Potential of arrowroot (Maranta arundinacea) starch nanocrystal in edible bioplastic straw production

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Potential of arrowroot (*Maranta arundinacea*) starch nanocrystal in edible bioplastic straw production

Abstract

Indonesia produces approximately 2.5 liters of waste per capita daily, accumulating to 625 million liters nationwide, with continual increases due to population growth and environmental changes. This surge necessitates innovative alternatives to conventional plastics to curb plastic waste proliferation. A promising solution is developing bioplastic straws from arrowroot (*Maranta arundinacea*) starch, composed of 24.64% amylose and 73.46% amylopectin. The high amylose content makes it an ideal, strong, and flexible raw material for bioplastic straw production. This study aimed to explore the potency of arrowroot starch nanocrystal as an edible straw material. The concept of edible straw material utilizes nanocrystalline arrowroot starch as the main component, enhanced with chitosan as a polymer, glycerol as a plasticizer, and synthetic food colorants and flavorings. The goal is to explore and establish the process for creating non-food products from agricultural starch and assess their societal and environmental impacts. The nanocrystalline starch is extracted from arrowroot tubers using a wet method and modified through acid hydrolysis. It is then processed with water, glycerol, chitosan, and synthetic additives, heated, and molded into straws. The resulting edible straws from nanocrystalline arrowroot starch have the potential to offer unique taste, color, and thicker consistency compared to traditional plastic straws, presenting an eco-friendly and innovative alternative in waste management.

Keywords: arrowroot, bioplastic, nanocrystals, starch, straw

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Introduction

Indonesia, which has a large population, had a total population of 244.2 million in 2012, according to data from the Indonesian Central Bureau of Statistics. The annual population growth impacts plastic usage, as plastics are commonly used as packaging and for utensils such as straws, spoons, and forks made from plastic. This is because conventional plastics are lightweight, waterproof, flexible, and cost-effective. Plastic waste decomposition requires a significant amount of time by microorganisms present in the soil. Environmental awareness regarding plastic waste and its utilization still needs to be maximized due to limited knowledge and the absence of a plastic waste management system. According to the Ministry of Environment, the Indonesian population generates approximately 2.5 liters of waste per day, totaling 625 million liters from the entire population. Therefore, innovative solutions are needed as alternatives to conventional plastics to mitigate the increase in plastic waste.[1]

One of the starches that can be utilized as a raw material for bioplastic production is starch derived from arrowroot tubers. Arrowroot is a tuberous plant cultivated in rural areas since ancient times and can be utilized as an alternative source of carbohydrates. One of the simplest uses of arrowroot tubers is the processing of these tubers into arrowroot flour. Transforming arrowroot tubers into flour form simplifies the subsequent processing. Arrowroot flour has the potential to be used as an edible material. Arrowroot tubers benefit health due to their lower glycemic index than others.[2] Processing arrowroot tubers into starch undoubtedly enhances the economic value of arrowroot. Intensive cultivation of arrowroot tubers can yield an average of 25 tons per hectare, with the selling price of fresh tubers exceeding IDR 15,000.00 and the price of arrowroot starch surpassing IDR 20,000.00 for 1 kilogram.[3]

The reduction in plastic usage can be achieved by producing environmentally friendly bioplastic straws made from nanocrystalline arrowroot starch. The application of nanocrystals in straw production certainly requires modification through acid hydrolysis to break the amylose and amylopectin chains, resulting in a higher proportion of short amylose fractions and thus achieving a high crystalline fraction due to retrogradation. Maslahah & Sedyadi[4] reported that amylose and amylopectin in arrowroot starch will influence the mechanical properties of bioplastic straws. A high amylose content will result in bioplastic straws that are elastic and strong.

The addition of glycerol as a plasticizer will enhance flexibility in the starch structure, making it easier to shape the final product.[5] However, bioplastic straws require not only elasticity but also water resistance. Bioplastic straws are not resistant to water over an extended period, thus necessitating the addition of hydrophobic materials such as chitosan as an additional polymer. The addition of these materials enhances the water resistance of bioplastic straws.

The production of bioplastic straws is beneficial in reducing the use of conventional plastic straws that harm the environment, curbing plastic waste production, and mitigating global warming due to plastic waste.[6] This paper aims to uncover the potential of arrowroot starch nanocrystals for edible bioplastic straw production.

Methods

The approach adopted involves a comprehensive literature review pertinent to the subject matter. This method entails analyzing findings from previous research and integrating them with insights from other studies to yield robust outcomes and conclusions.

Bioplastic straw

The concept of bioplastic straws made from nanocrystalline cassava starch is producing an edible and can be consumed directly due to their natural ingredients, including nanocrystalline cassava starch, glycerol, chitosan, water, food coloring, and synthetic food flavoring. Bioplastic straws based on nanocrystalline cassava starch are environmentally friendly tableware and can easily biodegrade in the environment. Using these edible straws can help reduce environmental pollution caused by the accumulation of plastic waste. The advantages of these edible straws are their environmental friendliness, organic nature, 100% biodegradability, and safe food flavorings and colorings, thus leaving no hazardous waste that could pollute the environment. Furthermore, this product has garnered attention from the public, encouraging them to try it.

Potential of starch nanocrystal

A previous study indicated that nanocrystalline starch can be used as a reinforcing agent in producing various products, particularly biodegradable plastics. The production process of nanocrystals involves strong acid hydrolysis under gelatinization temperatures, resulting in nano-sized crystals that can reinforce polymers, including plastics.[7] These findings support the concept of Nano-BioStraws, which will utilize nanocrystalline cassava starch as the base material for producing edible biodegradable plastics. However, previous research has primarily focused on developing alternative environmentally friendly plastic materials as a solution to reduce environmental pollution. In other words, such plastics have yet to be fully optimized.

Meanwhile, plastic industries already manufacture and develop bags and straws made from environmentally friendly cassava starch. They utilize eco-plas resin made from cassava starch, which microorganisms can easily degrade. One successful company in this field is PT. Kharisma Plastik Indo (Indonesia), whose products have passed in-vivo testing and are patented. However, it is important to note that the patents filed by this company are related to products made from cassava starch. In contrast, our concept employs cassava starch as the raw material for producing edible straws, with several innovations, including adding food flavorings and colorings to make the product visually appealing. Research by Faridah et al.[8] indicates that cassava starch contains 24.64% amylose and 73.46% amylopectin, demonstrating that cassava starch has a higher amylose content compared to cassava starch, which typically contains around 20-27% amylose.

Modification of edible bioplastic straw

In the production of bioplastic straws, natural cassava starch undergoes modification to become nanocrystalline cassava starch to improve its unfavorable properties. According to Koswara,[9] natural starch often has weaknesses such as long cooking times, uneven suspension viscosity, limited solubility in water, sticky properties, acid intolerance, and a hard and cloudy paste texture. Using cassava starch as nanocrystals can overcome weaknesses by producing a low-viscosity suspension at high concentrations and strong binding strength due to its large active surface area. The production process of nanocrystals using a strong acid hydrolysis method can produce nano-sized crystals that can be used as reinforcements or fillers for other polymers, such as plastics, rubber, or thermoplastic starch. Nanocrystals from gelatinized starch also produce more amorphous nano-sized starch, a carrier matrix for active ingredients.[7]

Using nanocrystalline cassava starch as the base material can bring new novelty or differentiation to edible bioplastic straw production. The amylose and amylopectin content in cassava starch is crucial in producing these bioplastic straws. According to the research conducted by Faridah et al.,[8] cassava starch contains 24.64% amylose and 73.46% amylopectin. The high amylose content in cassava starch has the potential to create flexible and strong straws. In making bioplastic straws, glycerol is used as a plasticizer at 1%. The addition of chitosan at 2% in bioplastic production aims to enhance the mechanical properties of the resulting bioplastic straws. Additionally, the novelty of producing bioplastic straws involves the addition of synthetic food coloring to give the straws an attractive appearance. Synthetic food flavoring is also added to create a unique taste in these bioplastic straws. These plastics are edible due to their natural ingredients, are safe for consumption, and are non-toxic.

Concept of production

Faridah et al.[8] state that cassava starch contains 24.64% amylose and 73.46% amylopectin. In the studies conducted by Guilbert[10] and Ayuk,[11] it is explained that the stability of bioplastics is influenced by amylopectin, while amylose affects compactness. A high amylose content can produce flexible and strong bioplastics because the amylose structure allows for the formation of hydrogen bonds between glucose molecules. A three-dimensional network is formed during the heating process, capable of retaining water, resulting in strong gel properties.

The concept of producing bioplastic straws involves several steps. First, cassava starch is extracted from cassava tubers using the wet method, followed by the formation of nanocrystalline cassava starch using acid hydrolysis (Figure 1).[12] Next, the bioplastic straw dough is created by mixing nanocrystalline cassava starch, chitosan, glycerol, synthetic food coloring, and synthetic food flavoring. The final step is molding the dough into bioplastic straws (Figure 2). Faridah et al.[8] demonstrate cassava starch extraction, which begins with cleaning the cassava tuber samples to remove contaminants such as sand, dust, and insects. Then, the tuber skin is peeled, and the tubers are washed with clean water to remove contaminants. Afterward, the tubers are soaked in water for 1 hour, mashed with a blender, or grated with a ratio of water: tuber of 3.5:1. Subsequently, the mixture is filtered to separate solids from liquids. The starch is then precipitated, washed, and dried in an oven at 50°C. Once dried, the starch is ground, sieved, and sifted.

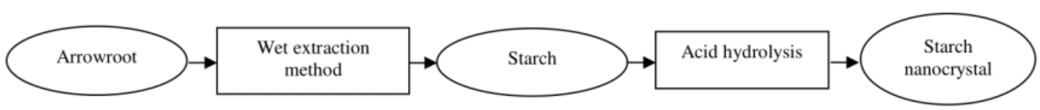

Figure 1 Arrowroot starch nanocrystal production scheme.

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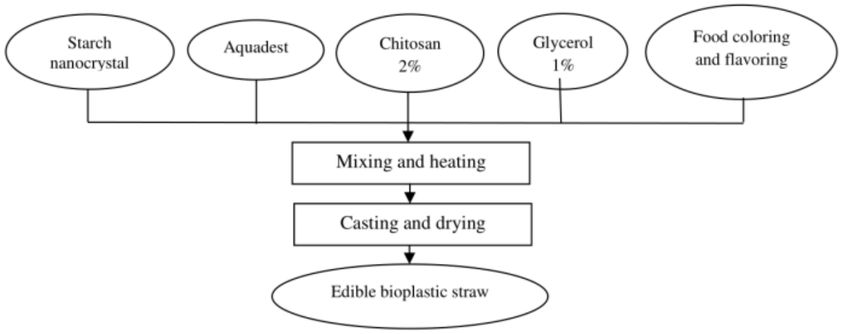

Figure 2 Edible bioplastic straw production scheme.

Modifying starch into nanocrystals begins with weighing 29.4 grams of cassava starch. The starch is then dissolved in 150mL of 3.16M H_2SO_4 and 2.2N HCl. This starch suspension is incubated at 40°C for 3 to 5 days, then centrifuged, washed with deionized water, and neutralized with NaOH until reaching a pH of 7. Next, the starch is processed with an ultraturax and sonicated for 30 minutes with the addition of Sodium Azide. The sample is filtered using filter paper, washed with ethanol, and the precipitate is dried using a freeze dryer until the water content reaches ± 10%. The starch is ground, sieved, and sifted.[13]

The addition of glycerol acts as a plasticizer that enhances the elasticity of the bioplastic straw polymer. Research by Layudha et al.[14] shows that adding 1% glycerol results in optimal mechanical properties of the bioplastic, with a tensile strength of 0.029 N/mm^2. Chitosan is an additional polymer and antibacterial agent derived from crustacean waste products. According to Darni & Utami,[15] starch-based bioplastics are usually not water-resistant (hydrophilic), so adding hydrophobic materials like chitosan is required to improve this property. Research by Layudha et al.[14] indicates that adding 2% chitosan produces optimal tensile strength, 0.076212 N/mm^2. Synthetic food coloring is added to provide attractive colors to the product, while synthetic food flavoring creates a unique taste in the bioplastic straws.

Strategic action for future implementation

Strategic steps to realize the idea of bioplastic straws made from cassava nanocrystals involve socialization and education about nanobiodegradable plastic. This includes understanding the differences between conventional plastic and nanobiodegradable plastic and the advantages of nanobiodegradable plastic that can degrade in the environment. Basic-level socialization can be achieved by introducing nanobiodegradable plastic into household environments through community groups and social media.

Furthermore, collaboration with the Ministry of Education to add plastic-related content into Environmental Education lessons is crucial. In economic aspects, government subsidies can assist in reducing the production costs of arrowroot-based plastic, making it economically viable for the public. Collaboration with manufacturers and market sectors such as cafes, supermarkets, and other beverage companies that require plastic straws will also be essential to expand the reach of arrowroot-based nanobiodegradable plastic straw products. The government also plays a vital role in distributing nanocrystal cassava starch straws by providing infrastructure facilities to ensure smooth distribution processes in various regions of Indonesia.[16–18]

The estimated time required to realize this idea is approximately eight years, with the following stages:

a) **Design (2022-2023):** Idea conceptualization, research, technology development, and socialization.

b) **Preparation (2024-2025):** Preparation of materials, experts, human resources, and contracts for facility availability and building space.

c) **Implementation Phase (2026-2028):** Large-scale product production and distribution across Indonesia.

d) **Development Phase (2029 and beyond):** Maintenance, production monitoring, product evaluation, and further development to address environmental concerns.

Conclusion

Using nanocrystalline arrowroot starch to produce biodegradable, edible bioplastic straws is becoming a potential innovative solution to Indonesia's plastic waste problem. The production of edible bioplastic straws involves the modification of arrowroot starch to nanocrystal, adding glycerol and chitosan. This initiative promises to reduce plastic waste and its associated environmental impact and offers economic benefits through the valorization of a traditional agricultural product. The implementation underscores the necessity of strategic planning, education, and government support for successful implementation, envisioning a gradual, multi-phase rollout over several years.

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Conflicts of interest

The authors declare no conflict of interest in writing the manuscript.

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