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Edible Coating from Breadfruit Starch and Chitosan for Food Packaging

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Abstract: Lectures that encompass Education for Sustainable Development (ESD) can encourage awareness about sustainable development by integrating current issues, such as the potential of breadfruit starch and chitosan for making edible coatings for food packaging. This work aimed to study the development of edible coating from breadfruit starch (BS) and chitosan (CH) for food packaging based on SDGs aspects and as preliminary research to develop worksheets for prospective chemistry teacher students. BS-CH edible film developed by solvent evaporation method, thickness measurement, and physical properties for application on chili, carrot, and sweet potato which. The results showed that the optimal comprehensive properties of the film were obtained when the mass ratio of 3% AS to 1% CH was 7:3. The solubility test results show that the addition of CH ratio increases the swelling of the film before the dissolution process. The tensile strength and elongation of the film increased with the addition of CH until the optimum condition with tensile strength values of 3.01 MPa and 58.26%. The optimum mass ratio was applied through the coating of carrot, chili, and sweet potato which can prevent mass weight and mushroom. Apart from that, student opinion data was generated in the form of potential edible coating topics in the theme of ESD issues. In addition, student opinion data was generated in the form of expectations of edible coatings topics in ESD-laden chemistry learning, including understanding and applying ESD principles and the context of edible coatings and introducing the potential of edible coatings in society so that it is expected to improve 21st-century skills. The results of this research show the need to integrate the topic of edible coating of breadfruit starch and chitosan in worksheets for prospective chemistry teacher students.

Keywords: Edible coating, Breadfruit and chitosan, Food packaging

Introduction

Fruits and vegetables are very easily damaged during the ripening process and after harvest so their shelf life is shorter and they are susceptible to microbial attack, oxidation, and browning (Matloob et al., 2023). Post-harvest technology is very necessary to maintain quality and extend the shelf life of harvested products. The importance of postharvest technology to maintain the quality of horticultural products in terms of organoleptic, physio-chemical, and sensory properties from various external damages including chemical, physical, and biological (Díaz-Montes & Castro-Muñoz, 2021; Matloob et al., 2023). *Edible coating* is a post-harvest technology in the form of packaging that is safe to use and can minimize moisture loss, water and gas exchange while improving the texture of the product (McHugh & Krochta, 1994). The nature of *edible coatings*, which are easy to eat, non-toxic, and cost-effective compared to other synthetic coatings, is very advantageous (Raghav et al., 2016). *Edible coatings* can be made from proteins, polysaccharides, lipids, plasticizers, and emulsifiers which are environmentally friendly (Matloob et al., 2023; Bizymis & Tzia, 2022). *Edible coating* simultaneously addresses the problem of pollution generated by waste, as well as developing strategies for obtaining food that benefits consumer health (Iamareerat et al., 2018; Vega-Castro et al., 2022).

This research used breadfruit starch and chitosan as the main matrix for edible coatings. Among various biopolymers, starch was chosen to be mixed with chitosan, because starch has specific advantages including being tasteless, odorless, transparent, and resistant to O_2 flow. In addition, starch is a cheap, abundant, and easy-to-process raw material (Zheng et al., 2019). Sukun is a typical tropical plant with a total fruit production of 28,078.5 tonnes in 2021 in West Java province, Indonesia (Open Data West Java, 2021). Its patriarchal content reaches 28.78% based on Bezerra et al. (2019) with the amylose and amylopectin contents varying from 16.4 to 53.7% and 72.3 to 77.5% depending on the maturity level, climatic conditions, and seasonal effect of the fruit (Turi et al., 2015). Perera et al. (2021) starch base material as edible has low tensile strength and elongation, so additional ingredients are needed, namely chitosan. Chitosan-based functional nanocomposite films improved physical properties and enhanced antioxidant and antimicrobial functions (Roy & Rhim, 2021). Chitosan can form intermolecular bonds with starch, which helps improve film structure and physical properties, transparency, and antibacterial activity (Shah et al., 2016). Modified starch-based edibles have been successfully used in preserving fruits, one of which is banana starch and chitosan for coating strawberry, apple, and mango fruits which can reduce mass shrinkage and increase shelf life (Abera et al., 2024).

Edible coating as a food packager is included in several SDGs goals in economic, social, and environmental aspects. The first goal of the SDGs, namely "eliminating poverty", this topic can be linked to the issue of low welfare of local farmers due to the lack of post-harvest technology. The second goal is "food security" which can be overcome through sustainable agriculture by increasing the value of agricultural products through *edible post-harvest technology*. The ninth objective is "industry, innovation and infrastructure" regarding predictions of the potential *of edible coatings* to increase the shelf life of agricultural products on an industrial scale. The fifteenth goal is "life on land" regarding biodiversity as the main raw material for making *edibles,* the potential for *edible coatings* to increase the shelf life of agricultural products on an industrial scale (UNESCO, 2014). The relationship between the topic *of edible coatings* and several SDGs goals can be applied in learning chemistry with ESD content. Understanding the topic of *edible coatings* as food packaging is supported through courses studied which include organic and analytical chemistry, both theoretical in class and practicum. Universities play a strategic role towards sustainable development to provide a holistic perspective (Findler et al., 2019; Kohl et al., 2021). Educators are required to incorporate sustainable development (ESD) education into pre-service teacher training curricula (UNESCO, 2014). Lectures containing ESD can create agents of change for the future, improve character and values, increase knowledge and skills, support sustainable development, and serve as learning innovation. Therefore, implementing ESD in lectures, especially in chemistry education study programs, still needs to be carried out and studied in more depth.

In this era of globalization, skills in terms of sustainability are needed to face a complex and ever-changing world by looking at problems from various perspectives to find sustainable solutions so that the actions taken are more responsible (Tarrant, 2016 & Anita et al., 2023). According to Singh-Pillay (2020), ESD-oriented learning gives rise to three main learning experiences, namely encouraging social learning abilities, promoting real-world contexts, and as a catalyst for student-teacher awareness regarding their role as agents of change. Students are required to care and be able to solve problems in the surrounding environment as well as tolerance for social and economic problems to realize ESD. Learning that is carried out with an ESD lens makes students have broader ideas about various aspects of sustainability such as economic, social, and even environmental aspects (Paristiowati et al., 2022; Singh-Pillay, 2020). ESD-oriented learning can be implemented in two methods, either online (Paristiowati et al., 2022) through a summer school program or face-to-face (Singh-Pillay, 2020) with maximum results according to the expected learning objectives. Based on the background explanation, shows the potential for integrating the topic *of edible coating* from breadfruit starch and chitosan in worksheets for prospective chemistry teacher students with ESD content.

Method

This research used the laboratory experiment method which is strengthened by open-ended questionnaire data relating to ESD content and the topic of BS-CH edible coating as food packaging in chemistry learning. Questionnaires were given to 36 chemistry education students at one of the universities in Bandung City. The data obtained was analyzed to identify students' opinions and expectations regarding the chemistry learning they had taken. The results of the experiment and answers to open-ended questions provide insight into the application of BS-CH edible coating as food packaging and the need for this topic to be integrated into ESD-based chemistry learning in worksheets for prospective chemistry teacher students.

Materials

Ripe breadfruit (*Artocarpus altilis*), distilled water, chitosan produced by Surindo Biotech Cirebon Indonesia, glacial acetic acid 98%, glycerin. The researcher selected breadfruit depending on availability and harvesting stage. The chilies (*Capsicum frutescens*) and carrots (*Daucus carota L.*) used were obtained from farmers directly to determine the time of picking which made it easier for researchers to calculate the optimum period of coating. Meanwhile, sweet potato (*Ipomoea batatas L.*) was obtained from the market based on availability.

Breadfruit Starch Preparation

The starch content in breadfruit was obtained from 4 breadfruit grains with a mass of 2.7 kg. The breadfruit was peeled and washed, cut into pieces, and crushed with water (1:4 b/v ratio). After grinding, the starch slurry was kept to settle for 12 hours. The starch was allowed to settle in a container, the liquid part above was discarded, and the starch was separated. The prepared raw starch was kept for evaporation and dried in an oven at 100°C for 6 hours (Abera et al., 2024). The yield of starch obtained was calculated as given in Equation (1):

Yield = (Mass of dried starch, g / Total mass of breadfruit, g) x 100 (Modesti et al., 2019)

Edible Film Preparation

The starch solution was prepared (by dissolving 3 g of starch in 100 mL distilled water) and heating it for 35 minutes on a hot plate (85^{o}C). The gelatinized starch solution (indicated by a clear color) was lowered to 50◦C while stirring, then 1% glycerin was added and homogenized for 15 minutes. Chitosan solution was prepared by mixing 1 g chitosan with 1% (v/v) glacial acetic acid (100 mL). The chitosan solution was allowed to stand for 1x24 hours before being added to the starch-glycerin solution at 50◦C while stirring until the solution was completely homogeneous for 10 minutes. The starch-chitosan-glycerol solution was reduced in temperature while stirring for 10 minutes at 25◦C to remove bubbles (Abera et al., 2024). The solution was dried at room temperature for 3x24 hours in a 110x130 mm container at a total volume of 50 mL. The molded edible film was peeled off, stored in a plastic bag at room temperature, and kept in a desiccator before further examination.

Physical and Mechanical Properties Edible Film

Film Thickness

Film thickness was measured with a digital micrometer (Krisbow Micrometer Digital 10175725 0-25 mm/ 0,001 mm) at two random positions Determination of Tensile Strength and Elongation at Break.

Water Solubility

The water solubility of the films was determined based on the methodology described Zhang *et al* (2019) with slight modifications. Specifically, 2 specimens of each film (2 cm × 3 cm) were initially weighed (W1) and then placed in 50 mL of distilled water for 24 hours at room temperature. Excess water on top of the film was carefully scraped off using filter paper. The undissolved film was dried at room temperature and weighed at time intervals of 30, 60, and 90 min and then weighed again (W2). Water Solubility (WS) was calculated according to the following equation:

$$\text{WS (\%)} = \frac{(W1-W2)}{W1} \text{ x } 100\%$$

Tensile Strength and Elongation at Break

The mechanical properties of the film were determined using a material testing machine (Zwicky 2,5 kN). The test was conducted according to ASTM D882-09. Samples were cut into strips (10,5 cm × 2,5 cm) and inserted into the apparatus. Tensile strength (TS) and percent elongation at break (EAB) were calculated as follows:

$$TS = \frac{F}{d \ x \ L}$$

where F was the maximum tension (N), d was the initial grip separation (30 mm), and L was the average film thickness (mm).

$$EAB\% = \frac{l1 - l0}{l0} \ x \ 100\%$$

where l1 was the final displacement (mm), l0 was the initial displacement.

Preparation of Coating

Chilies, carrots, and sweet potatoes were coated with the dipping method. Some samples were divided into control and coated vegetables. The prepared coating solution was poured into a container. Each weighed sample was dipped into the coating solution for 1 minute and then held for 30 seconds to remove excess solution. Chilies, carrots, and sweet potatoes were coated with the dipping method. Some samples were divided into control and coated vegetables. The prepared coating solution was poured into a container. Each weighed sample was dipped into the coating solution for 1 minute and then held for 30 seconds to remove excess solution. The control and coated vegetables were stored for 15 days at ambient condition (25 ± 1˚C) with a 5-day sample weighing interval (Chettri et al., 2023).

Results and Discussion

Results of Breadfruit Starch Extraction

Based on the extraction results, the starch yield was 14.3089% (w/w) after the starch was sieved using a 100 mesh sieve. The resulting starch is white with very fine granules as presented in the image below

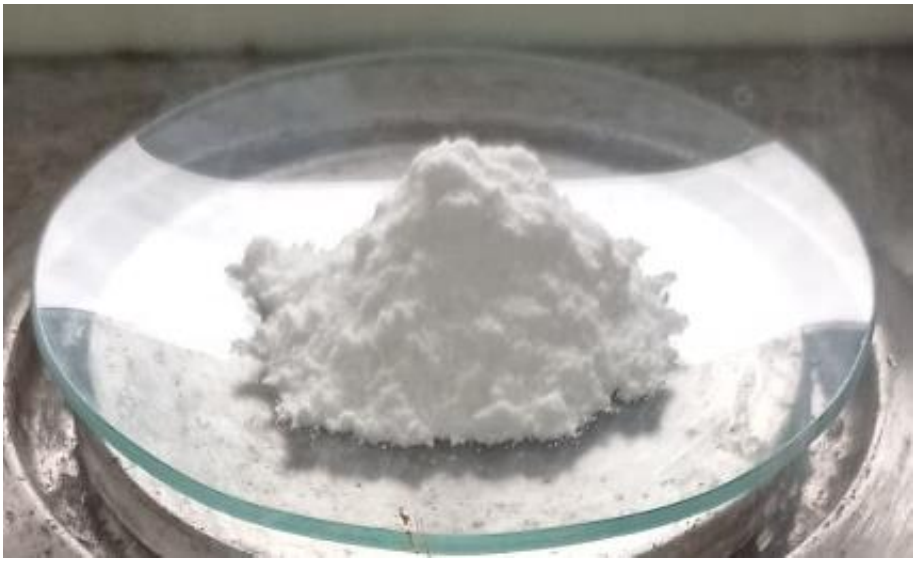


Figure 1. Breadfruit starch

Morphology Analyze

The morphology of edible film is one of the properties that need to be considered as food packaging (Zheng *et al*., 2019). Based on Figures 2 and 3 below, the BS-CH edible film is transparent and almost colorless at various BS-CH variations. The writing on the edible film is very clear, this shows that breadfruit starch is fully gelatinized and homogeneous when mixed with chitosan solution. The BS-CH edible film did not break easily and was flexible when held, indicating that the addition of chitosan improved the mechanical properties of the edible film. These morphological observations suggest a continuous transparent film through the process of homogenization and drying at room temperature.

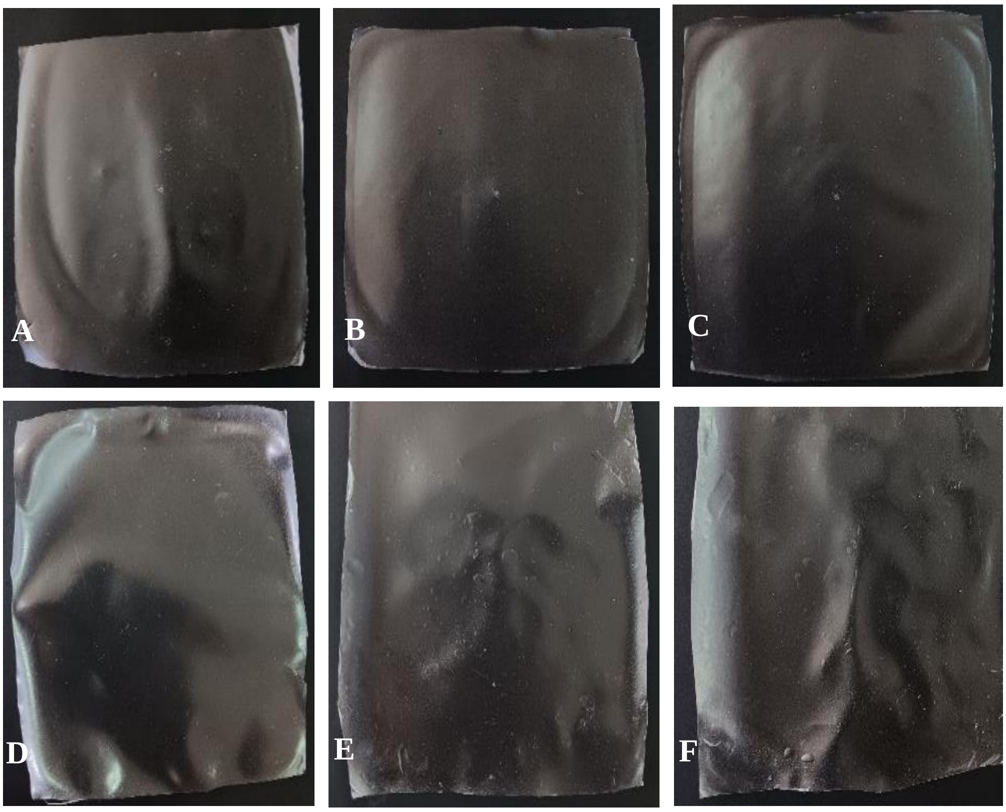


Figure 2. Appearance of BS-CH edible film in various compositions of BS:CH (A) 10:0, (B) 9:1, (C) 8:2, (D) 7:3, (E) 6:4, (F) 5:5 on a Black Background

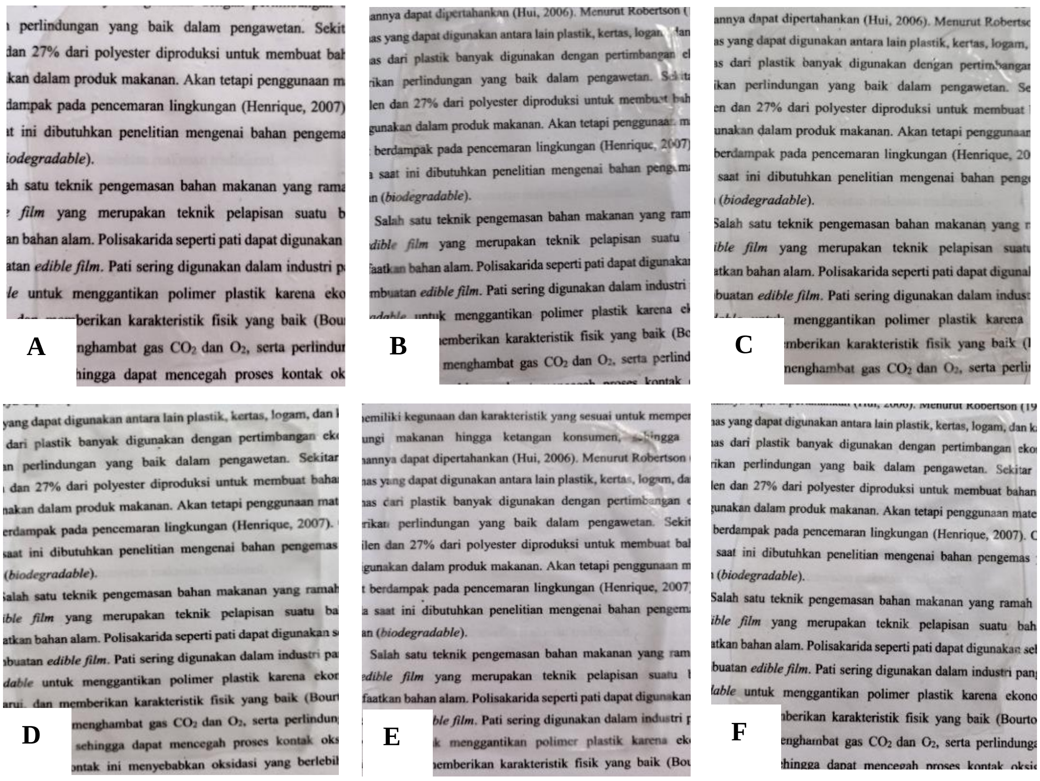


Figure 3. Appearance of BS-CH edible film in various compositions of BS:CH (A) 10:0, (B) 9:1, (C) 8:2, (D) 7:3, (E) 6:4, (F) 5:5 on a Black Background on a Letter

Physical Properties Edible Film

Table 1. Physical properties of different films

Edible Films	Thickness (mm)	Water Solubility (%)		
		30 minutes	60 minutes	90 minutes
Variation of BS				
2%	0,1 ± 0,0707	10 ± 0,0352	36 ± 0,0176	36 ± 0,0012
3%	0,157 ± 0,03535	-33 ± 0,0941	13 ± 0,0610	24 ± 0,0066
4%	0,165 ± 0,0212	-49 ± 0,0948	-7 ± 0,1627	17 ± 0,0645
5%	0,22375 ± 0,0159	-75 ± 0,0563	-31 ±0,0563	8 ± 0,0495
Variation of BS:CH				
10:0	0,157 ± 0,0353	-33 ± 0,0941	13 ± 0,061	24 ± 0,0066
9:1	0,1535 ± 0,0318	-82 ± 0,0718	26 ± 0,0163	28 ± 0,0028
8:2	0,115 ± 0,0056	-123 ± 0,0690	19 ± 0,0027	28 ± 0,0064
7:3	0,096 ± 0,0042	-138 ± 0,1154	18 ± 0,1676	31 ± 0,0113
6:4	0,08 ± 0,0155	-213 ± 0,0000	-54 ± 0,0000	21 ± 0,0000
5:5	0,075 ± 0,0042	-394 ± 0,2791	-112 ± 0,2558	15 ± 0,0139

Edible Film Thickness

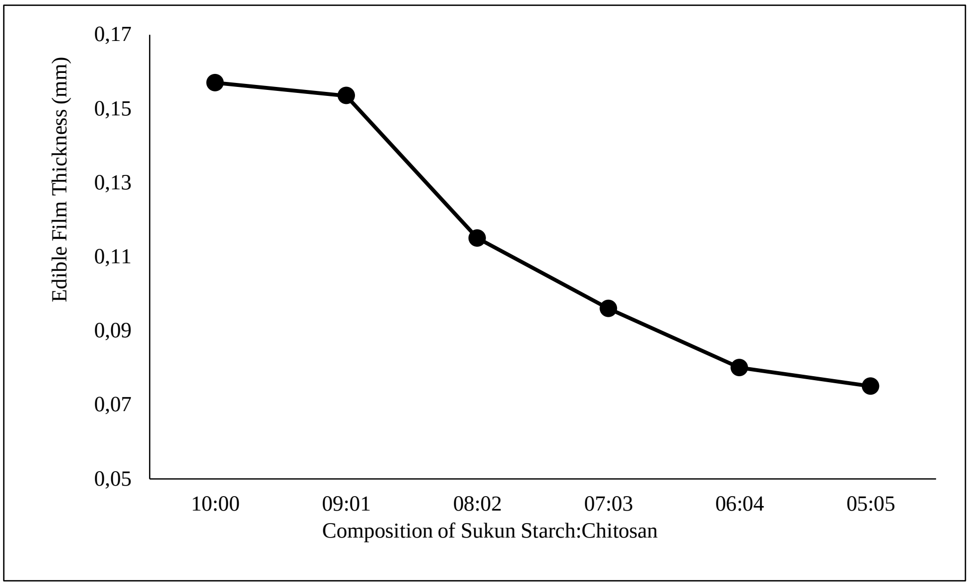
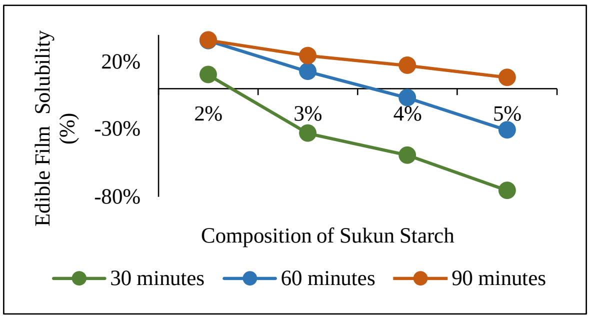


Figure 4. Edible film thickness

Film thickness is an important property, as it significantly affects various physical characteristics, including opacity, mechanical properties, and water vapor permeability (Loukri et al., 2024). Based on the film thickness measurement results in Table 1 or Figure 4, the film thickness is affected by different treatments. Increasing the volume of starch solution makes the film thickness increase significantly, with thickness in the range of 0.075 - 0.157 mm, this indicates that the total soluble starch solids in the film are greater than chitosan.

Water Solubility

One of the physical properties of the film that needs to be considered is water solubility, which provides information about the durability of edible films in water (Loukri et al., 2024). Food products require materials with certain properties to ensure their quality during storage, distribution, and consumption (Filipini et al., 2020). The water solubility of BS edible film decreased significantly with increasing concentration of starch solution, from 36% to 8% at weighing at constant mass 90th minutes after drying. Before dissolving in water, the BS edible film experienced swelling where water entered the edible film cavity at 30th and 60th minutes after drying as shown in Table 2. or Figure 5. (Left). Complete dissolution of starch is relatively slow, starch undergoes swelling before dissolving into water. During the swelling process, solvent molecules diffuse into the starch granules which increases the volume of starch. This causes the movement of starch macromolecular segments to increase before forming a stable dissolving phase (Perez-rea et al., 2015; Zdanowicz & Spychaj, 2016). The range of swelling value of BS edible film is greater at 31-75% than its solubility, in line with research Palijama et al. (2017) BS has a swelling value in water in the range of 17.37-20.01% and solubility of 3.74-6.64%. The low water solubility of BS is influenced by the high amylose content of about 27.17% (Bezerra et al., 2019). The increased solubility of the film in water is favorable for the development of food packaging that requires dissolving before consumption (Filipini et al., 2020). The solubility of BS edible film in water reached the optimum condition at 2% BS concentration, but it had 0,100 mm thickness which was much different from 3% BS concentration of 0.157 mm, thus affecting its mechanical properties. Therefore, 3% BS was used as the optimum concentration for the mechanical test.



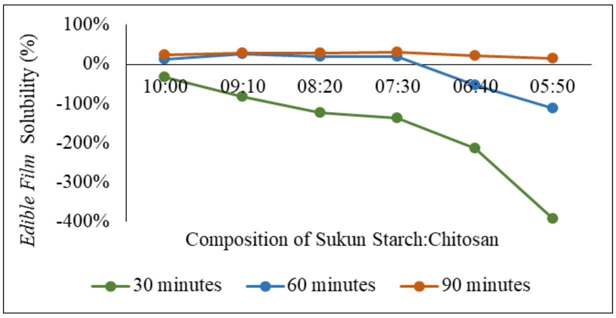


Figure 5. Water solubility of BS edible film in various composition (Left) and water solubility of BS-CH edible film in various composition (Right)

The water solubility of BS-CH edible film increased significantly with the addition of CH to the film. The increase in solubility reached an optimum condition at the BS:CH ratio of 07:03 at 31% after constant mass weighing at 90 minutes. After that, it decreased to a ratio of 05:05 by 15% as shown in Table 2 or Figure 5 (Right). The addition of CH concentration to the edible film causes the edible film to have a lower pH, this increases the swelling value significantly. Singh & Adedeji (2017) The swelling power of starch increases as the pH of the edible film decreases due to structural weakening and starch depolymerization.

Tensile Strength and Elongation at Break

Table 2. Mechanical properties of different films

Edible Films (BS:CH)	Tensile Strength (Mpa)	Elongation at Break (%)
10:0	1,9785 ± 0,2773	14,53715 ± 0,4671
9:1	2,40957 ± 0,2922	34,901 ± 0,9022
8:2	2,49935 ± 0,1067	42,44525 ± 2,4296
7:3	3,01895 ± 0,3981	58,2625 ± 5,3184
6:4	4,58105 ± 0,2242	51,54895 ± 6,4334
5:5	9,57735 ± 0,0812	35,86525 ± 4,7048

Tensile strength (TS) and elongation at break (EAB) tests were conducted to see the mechanical properties due to the addition of CH into the BS edible film. Mechanical properties are feasibility parameters that play an important role in the process of food packaging and storage (Qian et al., 2022). The TS and EAB of CH-BS edible film are shown in Table 2. and Figure 6. It can be seen the TS of CH-BS edible film increased significantly with the addition of CH in BS edible film in the range of 1.9785-9.5773 Mpa. The addition of CH concentration into the edible film increases the TS due to the formation of hydrogen bonds between molecules of the NH2-functional group in CH and the OH-functional group in BS so that the film density increases. As the concentration of BS increased, the TS decreased significantly due to the intramolecular bonding of the -OH group on BS being greater than the intermolecular bonding between the functional groups NH_2 and -OH (Elsabee & Abdou, 2013; Zheng et al., 2019). The EAB value of the film increased significantly due to CH concentration up to the optimum condition of BS:CH, namely 07:03 with a value of 58.2625%. The addition of CH into the film matrix overcomes the brittle and rigid nature of BS, making the film more elastic (Susilowati et al., 2021). However, it experienced a sharp decline when the CH concentration was increased to 25.8652%. The addition of additives to the film matrix at certain concentrations reduces its mechanical properties. The EAB value is influenced by the intermolecular bond distance between the -NH_2 and -OH functional groups, the weakening of intermolecular bonds is due to the long distance between intermolecular bonds (Susilowati et al., 2021). The mechanical properties of BS-CH edible film are similar to the findings of research results (Abera et al., 2024; Hasan et al., 2020; Susilowati et al., 2021; Zheng et al., 2019).

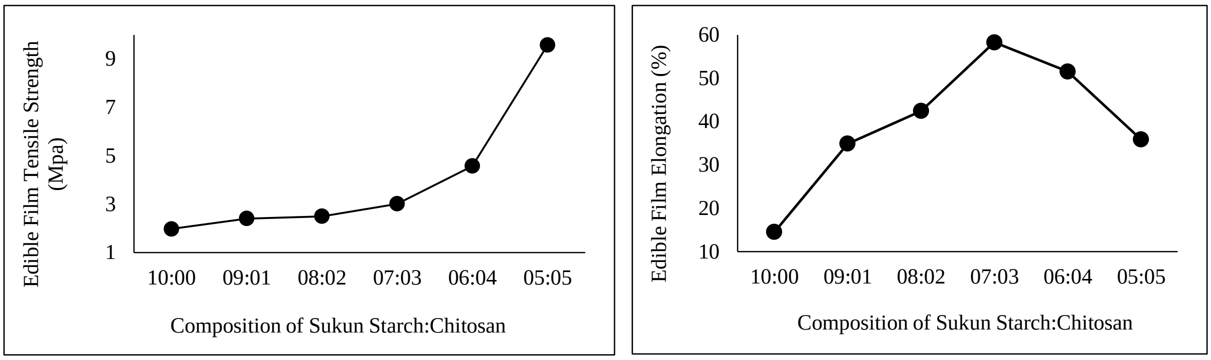


Figure 6. Mechanical test BS-CH Edible film: Tensile strength (Left) and elongation at break (Right)

Figure 7. Chilies and carrots coating on day 1, 5, and 10. The first row is a control sample (Without Coating) and the second row is a sample with coating

Application of the Coatings on Vegetables and Their Effect on Mass Loss

The prepared edible coatings were applied to several vegetables such as sweet potato, chili, and carrot. The vegetables that had been coated were then aerated to dry and then weighed the initial mass and reweighed at 5-day intervals during the storage period. Then the difference between initial mass and specific time interval divided by initial weight and finally denoted by percentage was calculated (Nasrin et al., 2020). The following table shows the mass loss of chilies and carrots:

Table 3. Mass loss of chilies and carrots

Vegetables	Treatment	Day-5	Day-10
Chilies	Experiment	27,27%	45,45%
	Control	42,85%	57,14%
Carrots	Experiment	34,92%	52,52%
	Control	41,79%	62,68%

Based on Table 3 above, it was found that chilies and carrots with coating (experiment) on day 5 and day 10 experienced a smaller mass reduction than without coating (control). This shows that the coating on chilies and carrots functioned well in retaining moisture from the food product to the environment. This happened because the control group was in direct contact with air, thereby accelerating moisture migration (Chen et al., 2022). As shown in Figure 7 (b), (c), (e), (f) the appearance of chilies coated (experiment) and without coating (control) is significantly different. For the control group of chilies in Figure 7 (b) and (c) first row, wrinkles appeared clearly on the 10th day of storage. While the coated chilies (experiment) wrinkles did not appear clearly and were almost non-existent. For the control group of carrots in figures (e) and (f) first row, wrinkles appeared clearly on the 5th day of storage and on the 10th day the surface of the carrots shrank further and signs of decay appeared. In the coated carrots (experiment) wrinkles appeared on the 10th day of storage in the second row. The differences in mass loss and appearance of the control and experimental groups in chilies and carrots are related to differences in water vapor transmission in the film coating the food product (Chen et al., 2022).

On the 5th day of storage in the control group, the sweet potatoes were covered with black mold, as seen in Figure 8. The mold grew rapidly on the 4th day of observation and caused the decay of the sweet potato to accelerate. In the experimental group, the sweet potatoes were not overgrown with mold, this is due to the BS-CH edible film preventing the entry of moisture from the surrounding environment so that mold cannot grow in food products. This is in line with research Chen et al (2022) that food products without coatings grow mold quickly because the transmission of water vapor into food products increases humidity, thus creating a good environment for mold growth.

Figure 8. Sweet potato without coating (First Row) and with coating (Second Row) on Day-5

Edible Coating **Starch in Learning Contains Education for Sustainable Development (ESD)**

Based on the questionnaire results data in Figure 4, it was found that 67% of students stated that the context of edible starch coating as food packaging was not presented in chemistry courses in the chemistry education study program. Edible coating starch as food packaging contributes to various aspects of the SDGs, especially in efforts to achieve a more sustainable food system. The integration of edible coatings in learning is very important because of its contribution to the promotion of sustainability in the food industry. Edible coatings, especially those derived from starch, have been identified as a potential solution to various challenges, including extending the shelf life of vegetables fruit and traditional sausages, reducing food waste, and increasing the economic value of products (Nunes et al ., 2023) . This is the basis for researchers to understand in depth the potential and need for the integration of edible starch coating as food packaging in ESD-loaded learning.

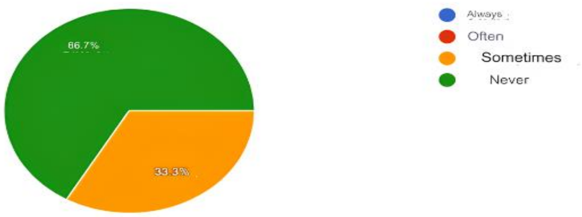


Figure 4. Percentage of edible coatings context taught in lecture

Lectures containing ESD in the context of edible coatings are expected to meet student expectations, presented in an overview of our theme clusters in Table. 4 following:

Table 4. Themes and sub-themes

Theme	Sub-themes
Aspects of the SDGs	Understanding of ESD principles
	Application of ESD principles
Context of edible coatings	Understanding the context of edible coatings
	Selection of the main matrix for edible coating
	Making edible coatings
	Application of edible coatings to food
	Introduction to the context of edible coatings in society
Improve 21st-century skills	Critical thinking skills
	Collaboration opportunities
	Presentation and communication skills

Theme 1: Aspects of the SDGs

Students expressed their hope that ESD-oriented learning on the topic of edible starch coating as food packaging could provide an in-depth understanding of sustainable concepts and aspects. Apart from understanding, they also hope for the application of sustainable principles. The application of this sustainable principle can take the form of increasing awareness regarding alternatives to plastic packaging as food packaging to reduce the negative impact of plastic waste in terms of health and the environment. Indirectly, students are trained to care more about the environment. Students can utilize biological and animal natural resources as the main matrix for making edible coatings, through this they can increase students' sensitivity regarding the potential of natural resources in the surrounding environment.

Theme 2: Edible Coating Context

In the sub-theme of understanding the context of edible coating, students hope to gain an in-depth understanding of the context of edible coating on starch as food packaging. This understanding includes definitions, types of matrices that make up edible coatings, the advantages of edible coatings as food packaging, and the application of edible coatings to various food ingredients. Students also want an understanding of the procedures for making edible coatings including quality control and safety standards for applying edible coatings to food ingredients. Through this understanding, students can describe the potential of edible coatings as food packaging.

In the sub-theme of selecting the main matrix for edible coatings, students hope to be able to determine the basic ingredients as the main matrix for making up edible coatings, both from various potential natural resources around them. This is used as the basis for developing environmentally friendly and sustainable edible coatings. Apart from selecting the basic ingredients for edible coatings, determining sustainable procedures also needs to be studied so that the resulting products do not cause various negative impacts in terms of health, environment and economics.

In the sub-theme of making edible coatings, students expect direct practice in making edible coatings after being able to determine the main matrix and procedures for making edible coatings. Edible coatings are made paying attention to several aspects such as materials and procedures for making edible coatings that are environmentally friendly and minimize negative impacts on health.

In the sub-theme of applying edible coatings to food, prepared edible coatings can be applied to foods such as vegetables, meat, and fruit to resist spoilage so that their shelf life is longer. In the sub-theme of introducing the context of edible coatings in society, students hope not only to be able to make and apply them to various foods to increase their shelf life but also to introduce the potential of edible coatings as food packaging widely in society. This is an opportunity for students to contribute directly to society so that projects carried out in the laboratory can have a direct impact on reducing food waste and reducing the use of hazardous chemicals in food packaging. The introduction of this context is also a new step in supporting the reduction of plastic waste.

Theme 2: Improving 21st-Century Skills

In the sub-theme of critical thinking skills, students hope to be able to develop their critical thinking regarding ESD content in the context of edible coatings on food packaging and innovation skills related to the development of environmentally friendly materials. In the sub-theme of collaboration opportunities, students hope for the opportunity to work in teams so that they can improve collaboration skills between students in achieving sustainable project goals. In the sub-theme of presentation and communication skills, students want to improve their presentation and communication skills to be able to present projects they have worked on.

Based on analysis of the *edible coating* starch content on food packaging from various reading sources and *edible starch coating* in learning containing Education for Sustainable Development (ESD) through answers to the open-ended questionnaire, it was found that the context of *edible coating* starch on food packaging has a very broad and comprehensive scope of study to be included in chemical learning containing ESD. Apart from that, this context is explicitly related to various aspects of the SDGs in the economic, social, and environmental spheres. Utilizing starch from typical tropical fruit seeds can overcome the problem of organic waste pollution and increase the use value of waste. Starch-based *edible coatings* have the advantage of strong mechanical properties. Implementing each sub-topic in chemistry learning requires an in-depth understanding of chemical concepts so that students are expected to be able to study independently. Therefore, this topic has the potential to be included in the context of chemistry learning containing ESD.

This is supported by the results of the open-ended questionnaire that 66% of students stated that this topic had not been included in chemistry learning with ESD content and they had high hopes for how this topic would be taught in chemistry learning with ESD content and the resulting learning outcomes. The potential of the topic of edible coatings in learning sustainable development is very significant and supports sustainable economic development through the application of circular bioeconomy in the food industry. Thus, incorporating the topic of edible coatings into sustainable development learning can help students understand the importance of environmentally friendly innovation in the food industry and the role of food ingredients in achieving sustainable development goals (Nunes et al ., 2023) .

Conclusion

This research shows that lectures containing Education for Sustainable Development (ESD) play an important role in increasing awareness about sustainable development through the integration of current issues. Through experiment methods and answers to open-ended questionnaires, it was found that the use of starch from sukun starch in making edible coatings has the potential to increase the use value of breadfruit and increase the use value of waste. Edible coatings have physical and mechanical characteristics from variations in the composition of breadfruit starch and chitosan-based on tests that have been carried out. The results of these characteristics form the basis for the application of edible coatings as food packaging. Coated vegetable products such as chilies and carrots experienced a smaller mass shrinkage compared to those without coating. Edible coatings also prevent mold growth on sweet potatoes. Data from the open-ended questionnaire shows that students hope that this topic can be included in chemistry learning containing ESD to increase understanding and application of ESD principles and introduce the potential of edible coatings to the public. Therefore, there is a need to integrate the topic of edible coating starch from breadfruit starch in lecture designs with ESD content.

Recommendations

Based on the research results, it is recommended to integrate the topic regarding the use of starch from typical tropical fruit seeds in making edible coatings into the chemistry learning curriculum containing ESD, developing learning materials that include information regarding the potential use of starch from typical tropical fruit seeds in making edible coatings, as well as its impact on environmental, social, and economic aspects, as well as in the learning process, it is recommended to design activities that can stimulate student involvement in exploring this topic, such as case studies, field projects, or simulations of edible coating development practices. This will help students to develop 21st-century skills that are relevant to the demands of sustainable development.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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