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Antioxidant Properties and Thermal Stability of Active Packaging Incorporated with Dyes

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Abstract. Marine polysaccharides-based packaging that is both bio-based and biodegradable has garnered significant interest for preserving food freshness. This study introduces an eco-friendly packaging solution derived from agar and chitosan, designed not only to protect food but also to serve as an innovative indicator of rancidity and spoilage. By blending agar and chitosan using casting methods and mixed with various dyes, a material was created that demonstrated excellent compatibility due to their structural similarities and the thermal stability, confirmed by TGA and DSC analysis. TGA and DSC examinations verified the thermal stability of the blends at 180°C, with low crystallinity. Furthermore, agar and chitosan-based film with added 0.2% BTB dye possesses 493 ppm of DPPH scavenging activity while the control sample retains on 776.03 ppm. These results offer significant insights into the potential industrial applications of these compounds, particularly in sectors where both high thermal stability and effective antioxidant properties are crucial.

1 Introduction

In recent years, there has been a significant increase in the need for packaging solutions that are both ethical and environmentally sustainable, especially within the food sector. The biobased and biodegradable nature of packaging derived from marine polysaccharides has elevated its appeal as a feasible substitute for conventional materials [1]. When

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contemplating sustainability from an ecological perspective, it is imperative to actively contribute to ensure the lasting conservation of the environment and a resilient ecosystem consistently. Packaging materials are also intimately linked to this. Packaging materials that use fewer virgin resources and generate post-consumption materials that may be recycled or reused from readily available sources are classified as sustainable [2]. The increasing prevalence of agar and chitosan in the food industry can be attributed to their numerous benefits observed in packaging applications. Through a comparison of these biodegradable, naturally existing materials with conventional plastics, the environmental footprint is greatly diminished [3]. Agar is derived from seawater algae, whereas chitosan is produced from the chitin present in the shells of crustaceans [4]. Due to its very low cost and abundant availability, the utilization of seaweed has great potential in the creation of bioplastics [5]. The first phases of bioplastic growth have been conducted by utilizing agar as polymers and glycerol as plasticizer through extrusion methods with the inclusion of water. The findings suggest that the combination of these components produces a thermoplastic material [6]. Moreover, both chitosan and agar utilize antioxidant characteristics that mitigate oxidation and spoilage.

After careful consideration, the ability to include various additives to enhance functionality makes agar and chitosan a feasible alternative for effective and environmentally friendly food packaging solutions [7]. An innovative solution to the increasing worries over plastic pollution is provided by the production of biodegradable films utilizing blended copolymers of agar and chitosan. Collectively, they generate a synergistic impact that amplifies the mechanical characteristics and thermal durability of the resulting film [8]. The integration of several natural and synthetic dyes into biodegradable films composed of agar and chitosan offers a viable strategy in material science and food technology [9]. Dyes including phenolphthalein, bromothymol blue (BTB), curcumin, butterfly pea extract, and anthocyanin not only provide vibrant colours but also augment the functional attributes of these environmentally sustainable films [10].

Phenolphthalein, a recognized pH indicator, alters its colour in reaction to pH fluctuations, so becoming biodegradable films interactive for applications such as packaging, where the assessment of spoilage or freshness is essential [11]. Bromothymol blue functions as a pH-responsive dye, demonstrating the ability of molds to indicate environmental changes [12]. Natural dye such as curcumin, derived from turmeric, and anthocyanin from diverse fruits and vegetables, have advantages beyond just aesthetics. Curcumin is acclaimed for its antioxidant attributes, potentially prolonging the shelf life of food items, whilst anthocyanins offer considerable health advantages, encompassing anti-inflammatory and anti-cancer effects [13]. Butterfly pea extract, abundant in anthocyanins, has striking color-changing characteristics and enhances nutritional content, rendering it a favored option for health-oriented uses [14]. Integrating these dyes into agar and chitosan films not only fosters sustainability but also improves their mechanical, thermal, and barrier characteristics. The biocompatibility of chitosan and the gelling properties of agar combine to produce functional films suitable for diverse applications, including food packaging and biomedical uses [15].

This novel application of natural and synthetic colors in biodegradable films presents several benefits: minimizing environmental impact, delivering functionality, and augmenting the aesthetic allure of items. Ongoing research in this field enhances the feasibility of creating intelligent, biodegradable materials that react to environmental stimuli, thereby facilitating sustainable packaging solutions and health-related uses in the future [16]. Additionally, the antioxidant characteristics of the film aid in reducing oxidative degradation, therefore optimizing the shelf life of food products [17]. This study is a pivotal advancement in developing environmentally sustainable packaging options that are in line with current environmental objectives. The process employed involves casting combinations of agar and chitosan with various dyes to generate a film that exhibits excellent compatibility, as determined by its structural similarity and exceptional thermal stability.

2 Material and methods

2.1 Biodegradable Film Preparation

Materials, including agar and chitosan sourced from commercial products, were used to develop biodegradable films containing marine polysaccharides such as agar and chitosan. Additionally, sorbitol as plasticizer, the solvents and chemicals necessary for film preparation were acetic acid and distilled water, which were employed along with equipment for film casting and subsequent characterization. These materials formed the foundation for research aimed at exploring the potential of marine polysaccharides in creating sustainable and environmentally friendly film production in the laboratory of raw material preservation, IPB University.

This investigation employed multiple essential processes utilizing several colors. Initially, the marine polysaccharides, namely 3% (w/v) agar and different concentrations of chitosan at 0% (F0), 1% (F1), 2% (F2), 3% (F3), and 4% (F4) (w/v), were solubilized in 1% (w/v) acetic acid. Various natural and synthetic dyes, including phenolphthalein, bromothymol blue, curcumin, butterfly pea, and anthocyanin, were subsequently integrated into the solutions at 0.2% w/v concentration to investigate the influence of dye on the film properties.

Subsequently, the solutions were meticulously combined with 1% (w/v) sorbitol to improve the film's flexibility and stability, yielding film-forming solutions with varying visual attributes contingent upon the included dye. The solutions were then poured onto petri dishes and dehydrated at 50°C for 5 hours to create biodegradable films. The films were meticulously removed, exposing a spectrum of colors based on the dye employed, and preserved in an evacuated desiccator for subsequent study.

All acquired films were assessed for tensile strength, elongation at break, thickness and water vapour permeability. To standardize conditions for subsequent tests, the samples were kept at room temperature for 15 minutes. Additional tests were performed to evaluate antioxidant activities and thermal stability, together with the impact of the inserted dyes on these attributes, facilitating a thorough assessment of the films' prospective applications. The use of diverse colors facilitated an investigation into the impact of color on the performance and aesthetics of the resultant biodegradable films.

2.2 Antioxidant Activity

For this investigation, we produced biodegradable film samples with dimensions of 3 × 3 cm, making sure that a minimum of three sections were randomly selected for analysis. Following that, the film samples were diluted in 10 mL of methanol and kept undisturbed for 24 hours to guarantee thorough extraction of soluble substances. After completing the extraction process, the liquid was filtered to eliminate any solid residues, yielding a transparent sample extract suitable for subsequent antioxidant testing. To evaluate the antioxidant properties of the extract, a precise experimental protocol was adhered to 500 ⌠L of the filtered sample extract were meticulously combined with 2 mL of a 0.06 mM DPPH (2,2-diphenyl-1-picrylhydrazyl) solution, which was synthesized in methanol.

The DPPH solution is a stable free radical frequently employed as a reagent to assess the capacity of different chemicals to scavenge free radicals. The mixture was thereafter kept in a condition of darkness for a duration of 30 minutes at room temperature. The designated incubation duration is of utmost importance since it facilitates the interaction between the antioxidant chemicals included in the film extract and the DPPH, resulting in a reduction of the radical and a subsequent decline in the absorbance. The absorbance of the solution obtained after incubation was measured using a spectrophotometer maintained at a wavelength of 517 nm and describe as follows:

$$\text{DPPH radical-scavenging activity} = \frac{A0 - A1}{A0} x\ 100$$

Where A0 is the absorbance of film extract and ethanol solutions without DPPH, and A1 is the absorbance of the film extract and DPPH solutions at 517 nm.

The selectivity of this wavelength in detecting DPPH allows for a precise assessment of the level of antioxidant activity exhibited by the film extract. An observed reduction in absorbance at this specific wavelength suggests an increased capacity of the free radicals to be scavenged. To compare and validate the results, a methanol solution was used as a reference blank to ensure that any absorbance measurements were reliably calibrated against a control without antioxidant activity.

Furthermore, quercetin, a widely recognized flavonoid renowned for its substantial antioxidant characteristics, was employed as a positive control to measure the efficacy of the film extracts. This study aims to determine the relative antioxidant capacity of the biodegradable films under investigation by comparing the absorbance values of the film samples with those of quercetin. The present methodology offers a comprehensive and methodical framework for assessing the prospective health advantages of innovative biodegradable materials.

2.3 Preparation and characterization of thermal stability

Thermogravimetric analysis (TGA) is a critical technique employed to assess the thermal stability and composition of materials. In this study, TGA was conducted using a Mettler-Toledo thermogravimetric analyzer, specifically the model TGA/SDTA851e, known for its precision and reliability in thermal analysis. The experimental procedure involved heating samples within a controlled temperature range of 40 to 500 °C, which is essential for observing any thermal degradation or weight loss that may occur during the process. The analysis was performed under a nitrogen atmosphere, providing an inert environment that minimizes the chances of oxidation and enables a more accurate representation of the sample's thermal behavior. The heating rate was consistently maintained at 10 °C per minute, ensuring uniform temperature increments and allowing for the observation of any phase transitions or decomposition reactions occurring within the sample.

For each TGA run, a small sample was prepared, with weights ranging from 4 to 10 mg. The precision in sample size is crucial, as it significantly impacts the accuracy of the thermal measurements. As the temperature increased, the mass of the sample and the corresponding pan was continuously recorded, generating a thermogravimetric curve that depicts the relationship between mass change and temperature. This curve serves as a critical tool for interpreting the material's thermal stability, identifying weight loss at specific temperature points, and informing on the composition of the sample, be it moisture content, volatile components, or residue remaining after thermal degradation. Overall, the methodology employed in this TGA analysis underscores its importance in material characterization and the thermophysical evaluation of various substances in research and industrial applications.

3 Results and Discussion

3.1 Mechanical properties

The presented data (Table 1) outlines the mechanical properties and water vapor permeability (WVP) of various formulations (F0-F4) of agar and chitosan with differing chitosan concentrations. Analyzing the correlations between tensile strength, elongation at break, thickness, and WVP provides insights into the performance and applicability of these formulations.

Table 1. Mechanical properties of film

Formulation	Tensile strength (MPa)	Elongation at break (%)	Thickness (mm)	WVP (g/ (m^2.24h)
F0	3.61	10.38	0.30	1270.4810
F1	2.92	20.98	0.42	1383.3635
F2	2.27	6.75	0.61	1387.7902
F3	3.17	5.30	0.62	1370.4810
F4	5.22	2.07	0.28	1088.9837

The tensile strength varies significantly across the formulations, with F4 exhibiting the highest value (5.22 MPa) and F2 showing the lowest (2.27 MPa). This trend suggests that the inclusion of chitosan improves the mechanical properties of the composite films to a certain extent. Higher tensile strength in F4 may be attributed to optimal chitosan concentration leading to better interactions and network formation within the matrix [18].

Elongation at break reflects the ductility of the material. Here, F1 has the highest elongation (20.98%), while F4 shows the lowest (2.07%). The increase in chitosan seems to modify the flexibility; the reduction in elongation in formulations with higher chitosan content might indicate a more rigid structure, affecting the material's ability to stretch before breaking. This inverse relationship between tensile strength and elongation could be aligned with findings from other studies, indicating a common behavior in biopolymer composites [19].

Thickness films generally possess better mechanical integrity but may increase the diffusion distance for water vapor, potentially impacting permeability. Future research should include these measurements for complete understanding [20]. Water vapor permeability is a critical factor in food packaging applications. The WVP results show variability across formulations, with F0 having the lowest (1270.481 g/m^2.24h) and F4 the lowest at (1088.9837 g/m^2.24h). This suggests that increased chitosan concentration does not consistently lower WVP, as might be expected with traditional polymer films. Instead, the film's structure, influenced by both agar and chitosan interactions, contributes to the overall permeability [21].

The results suggest that the formulation of agar and chitosan can effectively manipulate tensile properties and water vapor permeability, positioning these biopolymer composites as promising materials for various applications, particularly in food packaging [22].

3.2 Antioxidant characteristic

The results from table 2 demonstrate the effects of different natural dyes and their respective antioxidant properties when combined with specific concentrations of agar, chitosan, sorbitol, and aquadest. Each treatment revealed varying levels of antioxidant activity, with notable implications for both food science and potential applications in natural dyeing processes.

Table 2. Antioxidant activities of various dyes.

Treatment	Dyes	Agar (g)	Chitosan (g)	Sorbitol (g)	Aquadest (mL)	Dyes	Antioxidant (ppm)
A1	Phenolphthalein (mL)	3	1	1	100	0.2	337.42
B2	BTB (mL)	3	1	1	100	0.2	493
C3	Curcumin (g)	3	1	1	100	0.2	347.72
D4	Butterfly pea (g)	3	1	1	100	0.2	139
E5	Anthocyanin (g)	3	1	1	100	0.2	25.28
F6	Control	3	1	1	100	0	776.03

In treatment A1 (phenolphthalein), the antioxidant achieved was 337 ppm This relatively moderate effectiveness may imply that while phenolphthalein is useful, its antioxidant capabilities may not be as pronounced compared to other dyes. Treatment B2 (bromothymol blue/ BTB), resulting in an antioxidant of 493 ppm. This suggests a more robust interaction within the system that enhances its antioxidant effectiveness [23]. For treatment C3 (curcumin) yielded an antioxidant of 347.72 ppm. The lower antioxidant level in comparison to BTB can be attributed to the chemical structure of curcumin, which, despite its known benefits, may have limitations under specific conditions of incorporation with chitosan and agar. In contrast, treatment D4 (butterfly pea), displayed a significantly lower antioxidant of 139 ppm. This suggests that while butterfly pea is acclaimed for its health benefits, its efficacy as an antioxidant extract within this specific formulation may require further exploration [24].

Anthocyanin in treatment (E5) produced an antioxidant of 256.28 ppm, indicating that this dye holds potential, albeit not as high as BTB, for antioxidant applications. The results from these treatments reflect the complex interaction between the compounds used, where the solubility, molecular weight, and affinity with chitosan and agar may influence the bioactivity of each dye [25]. Lastly, F6 the control group (without any dye) recorded the highest antioxidant at 776.03 ppm. This counterintuitive result could warrant further investigation, as it may indicate an intrinsic property of the agar or other non-dye components in the formulation that enhances antioxidant activity [9].

3.3 Thermal Stability

The thermal analysis data indicates a remarkable uniformity among the many chemicals evaluated throughout the temperature range of 0°C to 200°C (Figure 1). This stability indicates that all these compounds demonstrate negligible change and do not experience substantial mass loss within this temperature range. The controlled and tested compounds exhibit significant thermal stability, preserving their integrity efficiently up to around 200°C. As the temperature exceeds this threshold, notable discrepancies in the differential thermogravimetric analysis (dTGA) curves become evident. These differences indicate the emergence of distinct thermal degradation behaviors unique to each molecule. The dTGA peaks are essential indications, signifying the temperatures at which the most significant mass losses transpire, these points are directly associated with the decomposition processes of the substances involved [26]. Moreover, it is crucial to recognize that each chemical possesses distinct degradation characteristics, as evidenced by the differing peak positions and forms on the dTGA curves. These discrepancies emphasize the necessity of understanding the thermal properties of each molecule, illustrating their reactions to elevated temperatures and the potential implications for their practical applications or stability in diverse situations [27]. These findings provide important insights into thermal stability and degradation mechanisms, emphasizing the critical influence of temperature on the behavior of these materials.

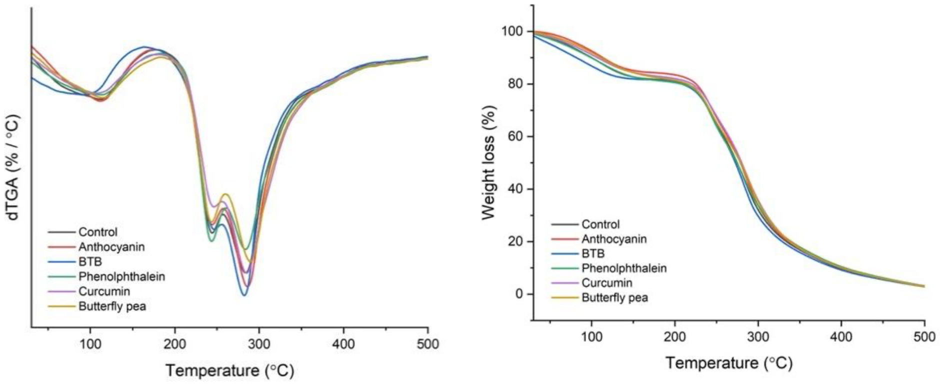

Fig. 1. The TG/dTGA curves for the tested compounds in thermal stability.

The thermal examination of the samples indicates that all curves exhibit a progressive decrease in weight across the assessed temperature range. The ongoing weight reduction is presumably due to the evaporation of water or other volatile constituents often present in diverse samples. This property is common in thermal studies, when moisture content or low-boiling point compounds are released as temperature increases [26]. As we advance over this temperature range, a more pronounced weight loss becomes evident in all samples. This event signifies substantial material degradation or the liberation of less stable chemicals, highlighting the reactivity and temperature sensitivity of the substances under examination [28].

Subsequent analysis of the data indicates that when temperatures attain roughly 400 to 500°C, all samples, including the control, uniformly converge to a residual weight loss ranging from 10% to 20%. The consistency in residual weight loss indicates that, despite previous differences in thermal behavior, the samples finally attain comparable thermal stability at high temperatures. This convergence underscores the commonalities in the fundamental composition and thermal characteristics of the examined compounds [26]. Additionally, an analysis of chemicals including anthocyanin, bromothymol blue (BTB), phenolphthalein, curcumin, and butterfly pea reveals that these samples have thermal degradation patterns similar to those of the control sample [29].

Nonetheless, there are minor differences in the shapes and placements of their deterioration curves. These discrepancies may signify disparities in the thermal stability or degradation mechanisms of each chemical [27]. The findings offer essential insights into the thermal properties of the compounds and their potential for stability, degradation, and functionality at elevated temperatures [30].

4 Conclusion

Research shows that biodegradable films made from marine polysaccharides like agar and chitosan, combined with various natural and synthetic dyes, offer a sustainable alternative for food packaging. These films help maintain food freshness and indicate spoilage. They demonstrate excellent thermal stability, maintaining integrity up to 180°C, with notable antioxidant properties, particularly when bromothymol blue dye is included. The study emphasizes their potential industrial applications due to these environmental and functional benefits. Additionally, the examination of natural colorants like curcumin and anthocyanins revealed that curcumin has significant antioxidant activity, while anthocyanins show more modest effects. All tested compounds maintain thermal stability up to 200°C, with varying degradation beyond this point. Overall, the findings highlight the importance of antioxidant effectiveness and thermal stability, suggesting potential applications in food preservation and as therapeutic agents for oxidative stress-related conditions.

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References

1. M. A. Sani, M. Azizi-Lalabadi, M. Tavassoli, K. Mohammadi, and D. J. McClements, Recent advances in the development of smart and active biodegradable packaging materials, Nanomaterials, **11**, 5, 1–34 (2021) https://doi.org10.3390/nano11051331.
2. A. Liyanapathiranage et al., Recent Developments in Edible Films and Coatings for Fruits and Vegetables, Coatings, **13**, 7, 1–34 (2023) https://doi.org 10.3390/coatings13071177.
3. U. Siripatrawan and W. Vitchayakitti, Improving functional properties of chitosan films as active food packaging by incorporating with propolis, Food Hydrocoll., **61**, 695–702, 2016, https://doi.org10.1016/j.foodhyd.2016.06.001.
4. E. Science, Physical properties of bioplastic agar /chitosan blend Physical properties of bioplastic agar /chitosan blend, 0–11, https://doi.org10.1088/1755-1315/978/1/012046.
5. S. Lordan, R. P. Ross, and C. Stanton, Marine bioactives as functional food ingredients: Potential to reduce the incidence of chronic diseases, Mar. Drugs, **9**, 6, 1056–1100 (2011) https://doi.org10.3390/md9061056.
6. M. Ahmad, N. P. Nirmal, M. Danish, J. Chuprom, and S. Jafarzedeh, Characterisation

of composite films fabricated from collagen/chitosan and collagen/soy protein isolate for food packaging applications, RSC Adv., **6**, 85, 82191–82204 (2016) https://doi.org10.1039/c6ra13043g.

7. C. Li and J. Lin, Applications and Future Trends, Microw. Noncontact Motion Sens. Anal., 157–202 (2013) https://doi.org10.1002/9781118742556.ch5.
8. Y. Zhao et al., Comprehensive review of polysaccharide-based materials in edible packaging: A sustainable approach, Foods, **10**, 8 (2021) https://doi.org10.3390/FOODS10081845.
9. F. Versino, F. Ortega, Y. Monroy, S. Rivero, O. V. López, and M. A. García, Sustainable and Bio-Based Food Packaging: A Review on Past and Current Design Innovations, Foods, **12**, 5 (2023) https://doi.org10.3390/foods12051057.
10. R. van Tuil, P. Fowler, M. Lawther, and C. J. Weber, Biobased Packaging Materials for the Food Industry (2000)
11. K. V. Aleksanyan, Polysaccharides for Biodegradable Packaging Materials: Past, Present, and Future (Brief Review), Polymers (Basel)., **15**, 2 (2023) https://doi.org10.3390/polym15020451.
12. S. Sutthasupa, C. Padungkit, and S. Suriyong, Colorimetric ammonia (NH3) sensor based on an alginate-methylcellulose blend hydrogel and the potential opportunity for the development of a minced pork spoilage indicator, Food Chem., **362**, 130151 (2021) https://doi.org10.1016/j.foodchem.2021.130151.
13. S. Ghareghomi, M. Rahban, Z. Moosavi-Movahedi, M. Habibi-Rezaei, L. Saso, and A. A. Moosavi-Movahedi, The potential role of curcumin in modulating the master antioxidant pathway in diabetic hypoxia-induced complications, Molecules, **26**, 24, 1–26 (2021) https://doi.org10.3390/molecules26247658.
14. C. G. Lavinia, Hue expression and shelf-life stability studies of natural blue food color in beverage model solution: Clitoria ternatea extract, Spirulina, Genipa americana (2016).
15. E. a El-hefian and A. H. Yahaya, Rheological study of chitosan and its blends: An overview, Maejo Int. J. Sci. Technol., **4**, 02, 210–220 (2010).
16. K. Chi, H. Wang, and J. M. Catchmark, Sustainable starch-based barrier coatings for packaging applications, Food Hydrocoll., **103**, 1, 105696 (2020) https://doi.org10.1016/j.foodhyd.2020.105696.
17. P. K. Pidatala, D. Bellmer, and W. McGlynn, Oxidative Stability of a New Peanut Butter Bite Product, Int. J. Food Sci., **2021**, 1–9 (2021) https://doi.org10.1155/2021/5528315.
18. N. Rachmawati, R. Triwibowo, and R. Widianto, Squalen Bulletin of Marine & Fisheries Postharvest & Biotechnology Mechanical Properties And Biodegradability Of Acid-Soluble Chitosan-Starch Based Film, **10**, 1, 1–7 (2015).
19. J. Liu, S. Liu, Y. Chen, L. Zhang, J. Kan, and C. Jin, Physical, mechanical and antioxidant properties of chitosan films grafted with different hydroxybenzoic acids, Food Hydrocoll., **71**, 176–186 (2017) https://doi.org10.1016/j.foodhyd.2017.05.019.
20. S. Hidayati, Zulferiyenni, U. Maulidia, W. Satyajaya, and S. Hadi, Effect of glycerol concentration and carboxy methyl cellulose on biodegradable film characteristics of seaweed waste, Heliyon, **7**, 8 (2021) https://doi.org10.1016/j.heliyon.2021.e07799.
21. P. Cazón, G. Velazquez, J. A. Ramírez, and M. Vázquez, Polysaccharide-based films and coatings for food packaging: A review, Food Hydrocoll., **68**, 136–148 (2017) https://doi.org10.1016/j.foodhyd.2016.09.009.

22. T. Gasti et al., Smart biodegradable films based on chitosan/ methylcellulose containing Phyllanthus reticulatus anthocyanin for monitoring the freshness of fish fillet, Int. J. Biol. Macromol., **187**, 7, 451–461 (2021) https://doi.org10.1016/j.ijbiomac.2021.07.128.
23. F. W. Mahatmanti, M. Alauhdin, and S. B. C. Kusumaningrum, Smart and Green Packaging Made from Chitosan-based Biofilm with the Addition of Ginger Oil and Anthocyanins from Butterfly Pea Flower Extract (Clitoria Ternatea L), J. Kim. Sains dan Apl., **27**, 2, 53–63 (2024) https://doi.org10.14710/jksa.27.2.53-63.
24. O. Romruen, P. Kaewprachu, T. Karbowiak, and S. Rawdkuen, Development of Smart Bilayer Alginate/Agar Film Containing Anthocyanin and Catechin-Lysozyme, Polymers (Basel)., **14**, 22 (2022) https://doi.org10.3390/polym14225042.
25. S. Sahraee, J. M. Milani, J. M. Regenstein, and H. S. Kafil, Protection of foods against oxidative deterioration using edible films and coatings: A review, Food Biosci., **32**, 4 (2019) https://doi.org10.1016/j.fbio.2019.100451.
26. M. Worzakowska, M. Sztanke, J. Rzymowska, and K. Sztanke, Thermal Decomposition Path—Studied by the Simultaneous Thermogravimetry Coupled with Fourier Transform Infrared Spectroscopy and Quadrupole Mass Spectrometry—Of Imidazoline/Dimethyl Succinate Hybrids and Their Biological Characterization, Materials (Basel)., **16**, 13 (2023) https://doi.org10.3390/ma16134638.
27. C. Tsioptsias, D. Fardis, X. Ntampou, I. Tsivintzelis, and C. Panayiotou, "Thermal Behavior of Poly(vinyl alcohol) in the Form of Physically Crosslinked Film," Polymers (Basel)., **15**, 8 (2023) https://doi.org10.3390/polym15081843.
28. M. S. Jayaprakash, Shashidhar, A. Lagashetty, S. K. Ganiger, and T. K. Vishnuvardhan, Thermal and morphological studies of chitosan and agar-agar blends, Curr. Chem. Lett., **12**, 2, 375–382 (2023) https://doi.org10.5267/j.ccl.2022.12.002.
29. L. C. Soedirga, I. C. Matita, and J. Sidharta, Physicochemical Characteristics of Butterfly Pea Flower Petals Steep Obtained at Different Steeping Temperature and Time, Reaktor, **23**, 1, 9–15 (2023), https://doi.org/10.14710/reaktor.
30. M. I. Din, T. Ghaffar, J. Najeeb, Z. Hussain, R. Khalid, and H. Zahid, Potential perspectives of biodegradable plastics for food packaging application-review of properties and recent developments, Food Addit. Contam. - Part A Chem. Anal. Control. Expo. Risk Assess., **37**, 4, 665–680 (2020) https://doi.org10.1080/19440049.2020.1718219.