by formaldehyde. *Process Biochemistry*. https://doi.org/10.1016/j.procbio.2020.04.021

Munawaroh, H. S. H., Pratiwi, R. N., Gumilar, G. G., Aisyah, S., Rohilah, S., Nurjanah, A., Ningrum, A., Susanto, E., Pratiwi, A., Arindita, N. P. Y., Martha, L., Chew, K. W., & Show, P. L. (2023). Synthesis, modification and application of fish skin gelatin-based hydrogel as sustainable and versatile bioresource of antidiabetic peptide. *International Journal of Biological Macromolecules*. https://doi.org/10.1016/j.ijbiomac.2023.123248

Musso, Y. S., Salgado, P. R., & Mauri, A. N. (2019). Smart gelatin films prepared using red cabbage (Brassica oleracea L.) extracts as solvent. *Food Hydrocolloids*. https://doi.org/10.1016/j.foodhyd.2018.11.036

Naghdi, S., Rezaei, M., & Abdollahi, M. (2021). A starch-based pH-sensing and ammonia detector film containing betacyanin of paperflower for application in intelligent packaging of fish. *International Journal of Biological Macromolecules*. https://doi.org/10.1016/j.ijbiomac.2021.09.045

Narancic, T., Verstichel, S., Reddy Chaganti, S., Morales-Gamez, L., Kenny, S. T., De Wilde, B., Babu Padamati, R., & O'Connor, K. E. (2018). Biodegradable Plastic Blends Create New Possibilities for End-of-Life Management of Plastics but They Are Not a Panacea for Plastic Pollution. *Environmental Science and Technology*. https://doi.org/10.1021/acs.est.8b02963

Nazzaro, F., Fratianni, F., De Martino, L., Coppola, R., & De Feo, V. (2013). Effect of essential oils on pathogenic bacteria. In *Pharmaceuticals*. https://doi.org/10.3390/ph6121451

Nemet, N. T., Šošo, V. M., & Lazić, V. L. (2010). Effect of glycerol content and pH value of film-forming solution on the functional properties of protein-based edible films. *Acta Periodica Technologica*. https://doi.org/10.2298/APT1041057N

Nicoletti, M. (2016). Microalgae nutraceuticals. *Foods*. https://doi.org/10.3390/foods5030054

Niu, L., Zhou, X., Yuan, C., Bai, Y., Lai, K., Yang, F., & Huang, Y. (2013). Characterization of tilapia (Oreochromis niloticus) skin gelatin extracted with alkaline and different acid pretreatments. *Food Hydrocolloids*. https://doi.org/10.1016/j.foodhyd.2013.04.014

Nur Hanani, Z. A., Roos, Y. H., & Kerry, J. P. (2014). Use and application of gelatin as potential biodegradable packaging materials for food products. *International Journal of Biological Macromolecules*. https://doi.org/10.1016/j.ijbiomac.2014.04.027

Nurilmala, M., Nurjanah, N., Fatriani, A., Indarwati, A. R., & Pertiwi, R. M. (2022). KEMUNDURAN MUTU IKAN BARONANG (Siganus javus) PADA PENYIMPANAN SUHU CHILLING. *Jurnal Teknologi Perikanan Dan Kelautan*. https://doi.org/10.24319/jtpk.12.93-101

Nurilmala, M., Sriwahyuni, D., Nugraha, R., Ridzna Kartika, V., Darmawan, N., Apriliani Wulandari Putri, E., Wirabudi Pranata, A., & Ochiai, Y. (2023). Response surface methodology (RSM) for optimization of gelatin extraction from pangasius fish skin and its utilization for hard capsules. *Arabian Journal of Chemistry*. https://doi.org/10.1016/j.arabjc.2023.104938

O' Callaghan, K. A. M., & Kerry, J. P. (2016). Consumer attitudes towards the application of smart packaging technologies to cheese products. *Food Packaging and Shelf Life*. https://doi.org/10.1016/j.fpsl.2016.05.001

Parshina, E. Y., & Lee, V. (2023). Spectral and conformational characteristics of phycocyanine associated with changes of medium pH. *Photosynthesis Research*.

Paswan, M. B., Chudasama, M. M., Mitra, M., Bhayani, K., George, B., Chatterjee, S., & Mishra, S. (2016). Fluorescence Quenching Property of C-Phycocyanin from Spirulina platensis and its Binding Efficacy with Viable Cell Components. *Journal of Fluorescence*. https://doi.org/10.1007/s10895-015-1742-7

Păușescu, I., Dreavă, D. M., Bîtcan, I., Argetoianu, R., Dăescu, D., & Medeleanu, M. (2022). Bio-Based pH Indicator Films for Intelligent Food Packaging Applications. *Polymers*. https://doi.org/10.3390/polym14173622

Pávai, M., Mihály, J., & Paszternák, A. (2015). pH and CO2 Sensing by Curcumin-Coloured Cellophane Test Strip. *Food Analytical Methods*. https://doi.org/10.1007/s12161-015-0102-1

Peng, J., Zi, Y., Xu, J., Zheng, Y., Huang, S., Hu, Y., Liu, B., Wang, X., & Zhong, J. (2022). Effect of extraction methods on the properties of tilapia scale gelatins. *International Journal of Biological Macromolecules*. https://doi.org/10.1016/j.ijbiomac.2022.09.094

Pez Jaeschke, D., Rocha Teixeira, I., Damasceno Ferreira Marczak, L., & Domeneghini Mercali, G. (2021). Phycocyanin from Spirulina: A review of extraction methods and stability. In *Food Research International*. https://doi.org/10.1016/j.foodres.2021.110314

Piñeros-Hernandez, D., Medina-Jaramillo, C., López-Córdoba, A., & Goyanes, S. (2017). Edible cassava starch films carrying rosemary antioxidant extracts for potential use as active food packaging. *Food Hydrocolloids*. https://doi.org/10.1016/j.foodhyd.2016.09.034

Purohit, A., Kumar, V., Chownk, M., & Yadav, S. K. (2019). Processing-Independent Extracellular Production of High Purity C-Phycocyanin from Spirulina platensis. *ACS Biomaterials Science and Engineering*. https://doi.org/10.1021/acsbiomaterials.9b00370

Putra, N. S. S. U., Lapong, I., Rimmer, M. A., Raharjo, S., & Dhand, N. K. (2013). Comparative Performance of Four Strains of Nile Tilapia (Oreochromis niloticus) in Brackish Water Ponds in Indonesia. *Journal of Applied Aquaculture*. https://doi.org/10.1080/10454438.2013.834282

Qin, Y., Liu, Y., Zhang, X., & Liu, J. (2020). Development of active and intelligent packaging by incorporating betalains from red pitaya (Hylocereus polyrhizus) peel into starch/polyvinyl alcohol films. *Food Hydrocolloids*. https://doi.org/10.1016/j.foodhyd.2019.105410

Ramos, M., Valdés, A., Beltrán, A., & Garrigós, M. (2016). Gelatin-Based Films and

Coatings for Food Packaging Applications. *Coatings*. https://doi.org/10.3390/coatings6040041

Ranjani, R. (2013). Anticancer properties of blue green algae Spirulina platensis – Review. *International Journal of Medicine and Pharmaceutical Sciences (IJMPS)*.

Rawdkuen, S., Thitipramote, N., & Benjakul, S. (2013). Preparation and functional characterisation of fish skin gelatin and comparison with commercial gelatin. *International Journal of Food Science and Technology*. https://doi.org/10.1111/ijfs.12067

Realini, C. E., & Marcos, B. (2014). Active and intelligent packaging systems for a modern society. *Meat Science*. https://doi.org/10.1016/j.meatsci.2014.06.031

Reis, A., Mendes, A., Lobo-Fernandes, H., Empis, J. A., & Novais, J. M. (1998). Production, extraction and purification of phycobiliproteins from Nostoc sp. *Bioresource Technology*. https://doi.org/10.1016/S0960-8524(98)00064-9

Renugadevi, K., Valli Nachiyar, C., Sowmiya, P., & Sunkar, S. (2018). Antioxidant activity of phycocyanin pigment extracted from marine filamentous cyanobacteria Geitlerinema sp TRV57. *Biocatalysis and Agricultural Biotechnology*. https://doi.org/10.1016/j.bcab.2018.08.009

Rezaei, M., & Motamedzadegan, A. (2015). The Effect of Plasticizers on Mechanical Properties and Water Vapor Permeability of Gelatin-Based Edible Films Containing Clay Nanoparticles. *World Journal of Nano Science and Engineering*. https://doi.org/10.4236/wjnse.2015.54019

Rhim, J. W., & Ng, P. K. W. (2007). Natural biopolymer-based nanocomposite films for packaging applications. *Critical Reviews in Food Science and Nutrition*.

https://doi.org/10.1080/10408390600846366

Ribes, S., Fuentes, A., Talens, P., & Barat, J. M. (2018). Prevention of fungal spoilage in food products using natural compounds: A review. *Critical Reviews in Food Science and Nutrition*. https://doi.org/10.1080/10408398.2017.1295017

Robertson, G. L. (2016). Food Packaging: Principles and Practice, Third Edition. In *Food Packaging: Principles and Practice, Third Edition*. https://doi.org/10.1201/b21347

Romay, C., Gonzalez, R., Ledon, N., Remirez, D., & Rimbau, V. (2005). C-Phycocyanin: A Biliprotein with Antioxidant, Anti-Inflammatory and Neuroprotective Effects. *Current Protein & Peptide Science*. https://doi.org/10.2174/1389203033487216

Roy, S., Priyadarshi, R., Ezati, P., & Rhim, J. W. (2022). Curcumin and its uses in active and smart food packaging applications - a comprehensive review. In *Food Chemistry*. https://doi.org/10.1016/j.foodchem.2021.131885

Roy, S., & Rhim, J. W. (2021). Fabrication of bioactive binary composite film based on gelatin/chitosan incorporated with cinnamon essential oil and rutin. *Colloids and Surfaces B: Biointerfaces*. https://doi.org/10.1016/j.colsurfb.2021.111830

Sadeghi, K., Yoon, J. Y., & Seo, J. (2020). Chromogenic Polymers and Their Packaging Applications: A Review. In *Polymer Reviews*. https://doi.org/10.1080/15583724.2019.1676775

Sae-Leaw, T., Benjakul, S., & O'Brien, N. M. (2016). Effect of Pretreatments and Defatting of Seabass Skins on Properties and Fishy Odor of Gelatin. *Journal of Food Biochemistry*. https://doi.org/10.1111/jfbc.12267

Safari, R., Amiri, R. Z., & Esmaeilzadeh Kenari, R. (2020). Antioxidant and antibacterial activities of C-phycocyanin from common name Spirulina platensis. *Iranian Journal of Fisheries Sciences*. https://doi.org/10.22092/ijfs.2019.118129

Salinas-Hernández, R. M., González-Aguilar, G. A., & Tiznado-Hernández, M. E. (2015). Utilization of physicochemical variables developed from changes in sensory attributes and consumer acceptability to predict the shelf life of fresh-cut mango fruit. *Journal of Food Science and Technology*. https://doi.org/10.1007/s13197-013-0992-0

Sani, I. K., Pirsa, S., & Tağı, Ş. (2019). Preparation of chitosan/zinc oxide/Melissa officinalis essential oil nano-composite film and evaluation of physical, mechanical and antimicrobial properties by response surface method. *Polymer Testing*. https://doi.org/10.1016/j.polymertesting.2019.106004

Santoso, B., Sinaga, T. L. D., Priyanto, G., & Hermanto. (2022). Effect of natural active compound addition on mechanical and functional properties ocanna starch based edible film. *Food Science and Technology (Brazil)*. https://doi.org/10.1590/fst.51020

Schaefer, D., & Cheung, W. M. (2018). Smart Packaging: Opportunities and Challenges. *Procedia CIRP*. https://doi.org/10.1016/j.procir.2018.03.240

See, S. F., Ghassem, M., Mamot, S., & Babji, A. S. (2015). Effect of different pretreatments on functional properties of African catfish (Clarias gariepinus) skin gelatin. *Journal of Food Science and Technology*. https://doi.org/10.1007/s13197-013-1043-6

Sergeeva, Y. E., Zakharevich, A. A., Sukhinov, D. V., Koshkalda, A. I., Kryukova, M. V., Malakhov, S. N., Antipova, C. G., Klein, O. I., Gotovtsev, P. M., & Grigoriev, T. E. (2023). Chitosan Sponges for Efficient Accumulation and Controlled Release of C-Phycocyanin. *BioTech*, *12*(3), 55.

https://doi.org/10.3390/biotech12030055

Shi, C., Ji, Z., Zhang, J., Jia, Z., & Yang, X. (2022). Preparation and characterization of intelligent packaging film for visual inspection of tilapia fillets freshness using cyanidin and bacterial cellulose. *International Journal of Biological Macromolecules*. https://doi.org/10.1016/j.ijbiomac.2022.02.072

Shreaz, S., Wani, W. A., Behbehani, J. M., Raja, V., Irshad, M., Karched, M., Ali, I., Siddiqi, W. A., & Hun, L. T. (2016). Cinnamaldehyde and its derivatives, a novel class of antifungal agents. In *Fitoterapia*. https://doi.org/10.1016/j.fitote.2016.05.016

Silhavy, T. J., Kahne, D., & Walker, S. (2010). The bacterial cell envelope. In *Cold Spring Harbor perspectives in biology*. https://doi.org/10.1101/cshperspect.a000414

Silva, L. A., Kuhn, K. R., Moraes, C. C., Burkert, C. A. V., & Kalil, S. J. (2009). Experimental Design as a Tool for Optimization of C-Phycocyanin Purification by Precipitation from Spirulina platensis. *Journal of the Brazilian Chemical Society*. https://doi.org/10.1590/S0103-50532009000100003

Sinthusamran, S., Benjakul, S., & Kishimura, H. (2015). Molecular characteristics and properties of gelatin from skin of seabass with different sizes. *International Journal of Biological Macromolecules*. https://doi.org/10.1016/j.ijbiomac.2014.11.024

Sobiechowska-Sasim, M., Stoń-Egiert, J., & Kosakowska, A. (2014). Quantitative analysis of extracted phycobilin pigments in cyanobacteria—an assessment of spectrophotometric and spectrofluorometric methods. *Journal of Applied Phycology*. https://doi.org/10.1007/s10811-014-0244-3

Sohany, M., Tawakkal, I. S. M. A., Ariffin, S. H., Shah, N. N. A. K., & Yusof, Y. A. (2021). Characterization of anthocyanin associated purple sweet potato starch and peel-based ph indicator films. *Foods*. https://doi.org/10.3390/foods10092005

Soni, B., Kalavadia, B., Trivedi, U., & Madamwar, D. (2006). Extraction, purification and characterization of phycocyanin from Oscillatoria quadripunctulata-Isolated from the rocky shores of Bet-Dwarka, Gujarat, India. *Process Biochemistry*. https://doi.org/10.1016/j.procbio.2006.04.018

Sothornvit, R., & Krochta, J. M. (2001). Plasticizer effect on mechanical properties of β-lactoglobulin films. *Journal of Food Engineering*. https://doi.org/10.1016/S0260-8774(00)00237-5

Stadnichuk, I. N., & Tropin, I. V. (2017). Phycobiliproteins: Structure, functions and biotechnological applications. *Applied Biochemistry and Microbiology*, *53*(1), 1–10. https://doi.org/10.1134/S0003683817010185

Stefani, R. (2015). Development and Evaluation of a Smart Packaging for the Monitoring of Ricotta Cheese Spoilage. *MOJ Food Processing & Technology*. https://doi.org/10.15406/mojfpt.2015.01.00004

Stunda-Zujeva, A., Berele, M., Lece, A., & Šķesters, A. (2023). Comparison of antioxidant activity in various spirulina containing products and factors affecting it. *Scientific Reports*. https://doi.org/10.1038/s41598-023-31732-3

Tanner, D. (2016). Impacts of Storage on Food Quality. In *Reference Module in Food Science*. https://doi.org/10.1016/b978-0-08-100596-5.03479-x

Tassanawat, S., Phandee, A., Magaraphan, R., Nithitanakul, M., & Manuspiya, H. (2007). pH-Sensitive PP/clay nanocomposites for beverage smart packaging. *Proceedings of the 2nd IEEE International Conference on Nano/Micro*

Engineered and Molecular Systems, IEEE NEMS 2007. https://doi.org/10.1109/NEMS.2007.352062

Tatol, M., & Mokrzycki, W. (2011). Color difference Delta E - A survey Colour difference Δ E - A survey. *Machine GRAPHICS & VISION*.

Terra, A. L. M., Moreira, J. B., Costa, J. A. V., & Morais, M. G. de. (2021a). Development of pH indicators from nanofibers containing microalgal pigment for monitoring of food quality. *Food Bioscience*. https://doi.org/10.1016/j.fbio.2021.101387

Terra, A. L. M., Moreira, J. B., Costa, J. A. V., & Morais, M. G. de. (2021b). Development of time-pH indicator nanofibers from natural pigments: An emerging processing technology to monitor the quality of foods. *LWT*. https://doi.org/10.1016/j.lwt.2021.111020

Tongnuanchan, P., Benjakul, S., & Prodpran, T. (2012). Properties and antioxidant activity of fish skin gelatin film incorporated with citrus essential oils. *Food Chemistry*. https://doi.org/10.1016/j.foodchem.2012.03.094

Tongnuanchan, P., Benjakul, S., & Prodpran, T. (2013). Physico-chemical properties, morphology and antioxidant activity of film from fish skin gelatin incorporated with root essential oils. *Journal of Food Engineering*. https://doi.org/10.1016/j.jfoodeng.2013.03.005

Turan, D. (2021). Water Vapor Transport Properties of Polyurethane Films for Packaging of Respiring Foods. *Food Engineering Reviews*. https://doi.org/10.1007/s12393-019-09205-z

Valcarcel, J., Hermida-Merino, C., Piñeiro, M. M., Hermida-Merino, D., & Vázquez, J. A. (2021). Extraction and characterization of gelatin from skin by-products of seabream, seabass and rainbow trout reared in aquaculture. *International Journal of Molecular Sciences*. https://doi.org/10.3390/ijms222212104

Vanderroost, M., Ragaert, P., Devlieghere, F., & De Meulenaer, B. (2014). Intelligent food packaging: The next generation. In *Trends in Food Science and Technology*. https://doi.org/10.1016/j.tifs.2014.06.009

Vasconcelos, N. G., Croda, J., & Simionatto, S. (2018). Antibacterial mechanisms of cinnamon and its constituents: A review. In *Microbial Pathogenesis*. https://doi.org/10.1016/j.micpath.2018.04.036

Vázquez, J. A., Hermida-Merino, C., Hermida-Merino, D., Piñeiro, M. M., Johansen, J., Sotelo, C. G., Pérez-Martín, R. I., & Valcarcel, J. (2021). Characterization of gelatin and hydrolysates from valorization of farmed salmon skin by-products. *Polymers*. https://doi.org/10.3390/polym13162828

Veličković, L., Simović, A., Gligorijević, N., Thureau, A., Obradović, M., Vasović, T., Sotiroudis, G., Zoumpanioti, M., Brûlet, A., Ćirković Veličković, T., Combet, S., Nikolić, M., & Minić, S. (2023). Exploring and strengthening the potential of R-phycocyanin from Nori flakes as a food colourant. *Food Chemistry*. https://doi.org/10.1016/j.foodchem.2023.136669

Vieira, M. G. A., Da Silva, M. A., Dos Santos, L. O., & Beppu, M. M. (2011). Natural-based plasticizers and biopolymer films: A review. In *European Polymer Journal*. https://doi.org/10.1016/j.eurpolymj.2010.12.011

Wang, B., Xu, X., Fang, Y., Yan, S., Cui, B., & Abd El-Aty, A. M. (2022). Effect of Different Ratios of Glycerol and Erythritol on Properties of Corn Starch-Based Films. *Frontiers in Nutrition*. https://doi.org/10.3389/fnut.2022.882682

Wang, F., Xie, C., Tang, H., Hao, W., Wu, J., Sun, Y., Sun, J., Liu, Y., & Jiang, L.

(2023). Development, characterization and application of intelligent/active packaging of chitosan/chitin nanofibers films containing eggplant anthocyanins. *Food Hydrocolloids*. https://doi.org/10.1016/j.foodhyd.2023.108496

Wang, J., Sun, X., Zhang, H., Dong, M., Li, L., Zhangsun, H., & Wang, L. (2022). Dual-functional intelligent gelatin based packaging film for maintaining and monitoring the shrimp freshness. *Food Hydrocolloids*. https://doi.org/10.1016/j.foodhyd.2021.107258

Wang, Y., Zhao, R., Yu, L., Zhang, Y., He, Y., & Yao, J. (2014). Evaluation of cinnamon essential oil microemulsion and its vapor phase for controlling postharvest gray mold of pears (Pyrus pyrifolia). *Journal of the Science of Food and Agriculture*. https://doi.org/10.1002/jsfa.6360

Wu, C., Sun, J., Chen, M., Ge, Y., Ma, J., Hu, Y., Pang, J., & Yan, Z. (2019). Effect of oxidized chitin nanocrystals and curcumin into chitosan films for seafood freshness monitoring. *Food Hydrocolloids*. https://doi.org/10.1016/j.foodhyd.2019.04.047

Wu, H., Jiao, C., Li, S., Li, Q., Zhang, Z., Zhou, M., & Yuan, X. (2022). A Facile Strategy for Development of pH-Sensing Indicator Films Based on Red Cabbage Puree and Polyvinyl Alcohol for Monitoring Fish Freshness. *Foods*. https://doi.org/10.3390/foods11213371

Wu, H. L., Wang, G. H., Xiang, W. Z., Li, T., & He, H. (2016). Stability and Antioxidant Activity of Food-Grade Phycocyanin Isolated from Spirulina platensis. *International Journal of Food Properties*. https://doi.org/10.1080/10942912.2015.1038564

Wu, J., Sun, X., Guo, X., Ge, S., & Zhang, Q. (2017). Physicochemical properties, antimicrobial activity and oil release of fish gelatin films incorporated with cinnamon essential oil. *Aquaculture and Fisheries*. https://doi.org/10.1016/j.aaf.2017.06.004

Xie, Y., Huang, Q., Wang, Z., Cao, H., & Zhang, D. (2017). Structure-activity relationships of cinnamaldehyde and eugenol derivatives against plant pathogenic fungi. *Industrial Crops and Products*. https://doi.org/10.1016/j.indcrop.2016.12.043

Yan, J., Zhang, H., Yuan, M., Qin, Y., & Chen, H. (2022). Effects of anthocyanin-rich Kadsura coccinea extract on the physical, antioxidant, and pH-sensitive properties of biodegradable film. *Food Biophysics*. https://doi.org/10.1007/s11483-022-09727-w

Ye, Z., Xiu, S., Shahbazi, A., & Zhu, S. (2012). Co-liquefaction of swine manure and crude glycerol to bio-oil: Model compound studies and reaction pathways. *Bioresource Technology*. https://doi.org/10.1016/j.biortech.2011.09.126

Yousuf, B., Deshi, V., Ozturk, B., & Siddiqui, M. W. (2019). Fresh-cut fruits and vegetables: Quality issues and safety concerns. In *Fresh-Cut Fruits and Vegetables: Technologies and Mechanisms for Safety Control*. https://doi.org/10.1016/B978-0-12-816184-5.00001-X

Yu, Z., Alsammarraie, F. K., Nayigiziki, F. X., Wang, W., Vardhanabhuti, B., Mustapha, A., & Lin, M. (2017). Effect and mechanism of cellulose nanofibrils on the active functions of biopolymer-based nanocomposite films. *Food Research International*. https://doi.org/10.1016/j.foodres.2017.05.009

Zhai, X., Shi, J., Zou, X., Wang, S., Jiang, C., Zhang, J., Huang, X., Zhang, W., & Holmes, M. (2017). Novel colorimetric films based on starch/polyvinyl alcohol incorporated with roselle anthocyanins for fish freshness monitoring. *Food Hydrocolloids*. https://doi.org/10.1016/j.foodhyd.2017.02.014

Zhang, X., Lu, S., & Chen, X. (2014). A visual pH sensing film using natural dyes from Bauhinia blakeana Dunn. *Sensors and Actuators, B: Chemical*. https://doi.org/10.1016/j.snb.2014.02.094

Zheng, L., Liu, L., Yu, J., & Shao, P. (2022). Novel trends and applications of natural pH-responsive indicator film in food packaging for improved quality monitoring. In *Food Control*. https://doi.org/10.1016/j.foodcont.2021.108769