



SENTACUP: Utilization of cellulose from tea dregs waste as a waterproof biodegradable cup to support the circular economy and environmental sustainability

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ABSTRACT

Background: The extensive use of single-use plastic cups has caused serious environmental problems, including plastic accumulation and microplastic pollution. At the same time, tea-processing industries generate large quantities of spent tea waste that remain underutilized despite their high cellulose content. This study aims to propose an innovative and sustainable solution by utilizing cellulose extracted from spent tea waste to produce a biodegradable and water-resistant cup that supports circular economy principles. **Methods:** This study employed an experimental and material development approach. Spent tea waste was collected, sorted, dried, and milled to obtain uniform particles. The cellulose-rich material was blended with cassava starch as a natural binder and molded using a press-molding technique. A natural wax coating was applied to improve water resistance. The developed product was evaluated through mechanical strength tests, water absorption tests, water resistance tests, and biodegradability assessment, supported by descriptive and comparative analysis. **Findings:** The results indicate that SentaCup has sufficient mechanical strength for beverage containers, demonstrates good resistance to water, and is capable of biodegrading within approximately 90–120 days. The utilization of cellulose as a natural polymer contributes to structural strength, flexibility, and thermal stability. This innovation shows strong potential as an environmentally friendly alternative to conventional single-use plastic cups while adding value to organic waste. **Conclusion:** The development of SentaCup demonstrates that spent tea waste can be effectively transformed into a functional, biodegradable, and water-resistant cup. This innovation contributes to reducing plastic waste, supporting circular resource management, and promoting environmental sustainability. **Novelty/Originality of this article:** The novelty aspect refers to the new or innovative elements in a research study that distinguish it from previous work. It includes unique contributions, new methods, or findings that have not been explored before in the field.

KEYWORDS: biodegradable; cellulose; circular economy; tea grounds.

1. Introduction

The use of plastic cups in Indonesia has increased rapidly along with economic growth and changes in lifestyle that increasingly emphasize convenience. According to the 2023 Census of the Nusantara River Affairs Research Agency (BRUIN), Indonesia is among the ten

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largest plastic waste-producing countries in the world, generating approximately 9.13 million tons of plastic waste. From street-side cold beverages to modern coffee shops in shopping centers, single-use plastic cups are ubiquitous (Arshad et al., 2025). Their convenience and relatively low cost make them the preferred choice for both vendors and consumers. However, behind this practicality lies a serious threat to environmental sustainability. The continuously increasing volume of plastic waste, with plastic cups as a significant contributor, has exceeded existing waste management capacities.

The main problem arises from the non-biodegradable nature of plastic cups. Synthetic polymer materials used as the primary raw material for plastic cups require hundreds to thousands of years to decompose naturally (Perera et al., 2023). As a result, discarded plastic cups accumulate in landfills, contaminating soil and water. Furthermore, a large portion of plastic waste eventually ends up in rivers and oceans, carried by currents and waves. The sight of plastic cups floating in waters or stranded along coastlines has become a distressing irony, undermining Indonesia's renowned natural beauty. The negative impacts of plastic cup waste extend beyond environmental aesthetics. Marine ecosystems are among the most severely affected (Ahmed et al., 2025). Marine animals such as turtles, seabirds, and fish often mistake plastic cups or their fragments for food. Ingestion of plastic can cause digestive blockages, internal injuries, and even death. In addition, microplastics—tiny plastic particles formed through the degradation of plastic cups in the environment—contaminate the food chain and pose potential risks to human health through seafood consumption.

The increasing generation of waste in Indonesia, including in Malang City, highlights major challenges in environmental management. Data from the Malang City Environmental Agency indicate that total waste generation increased from 247,389.19 tons in 2020 to 284,095.41 tons in 2024, with organic waste (57.86%) and plastic waste (16.45%) as the dominant components. Unfortunately, the waste-handling rate declined from 75.06% to 71.36% over the same period. This condition underscores the urgent need for sustainable waste management innovations aligned with circular economy principles, so that waste is not merely a burden but can be reutilized as a valuable resource. One tangible example is spent tea waste, which has long been considered worthless and discarded in landfills.

Indonesia is known as one of the countries with a relatively high level of tea consumption. Since 2015, domestic tea consumption has increased by approximately 4% annually, reaching 105,000 tons in 2018, or about 75% of total national tea production (Suprihatini et al., 2021). In addition, the number of beverage companies in Indonesia, including those using tea as their primary raw material, has grown rapidly since the late 1990s. Several tea beverage manufacturers, such as PT Sosro, generate up to 470 tons of spent tea waste per year, alongside other industries such as Teh Giju and Ultrajaya, indicating substantial and reliable availability of spent tea waste. National tea production has also shown a steady increase, averaging approximately 157,000 tons per year from 1993 to 2002 (Directorate General of Estate Crops, 2002).

After the brewing process, spent tea leaves are often regarded as a low-value by-product and disposed of as waste. In fact, spent tea contains various organic compounds, including cellulose, lignin, and hemicellulose, which have significant potential for further utilization. Spent tea waste, one of the major contributors to organic waste in Indonesia, contains a high cellulose fiber content of approximately 43.87% is the primary structural component of plant cell walls (Acquavia et al., 2024). To obtain cellulose fibers from plant materials, several treatments are required to extract cellulose from the cell walls and reorganize it into fibrous form (Wandhekar et al., 2025). The abundant availability of cellulose fibers from plant-based waste can be further developed into higher-value and more beneficial products (Wang et al., 2024). The characteristics of cellulose fibers arise from their crystalline and amorphous structures and include hydrophilic properties and biodegradability (Perera et al., 2023). These characteristics indicate that spent tea waste has strong potential as a raw material for cellulose-based products that are more environmentally friendly and versatile in application.

By utilizing organic waste such as spent tea, circular resource management can be implemented in practice by reducing waste volume, lowering greenhouse gas emissions, and generating economically valuable products. Therefore, innovation based on the utilization of spent tea waste not only helps address urban waste management issues but also supports the achievement of the Sustainable Development Goals, particularly SDG 12 on responsible consumption and production and SDG 13 on climate action. Therefore, the product innovation entitled “Sentacup: Utilization of cellulose from tea dregs waste as a waterproof biodegradable cup to support circular economy and environmental sustainability” can be developed into an environmentally friendly product that supports zero waste.

2. Methods

This study employed a qualitative descriptive approach using a comprehensive literature review to examine the potential utilization of cellulose derived from spent tea dregs waste as a waterproof biodegradable cup material under the SENTACUP concept. The study was designed as a non-experimental, literature-based investigation, focusing on conceptual analysis and critical synthesis of existing scientific evidence rather than laboratory-scale material testing. The research activities were conducted within an academic research environment at the Laboratory of Agricultural Product Engineering, Faculty of Agricultural Technology, Universitas Brawijaya, Malang, Indonesia, primarily as a center for literature analysis, conceptual discussion, and scientific interpretation related to biodegradable materials and sustainable product development.

Secondary data were collected from a wide range of peer-reviewed journal articles, conference proceedings, academic books, and institutional or governmental reports. The literature selection emphasized studies related to cellulose extraction from agricultural and food waste, physicochemical properties of cellulose-based biopolymers, biodegradable packaging materials, waterproofing strategies for bio-based products, and the application of circular economy principles in sustainable material design. Relevant international and national publications were identified through academic databases to ensure scientific credibility and relevance. The collected literature was analyzed using a thematic analysis approach, whereby key themes were systematically identified and grouped. These themes included raw material availability and characteristics of tea dregs waste, cellulose extraction and modification techniques reported in previous studies, material performance indicators relevant to cup applications (such as water resistance and biodegradability), and environmental and sustainability impacts associated with biodegradable materials. The final stage of analysis involved the synthesis and integration of findings across different sources to develop a conceptual framework illustrating the feasibility and potential advantages of SENTACUP as an alternative to conventional plastic cups. This framework highlights the role of tea dregs waste valorization in supporting circular economy strategies, reducing plastic waste, and promoting environmentally sustainable product innovation.

2.1 Materials

The primary material used in this study was spent tea waste obtained from local tea beverage producers in Malang City, Indonesia. This waste was collected, sorted, and processed to ensure uniformity and suitability for experimental use. Additional materials included cassava starch, which functioned as a natural and biodegradable binder, distilled water as a mixing medium, and natural wax applied as a surface coating to improve water resistance and durability. All chemicals and supporting materials employed in this research were of analytical grade, non-toxic, and environmentally friendly, ensuring that the overall process aligned with sustainable material development principles and minimized potential environmental impacts.

2.2 Preparation of spent tea cellulose

Spent tea waste was initially collected and subjected to a thorough cleaning process to eliminate physical impurities, residual sugars, colorants, and other soluble compounds remaining from the brewing process (Xu et al., 2021). The material was repeatedly washed using distilled water to ensure the removal of contaminants that could interfere with subsequent treatments (Rahman et al., 2017). After washing, the spent tea waste was dried in a controlled oven at 60 °C until a constant weight was achieved, indicating stable moisture content. This drying step was essential to minimize water content, inhibit microbial growth, and improve storage stability. The dried material was then mechanically milled and sieved to obtain a uniform particle size, ensuring homogeneity and consistent reactivity during further processing stages.

To isolate cellulose-rich material, the powdered spent tea waste underwent an alkaline treatment using a suitable alkaline solution to remove non-cellulosic components, particularly lignin, hemicellulose, and residual extractives. This treatment enhanced the purity of cellulose and improved its compatibility with the biocomposite matrix. Following alkaline treatment, the material was rinsed multiple times with distilled water until a neutral pH was achieved, ensuring the complete removal of residual alkali. The resulting cellulose-rich fraction was then dried again at 60 °C to achieve constant weight and subsequently stored in airtight containers to prevent moisture absorption prior to its use in biocomposite formulation (Jiang et al., 2022).

2.3 Cup fabrication process

The prepared spent tea-derived cellulose was blended with cassava starch, which served as a natural and biodegradable binder, at predetermined weight ratios to achieve optimal mechanical and physical properties (Deshmukh & Talwar, 2024). Distilled water was gradually added to the mixture while stirring continuously to obtain a homogeneous slurry with suitable viscosity for molding. This gradual addition of water and constant agitation ensured uniform dispersion of cellulose fibers within the starch matrix, minimized agglomeration, and enhanced interfacial bonding between the components (Quinonez et al., 2025). A well-dispersed mixture is essential for producing biocomposites with consistent structure and performance.

The resulting homogeneous mixture was then transferred into molds and shaped into cup forms using a press-molding technique under controlled temperature and pressure conditions. This process facilitated proper compaction, improved fiber-matrix adhesion, and produced cups with uniform thickness and shape. After molding, the biocomposite cups were carefully removed from the molds and dried to reduce residual moisture content, which contributed to improved dimensional stability and mechanical strength. To further enhance water resistance and extend potential application as disposable packaging, the dried cups were coated with a thin and uniform layer of natural beeswax applied to the surface. Finally, the finished products were conditioned under ambient laboratory conditions for a specified period to allow moisture equilibrium before being subjected to mechanical, physical, and biodegradability evaluations.

2.4 Product Characterization

Product testing of SentaCup was conducted to ensure that the spent tea waste-based packaging with a beeswax coating meets safety, quality, and functional standards prior to commercialization. The tests performed in this study included: 1) Tensile strength test, 2) Water absorption test, 3) Water resistance test. All measurements were conducted in triplicate to ensure data reliability. The test results were used to evaluate the mechanical performance and functional suitability of SentaCup as a beverage container. The obtained

data also served as the basis for comparing the developed product with conventional single-use plastic cups.

2.5 Data analysis

Data analysis in this study was performed using a combination of quantitative and qualitative approaches to provide a comprehensive evaluation of the developed biocomposite cups. Quantitative data were obtained from various material characterization and performance tests, including mechanical strength, leakage resistance, and water absorption or water resistance measurements. These data were analyzed using descriptive statistical methods to summarize the results and comparative analysis to assess differences among sample variations and processing conditions. Qualitative data were derived from functional performance observations, such as structural integrity and usability, and were evaluated by referring to relevant standards and requirements commonly applied in the food packaging industry. In addition, a life cycle assessment (LCA) approach was employed to examine the potential environmental impacts associated with raw material acquisition, processing, manufacturing, and end-of-life stages of the product. The overall data analysis process was systematically conducted through stages of data reduction, data organization, interpretation, and the formulation of conclusions to ensure clarity, reliability, and consistency of the research findings.

3. Results and Discussion

3.1 Research Findings

Plastic materials are widely used in modern society due to their durability, flexibility, and low production cost. In the food sector, plastics are commonly utilized as packaging materials to protect products from physical damage, contamination, and moisture, as well as to extend shelf life. However, the extensive use of plastic packaging has raised serious concerns related to food safety and environmental sustainability. Improper management of plastic waste leads to its accumulation in terrestrial and aquatic environments, increasing the risk of long-term ecological and human health impacts. In recent years, scientific attention has increasingly focused on the interaction between plastic waste, environmental processes, and human exposure pathways. Plastic materials do not readily degrade in nature; instead, they undergo gradual fragmentation into smaller particles through physical, chemical, and biological mechanisms. This process results in the formation of microplastics and nanoplastics, which are now recognized as emerging environmental pollutants. These small plastic particles can enter soil, water, and food chains, creating potential risks for ecosystems and human health that require comprehensive investigation.

Some types of plastics have the potential to release harmful chemical compounds, such as bisphenol A (BPA) and phthalate, especially when heated. These compounds have been shown to be endocrine disruptors, which are substances that can disrupt the hormonal system in the human body. Exposure to BPA and phthalates is associated with an increased risk of various health disorders, including cancer, reproductive disorders, as well as obstacles in children's development (Siregar et al., 2024). In addition to the implications for human health, the use of plastic packaging also has a negative impact on the environment, especially on soil and water quality. Visual evidence of environmental pollution due to plastics can be observed in Fig 1. below.

Plastic contamination in the environment occurs through a series of physical, chemical, and biological processes that lead to the fragmentation of larger plastic materials into microplastics and nanoplastics. As illustrated in Fig 1., plastic waste deposited on soil surfaces undergoes photo-oxidation due to prolonged exposure to ultraviolet (UV) radiation, which weakens polymer chains and accelerates fragmentation. Mechanical forces such as plowing, harvesting, and natural weathering further break down plastic particles, enabling their migration into deeper soil layers and aquatic systems, including

groundwater. Additionally, limited biodegradation by microorganisms contributes to the formation of smaller plastic particles rather than complete mineralization. These micro- and nanoplastics can act as vectors for toxic additives and environmental pollutants, posing risks to soil health, water quality, and biota. Consequently, plastic contamination represents a persistent environmental issue with long-term implications for ecosystem stability and human health.

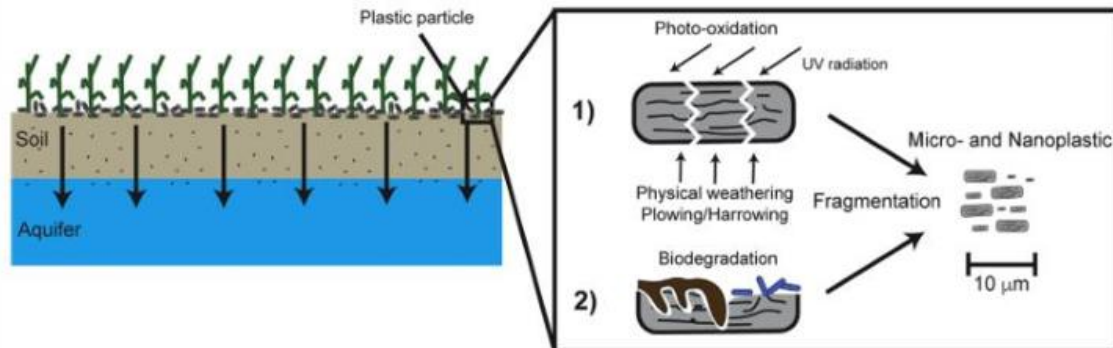


Fig 1. Plastic Contamination Process in the Environment
(Wanner, 2021)

Beyond their physical persistence, micro- and nanoplastics generated through environmental fragmentation processes exhibit complex interactions with surrounding ecosystems, thereby exacerbating their environmental impact. Due to their small size and high surface-area-to-volume ratio, these particles readily adsorb hazardous substances such as heavy metals, persistent organic pollutants, and residual agrochemicals, increasing their mobility and bioavailability in soil and aquatic environments. Once transported into groundwater systems or surface waters, microplastics may enter food webs through uptake by microorganisms, plants, and aquatic organisms, leading to bioaccumulation and potential biomagnification across trophic levels. The presence of microplastics in agricultural soils has also been associated with altered soil structure, reduced microbial activity, and impaired nutrient cycling, which may indirectly affect crop productivity and soil fertility. These multifaceted environmental and ecological risks highlight the limitations of conventional plastic materials and underscore the urgency of developing biodegradable alternatives, such as cellulose-based products, that are designed to minimize fragmentation-related pollution and support long-term environmental sustainability.

Plastic is also found in paper cup products, which generally have a plastic coating on the inner surface. The interior of the paper cup is coated with a hydrophobic film that is mostly made of plastic, such as polyethylene, and, in some cases, includes copolymers as additional materials. The plastic layer is at risk of melting at high temperatures, and the amount of substances released from the coating can increase with rising temperature. A more detailed explanation of this process can be seen in Fig 2 and Fig 3 below.

As illustrated in Fig 2, exposure to elevated temperatures induces substantial morphological transformations in plastic particles at the microscale. The observed changes include pronounced deformation, elongation, surface roughening, and partial coalescence of individual fragments, indicating progressive thermal softening and partial dissolution of the polymer matrix. These structural modifications arise from increased thermal energy that disrupts intermolecular bonding and reduces the crystallinity of polymer chains, thereby enhancing chain mobility and susceptibility to physical alteration. As a consequence, microplastic particles become more prone to fragmentation and surface erosion, which may accelerate their dispersion and persistence in environmental matrices. Furthermore, the increase in surface area associated with these morphological changes may enhance the adsorption of chemical contaminants and facilitate interactions with biological systems. Collectively, these observations suggest that thermal stress significantly amplifies the physicochemical reactivity and environmental mobility of microplastics under high-

temperature conditions (Ranjan et al., 2021).

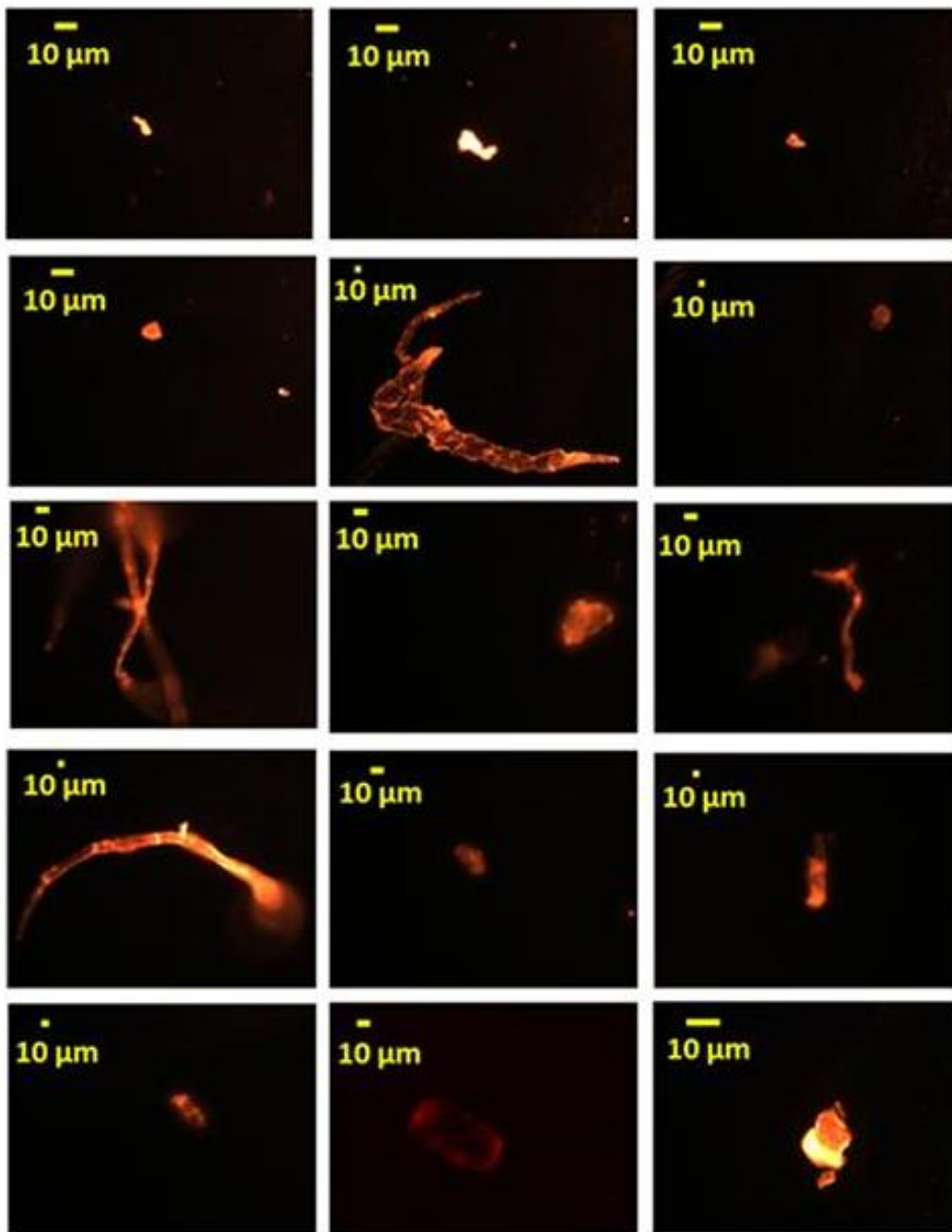


Fig 2. Dissolved Plastics At High Temperatures
(Ranjan et al., 2021)

The effect of temperature on microplastic solubility, as shown in Fig 3., exhibits a clear positive correlation across different polymer types, including polyethylene (PE), polypropylene (PP), and polystyrene (PS). Increasing temperature leads to higher concentrations of dissolved microplastics, although the extent of solubilization varies among polymers. Higher thermal conditions enhance molecular diffusion and reduce polymer structural integrity, thereby facilitating microplastic release into the medium. These findings underscore temperature as a critical factor governing microplastic availability, particularly in thermally influenced systems (Chen et al., 2023).

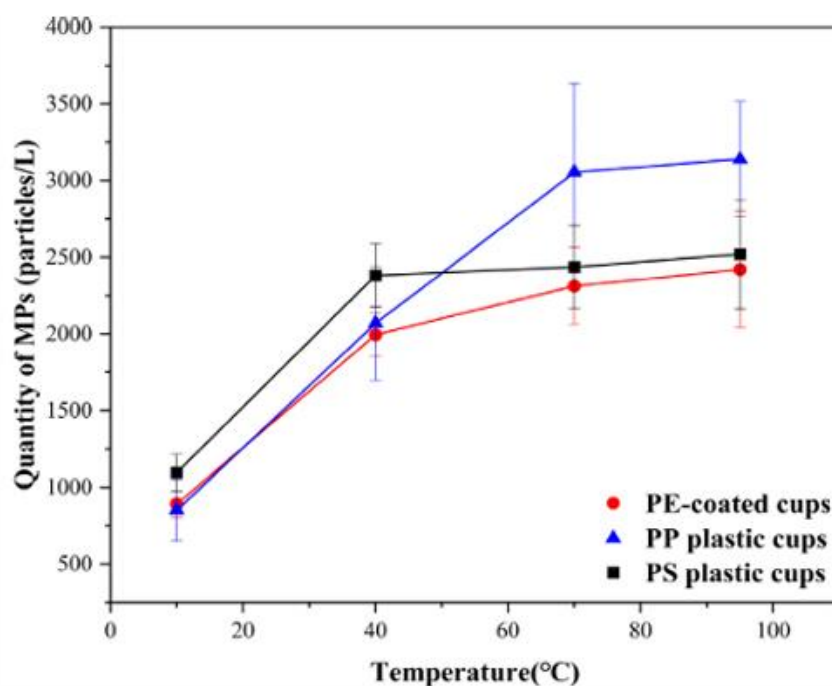


Fig 3. Solubility Levels of Micro Plastic Based on Temperature (Chen et al., 2023)

Based on these findings, innovation is needed in the development of packaging that is biodegradable and free from harmful chemicals. One of the natural materials that has the potential to be used is tea grounds, which are known to have a relatively high cellulose content and can be used as a basic material in making environmentally friendly packaging (Kustiyah et al., 2023). The cellulose content in tea grounds is reported to reach 43.78% (Afrilia et al., 2024), making it a promising source of fiber. This cellulose fiber functions as a filler that can increase the mechanical strength of packaging. To increase resistance to leakage, adding beeswax as a natural coating is an effective strategy. The presence of beeswax has been shown to inhibit the penetration of oxygenated groups found in cellulose acetate fibers in paper, thereby increasing its resistance to water properties (Oliveira et al., 2025). Beeswax itself consists of the main component in the form of myricyl palmitate, with a chemical structure that can be seen in Fig 4. below.

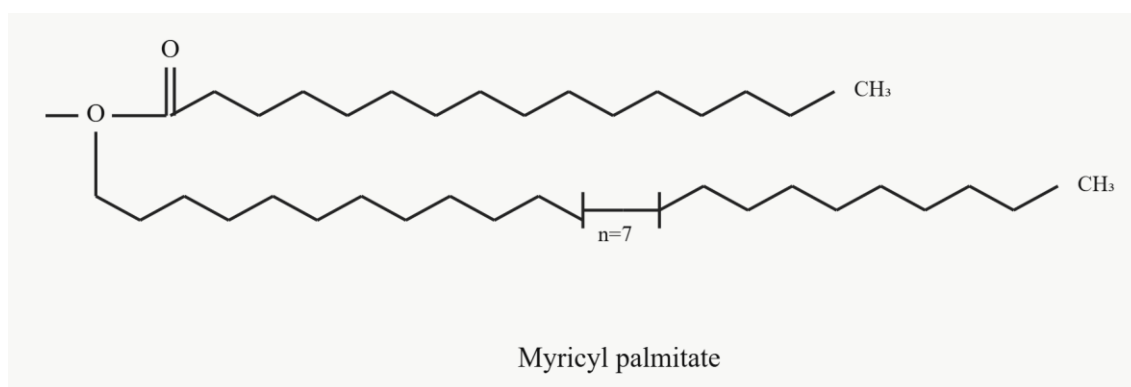


Fig 4. Structure of Myricyl Palmitate (Jahangiri et al., 2024)

Fig 4 shows the chemical structure of myricyl palmitate, which is the primary wax ester component of beeswax. This compound is formed through the esterification reaction between palmitic acid, a saturated fatty acid, and myricyl alcohol, a long-chain fatty alcohol. The resulting molecular structure consists of extended hydrocarbon chains with minimal polar functional groups, giving myricyl palmitate a highly hydrophobic character (Panza et

al., 2021). This hydrophobicity is a key property that underlies the functional performance of beeswax as a natural coating material (Chungsiriporn et al., 2022).

In the context of cellulose-based packaging, such as materials derived from tea grounds, the hydrophobic nature of myricyl palmitate plays a crucial role in improving barrier properties (Kashiri et al., 2025). Cellulose fibers contain abundant hydroxyl (-OH) groups, which readily interact with water molecules, leading to high moisture absorption and reduced mechanical stability. When beeswax is applied as a coating, the long-chain wax esters form a protective layer that partially covers or blocks these hydroxyl groups, thereby limiting water diffusion into the cellulose matrix. This interaction reduces water uptake and improves resistance to leakage, which is essential for food packaging applications.

Furthermore, the compact and continuous coating formed by myricyl palmitate enhances the oxygen barrier properties of the packaging material (Kathuria et al., 2022). By restricting oxygen penetration, beeswax-coated cellulose packaging can help slow down oxidation processes in food products, contributing to extended shelf life. This mechanism is particularly relevant for fresh and minimally processed foods that are sensitive to moisture and oxygen exposure. Thus, the molecular structure shown in Figure 4 provides a fundamental explanation for the functional effectiveness of beeswax in improving packaging performance.

From an environmental perspective, the use of beeswax as a natural coating aligns with the principles of sustainable and biodegradable packaging. Unlike synthetic polymer coatings, myricyl palmitate is biodegradable and non-toxic, making it safer for both human health and the environment. When combined with cellulose-rich tea grounds, beeswax-coated packaging materials offer a promising alternative to conventional plastic packaging by enhancing mechanical strength, water resistance, and barrier functionality while maintaining environmental compatibility.

3.2 Product description and features

SentaCup is an innovative product in the form of an eco-friendly beverage container developed from tea grounds waste as the main ingredient. This product comes in three size variants, namely 8 oz, 12 oz, and 16 oz, which are designed to meet the needs of different types of beverages. With this variety of sizes, SentaCup is very suitable for use by business actors in the Food and Beverage (FnB) sector, such as cafes, beverage shops, and catering services. The use of natural raw materials derived from organic waste makes SentaCup free of harmful chemicals and safe to use in the presentation of food and beverages. In addition, the biodegradable properties of the material allow the product to decompose naturally in the environment in about 90 to 120 days, without leaving any harmful residues. SentaCup's sterility is strictly maintained through a production process that begins with drying tea grounds at a temperature of 50°C - 70°C, to reduce moisture content and prevent the growth of microorganisms. To ensure the robustness of the product, cassava starch is used as a natural adhesive, which is then molded and heated at 100°C - 150°C to form a strong and stable container structure (Wang et al., 2024). In an effort to increase resistance to leaks, beeswax is used as a natural protective layer on the inside of the SentaCup, making it waterproof and safe when in direct contact with the drink. SentaCup's presence can be a sustainable alternative that supports the reduction of single-use plastic waste and encourages more environmentally responsible consumption.



Fig 5. SentaCup Prototype Overall View, Inside View, Top View

Fig 5. illustrates the overall appearance of the SentaCup prototype, which is designed in a cylindrical form similar to commonly used disposable beverage cups. The cup features an integrated lid, indicating its intended use for take-away beverages. The natural brown color and slightly coarse texture on the surface reflect the use of tea grounds as the primary raw material, emphasizing its eco-friendly and organic-based composition (Li et al., 2023). The inside view of the SentaCup shows a smooth and uniform inner surface, suggesting careful molding and coating during the production process. This smoothness indicates the application of a beeswax layer that serves as a natural protective coating to reduce liquid absorption and prevent leakage (Windarayahya et al., 2023). The even interior surface also supports hygienic use and direct contact with beverages, contributing to the functional reliability of the product. The top view highlights the structural design of the lid, including a drinking opening that allows practical and comfortable use by consumers. The lid appears to fit securely onto the cup, which helps minimize spills during handling and transportation. Overall, the prototype demonstrates a balance between functional design, material strength, and environmental sustainability, supporting its potential as a biodegradable alternative to single-use plastic cups.

3.3 Impact and risk assessment

SentaCup, as a biodegradable cup product derived from spent tea waste, has the potential to generate significant positive impacts for the community of Malang City. By utilizing locally available organic waste that has been largely underexploited, SentaCup not only contributes to reducing overall waste volume but also supports the development of a sustainable circular economy at the regional level. This innovation aligns with governmental efforts to establish more efficient and environmentally friendly waste management systems (Dutta & Karak., 2019). Through strategic collaboration with local authorities, SentaCup also creates opportunities for the empowerment of micro, small, and medium enterprises (MSMEs) and encourages the generation of new employment, particularly within the green industry and environmentally friendly manufacturing sectors. An illustration of the societal benefits of SentaCup is presented in Fig 6.



Fig 6. SentaCup Illustration Towards Surroundings

However, from a risk perspective, a comprehensive assessment is required to ensure the long-term sustainability of SentaCup implementation in Malang City. One of the main challenges is the fluctuating availability of spent tea grounds as raw materials, which

depends on the consistency of supply from local beverage producers. Market acceptance also represents a significant risk, as waste-based products may face skepticism regarding quality, safety, and performance among consumers. In addition, potential resistance from business actors, including manufacturers and retailers, may arise due to changes in production processes, perceived costs, or uncertainty about consumer demand. Other important considerations include the effective management of residual waste generated during production and the need to maintain operational cost efficiency. Poorly designed processes could lead to new environmental impacts or increased economic burdens. Therefore, systematic risk identification, analysis, and mitigation strategies are essential. Detailed risk analysis and proposed solutions for each identified challenge are presented in Table 1 to support informed decision-making and sustainable implementation.

Table 1. Number of receptors in each container

| Num. | Risk | Solution |
|------|---|--|
| 1 | Availability of Raw Material | Establishing cooperation with many parties not from Malang City, but also the areas around Malang and East Java to obtain diverse sources of raw materials and not depending on one party |
| 2 | Market Acceptance | Establish cooperation with the government as a provider of disposable beverage packaging in every activity, and tea beverage business actors as an effort to suppress the use of single-use packaging that is not environmentally friendly. Cooperation is also carried out with the Malang City souvenir center as one of the products of local "UKM" |
| 3 | Consumers Are Not Familiar With The Product | Conducting socialization and promotion at every government activity in various regions, and participating as a teenager in art activities or other forums that have the potential to be attended by many visitors |
| 4 | Production Waste | The aggregate from the rest of SentaCup production will be collected at each operation, to be further processed into additional materials in organic fertilizers that will be processed at the Supit Urang Landfill in Malang City |

3.4 Sustainability and circular economy alignment

The SentaCup concept aligns strongly with the core principles of sustainability and the circular economy by emphasizing waste valorization, resource efficiency, and reduced environmental impact. By utilizing spent tea dregs waste as a cellulose source, this approach transforms an underutilized organic by-product into a value-added biodegradable material (Nasiruddin et al., 2025). Such conversion supports the circular economy paradigm, which prioritizes closing material loops and minimizing waste generation through the continuous use of resources. Instead of following the conventional linear model of "take-make-dispose," SentaCup promotes a regenerative system in which waste streams are reintegrated into the production cycle.

From an environmental sustainability perspective, cellulose-based biodegradable cups offer potential advantages over conventional petroleum-based plastic cups, particularly in terms of biodegradability and reduced persistence in the environment (Debnath et al., 2024). The literature consistently highlights that cellulose is a renewable, bio-based polymer capable of decomposing naturally under appropriate conditions, thereby reducing long-term environmental pollution. The use of tea dregs waste as a raw material further enhances sustainability by decreasing the demand for virgin resources and reducing the environmental burden associated with waste disposal. This dual function—waste reduction and sustainable material substitution—positions SentaCup as a promising strategy for addressing plastic waste challenges.

The SentaCup framework also supports circular economy implementation through its compatibility with sustainable production and consumption principles. By sourcing raw materials from food and beverage waste streams, the concept encourages local resource

utilization and potentially shorter supply chains, which may contribute to lower transportation-related emissions. Moreover, the adoption of biodegradable cups derived from agricultural waste aligns with responsible consumption practices, particularly in sectors with high single-use cup consumption, such as food services and public events. This alignment reinforces the role of SentaCup as not only a material innovation but also a systemic solution supporting sustainable consumption patterns.

In addition, the sustainability orientation of SentaCup is consistent with global and national sustainability agendas, including circular economy frameworks and sustainable development goals related to responsible consumption and production, climate action, and innovation. By integrating environmental considerations into material selection and product design, SentaCup demonstrates how academic research can contribute to environmentally responsible innovation. Although further experimental validation is required, the conceptual alignment with sustainability and circular economy principles underscores the relevance of SentaCup as a foundation for future research and practical implementation in biodegradable packaging solutions.

3.5 Implementation strategy

The initial operational phase of the SentaCup product will be implemented on a regional scale, with the City of Malang designated as the primary pilot location. During this early stage, strategic partnerships will be established with the Malang City Department of Environmental Affairs (DLH) and the Supit Urang Final Disposal Site (TPA), which will serve as key partners in providing operational support, facilities, and suitable production locations. This collaboration is intended to optimize the use of existing waste management infrastructure while enhancing coordination between environmentally oriented industries and local government sustainability programs. By utilizing established systems, the production process can be made more efficient and cost-effective. Furthermore, integrating SentaCup into the local waste management framework is expected to create a replicable model for effective, measurable, and scalable waste-based innovation. This initiative not only contributes to government efforts to reduce waste accumulation but also creates opportunities for research, education, and active community participation, thereby supporting the development of a sustainable green industry ecosystem in Malang City.

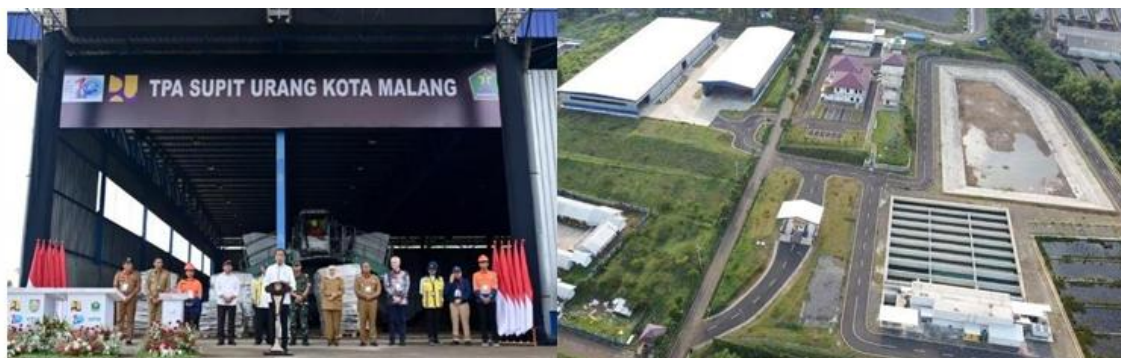


Fig 7. TPA Supit Urang Malang City
(Radar Malang, 2021)

To ensure the availability of the main raw material in the form of tea grounds, SentaCup will explore and establish cooperation agreements with various tea-based beverage industry players, such as ChaTime, Tea Break, Es Teh Indonesia, and Wonosari Tea Factory, as well as involve small-scale tea production centers in the Greater Malang region and its surroundings. This collaboration aims to build a stable, sustainable, and locally-based raw material supply chain. The tea grounds produced by the partners will be collected through a scheduled transport system, using a fleet of operational vehicles managed by the SentaCup team. To ensure the efficiency and quality of raw materials, the collection process will be

accompanied by standard protocols for handling organic waste, including the use of special containers and digital recording systems. In addition to supporting logistics efficiency, the approach also aims to build long-term relationships with industry partners, as well as expand collaborative networks that contribute to waste reduction and strengthening the circular economy at the local level.



Fig 8. SentaCup Partner Plan
(Google, 2025)

Fig 8. illustrates the potential partnership network supporting SentaCup's production system, particularly through collaboration with tea-processing industries and beverage brands. Partnerships with tea factories and tea-based beverage companies enable a sustainable raw material supply by utilizing tea grounds that would otherwise become organic waste. This collaboration not only reduces waste disposal burdens for partners but also creates added economic value from by-products, supporting a circular economy approach in which waste is reintegrated into the production cycle as a valuable resource.

Moreover, cooperation with local governments and regional institutions plays a strategic role in accelerating product adoption and public awareness. By showcasing SentaCup products at government-led events and sustainability campaigns, the product gains credibility as an environmentally responsible alternative to conventional plastic packaging. Such institutional support can also facilitate policy alignment, pilot programs, and wider distribution channels, strengthening SentaCup's position as a locally based innovation that contributes to waste reduction, green industry development, and the strengthening of the circular economy at the regional level.

SentaCup's marketing strategy will be focused on utilizing social media as the main promotional channel and establishing partnerships with the Malang City Government and the East Java Provincial Government. This product will be offered as an eco-friendly packaging alternative at various official government events to reduce the use of single-use plastics. In addition, marketing also targets raw material provider partners such as tea shops and the beverage industry, with incentives in the form of discounts as a form of appreciation. SentaCup also provides a logo inclusion service on the packaging at an additional fee without a limit on the minimum order quantity, so that it can reach businesses of various scales, while strengthening its image as a local product that supports

environmental sustainability. This approach is expected to expand SentaCup’s adoption while strengthening the brand’s image as a pioneer in organic waste-based, eco-friendly packaging at the regional level.

The operational framework of SentaCup is designed as an integrated and sustainable process that encompasses material sourcing, production, distribution, and commercialization (as illustrated in Fig 9.). The process begins with the handover and collection of raw materials, followed by systematic delivery to the production facility where manufacturing activities are conducted in accordance with efficiency and environmental considerations. After the production stage, finished products are distributed for market circulation and commercial sale, ensuring value creation throughout the supply chain. This structured operational flow emphasizes resource efficiency, waste minimization, and circular economy principles, thereby supporting the development of environmentally friendly products while enhancing operational transparency and scalability.



Fig 9. Illustration of the SentaCup Operational Stage

3.6 Competitor analysis

In the landscape of eco-friendly packaging markets, a thorough understanding of competitors is key to building strategic advantages, and the SentaCup project demonstrates clear differentiation from similar products such as Ecoplease. Ecoplease is an Indonesian company engaged in providing environmentally friendly packaging for food and beverage applications. Ecoplease focuses on the production of single-use packaging that is 100% plastic-free and home compostable. SentaCup builds a strong competitive advantage through waste-based innovation, utilizing cellulose derived from discarded tea grounds to produce waterproof biodegradable cups. SentaCup offers not only a product but also a solution that directly contributes to the circular economy, positioning it more favorably to attract consumers who are concerned about environmental and social impacts. A competitor analysis based on several aspects is presented in Table 2.

Table 2. Competitor Analysis of SentaCup and Ecoplease

| Comparison Aspect | SentaCup | Ecoplease |
|-------------------|--|--|
| Main raw material | Cellulose derived from tea grounds waste | General plant-based materials (e.g., corn starch, sugarcane) (Primawanti et al., 2025) |

| | | |
|-----------------------|--|---|
| Product focus | Unique and innovative solution that creates a strong narrative of “from tea waste,” attracting environmentally conscious consumers | Offers a variety of products without a strong storytelling element, making it difficult to stand out from competitors |
| Competitive advantage | Strong brand differentiation by building consumer loyalty | Focuses mainly on scalability (relying on mass production without significant added value) |

3.7 Discussion of the solution's relevance to the problem

The use of plastic-based single-use packaging causes various serious environmental problems. One of the main problems is the difficulty of plastic materials decomposing in nature, both on land and in waters, which leads to long term accumulation of waste and ecosystem damage. To overcome this, SentaCup comes as a solution by using the main ingredient of tea grounds which is biodegradable, so that it can decompose naturally in just 90 to 120 days. In addition, the use of plastic in hot beverage packaging also risks producing microplastic contamination that endangers health. To answer this problem, SentaCup is coated with beeswax, which is a natural wax that is safe and environmentally friendly, to increase the resistance to leakage without producing harmful substances when in contact with hot drinks.

The problem of the availability of raw materials, which are often unstable, is also a concern. For this reason, SentaCup collaborates with various parties, not only from Malang City but also from the area around Malang and other regions in East Java, to ensure a diverse supply of raw materials and not depending on one source. Meanwhile, to answer the challenges of market acceptance, SentaCup collaborates with the government as a partner in providing single-use beverage packaging at various official activities, as well as collaborating with tea beverage business actors to replace plastic packaging that is not environmentally friendly. This product is also marketed through a souvenir center in Malang City as part of the promotion of local “UKM” products.

As for overcoming consumers' unfamiliarity with this new product, socialization and active promotion are carried out in various government activities in various regions, as well as participation in art events or other public forums that have the potential to attract many visitors. Related to production waste, aggregate from SentaCup manufacturing waste will be collected regularly, then processed into organic fertilizer additives managed at the Supit Urang Final Disposal Site (TPA), Malang City. To address consumers' unfamiliarity with this new product, socialization and promotional activities are conducted through government-led events, art exhibitions, and public forums across various regions. These initiatives aim to increase public awareness and encourage the adoption of environmentally friendly packaging alternatives.

Finally, one of the obstacles that consumers often face is the existence of a minimum order policy from competitor products, especially for special design requests. SentaCup offers a flexible solution by not imposing a minimum order limit for custom designs, but instead applying additional fees to each unit of its product. That way, consumers can still order small quantities without having to be burdened with large costs at the beginning. Production waste generated from the SentaCup manufacturing process is collected regularly and managed in an environmentally responsible manner. The waste is processed into organic fertilizer additives at the Supit Urang Final Disposal Site (TPA), Malang City.

4. Conclusions

The SentaCup innovation makes a significant contribution to the implementation of circular economy principles and environmental preservation through the effective utilization of cellulose-rich spent tea waste. By transforming previously undervalued organic waste into a primary raw material for waterproof and biodegradable cups,

SentaCup reduces dependence on virgin resources and helps minimize the accumulation of organic waste in landfills. The biodegradable characteristics of SentaCup provide a more sustainable alternative to conventional single-use plastic products, which persist in the environment for long periods. Beyond its function as a consumer product, SentaCup represents an innovative approach to waste management by creating added value from overlooked resources. This initiative supports circular economy practices by extending the life cycle of organic materials and reintegrating them into productive use. Furthermore, SentaCup promotes public awareness of the economic and environmental potential of organic waste, encouraging more responsible consumption and production patterns. Overall, SentaCup demonstrates how locally based innovation and sustainable thinking can generate practical solutions that simultaneously benefit the environment and support green economic development.

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Author Contribution

Conceptualization, A.R.D.; Investigation, G.T. and H.Z.P.; Methodology, A.R.D. and H.Z.P.; Formal analysis, G.T. and A.R.D.; Data curation, G.T.; Validation, H.Z.P.; Visualization, G.T.; Writing—original draft, A.R.D.; Writing—review and editing, G.T. and H.Z.P. All authors have read and agreed to the published version of the manuscript.

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This study did not involve human participants, animal subjects, or sensitive personal data; therefore, ethical review and approval were not required.

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Conflicts of Interest

The authors declare no conflict of interest.

Declaration of Generative AI Use

The authors declare that the manuscript was prepared solely by the authors.

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