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Telefoon (597)464547, Fax (597)434211, E-mail: adekbib@uvs.edu

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Faculty of Mathematics and Natural Sciences

Department: Chemistry

An Approach for Transforming Waste Corrugated Cardboard, Starch and Coconut Fibers into Paper Pulp

A thesis submitted in partial fulfillment of the requirements for the
Degree of Bachelor of Science in Chemistry

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Student name:	Becker Melissa
Student number:	201700522

1. Name of the Head of the Department (RC): Dr. Kartopawiro J.
2. Name of the Main Supervisor : Dr. Birdja Y.
3. Name of the Co-Supervisor : Dr. Ejeromedoghene O.

4. Independent Expert : Dr. Grant C.

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Statement of Own Work

The student hereby declares that the submitted graduation work is her own work.

Name student:
Becker Melissa

Date:
November 18, 2025

Signature:

Abstract

This research focused on the transformation of waste corrugated cardboard and coconut fibers into paper pulp, aiming to address the growing concerns regarding the recycling of these materials and promoting sustainability in Suriname. The study determined the qualities of paper pulp when combining waste cardboard with modified coconut fibers and starch. Coconut fibers were incorporated into the pulp in predefined ratios, combined with waste cardboard mixtures of 50%, 70%, 75%, 85%, and 90%, depending on the sample composition. The results showed that the modified starch additive as a binding agent significantly enhances the properties of the paper pulp, by reducing the water absorption capacity (WAC), moisture content (MC) and thickness swelling degree (T-SD). Coconut fibers were modified using ethanol, acetic acid, and sulfuric acid treatment to improve fiber bonding. Waste cardboard was shredded, soaked, and blended to form a pulp. Maize and cassava starches underwent modification through a crosslinking process using trisodium citrate.

The findings showed that the addition of modified starch significantly reduced WAC, MC, and T-SD compared with unmodified mixtures. The 75%: 15%: 10% mixture of waste cardboard, modified cassava starch, and modified coconut fibers provided evidence that this is the most balanced overall performance sample, achieving a low MC of 5% and the lowest T-SD value of 13%. Although samples 13 and 27 achieved the lowest MC values (4%), and sample 26 showed competitive WAC results, these mixtures did not perform better than sample 20 when all three parameters are considered together. The better performance of sample 20 indicates that combining modified starch and modified coconut fibers with waste cardboard can produce a stable pulp, suitable for eco-friendly packaging material. This study serves as a significant contribution to the development of sustainable transformation of waste recycling and the feasibility of producing paper pulp from locally sourced waste cardboard and coconut fibers.

Acknowledgements

First, I am profoundly thankful to God for granting me the wisdom and strength to endure and overcome this journey.

Further, I would like to express my sincere gratitude to Dr. Birdja Y. for his kind support, expertise, and patience during this research project. Heartfelt thanks to Dr. Onome E., Dr. Kartopawiro J., and Dr. Grant C. for their invaluable guidance and support throughout this research endeavor. I also extend my appreciation to the student dean, Dr. Van Dijk P., the assistants in the Chemistry laboratory, the Staff administration FWNW, and my fellow students for their assistance and encouragement during this research project.

To my parents and partner, your love, support, and presence in my life have been invaluable. This achievement is as much yours as it is mine, and I am forever grateful for your unwavering belief in me. I cannot thank you all enough and I look forward to more life adventures ahead!

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List of Abbreviations and Acronyms

Abbreviation	**Definition**
$Ca(OH)_2$	Calcium hydroxide
CN	China
EPI	Epichlorohydrin
GHS	Globally Harmonized System of Classification and Labeling of Chemicals
HK	Hong Kong
IN	India
IWMP	Integrated Waste Management Plan
JM	Jamaica
MCF	Modified Coconut Fiber
MCS	Modified Cassava Starch
MMS	Modified Maize Starch
NaOH	Sodium hydroxide
NL	Netherlands
PK	Pakistan
$POCl_3$	Phosphoryl chloride
T-SD	Thickness Swelling degree
SOP	Monosodium phosphate
STMP	Sodium trimeta-phosphate
STPP	Sodium tripolyphosphate
SUWAMA	Suriname Waste Management Foundation
TW	Taiwan
UCF	Unmodified Coconut Fiber
UCS	Unmodified Cassava Starch
UMS	Unmodified Maize Starch
US	United States of America
WC	Waste Cardboard
ZA	South Africa

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Chapter 1: Introduction

1.1 General Overview

Manufacturers produce paper and cardboard worldwide, including in Suriname, where reliance on imported paper products has created significant waste challenges. Beyond its traditional roles as a surface for writing, printing, and packaging, recent scientific studies have unveiled its potential as a biodegradable, renewable, cost-effective, and versatile polymer substrate (Samuel et al., 2024). The packaging industry in Malaysia relies on secondary fibers like waste, corrugated cardboard, and waste papers as primary raw materials for paper production. Imported virgin long fiber pulp from softwood is essential to reinforce fiber strength for packaging applications (Main et al., 2014).

In Suriname, waste cardboard constitutes unwanted material that people consider no longer useful and must throw away immediately, regardless of the environmental effects of such waste processing practices. In Suriname, this waste cardboard can be recycled and mixed with other material such as coconut fibers and starch, to produce paper pulp for other eco-friendly protective or transport packaging products. According to United Nations Industrial Development Organization (UNIDO), (2018), approximately 167,000 tons of solid waste are annually deposited at the legal dumping site Ornamibo, originating mainly from households, shops, markets, offices, industries, and hospitals in the service areas.

Non-biodegradable plastics persist longer in the environment, because they do not break down which are making the environmental problem worse. Because less than 10% of waste is recycled in Suriname, The Basel Convention Regional Centre for Training and Technology Transfer for the Caribbean BCRC-Caribbean collaborated with the Suriname Waste Management Foundation (SUWAMA) to replace single-use plastic commodities (Replacing Single Use Plastic Commodities in the Economy of Suriname – BCRC Caribbean, 2021).

Waste separation still takes place to a minimal extent, also before collecting it from households. One of the effective ways to manage such wastepaper and minimize the pressure on landfills, including Ornamibo, is by recycling them. Wastepaper can be utilized to manufacture a range of alternative paper products, including paper egg trays. Keeping paper and cardboard waste separate can increase the prosperity of recycling and developing new paper products.

Amoo et al. (2016) identified that "Challenges of quality and quantity of paper egg tray in southwestern Nigeria called for attention". Therefore, it is crucial to assess the quality of the paper pulp as an alternative to producing other paper packaging material e.g., paper egg trays, instead of using new plants to obtain cellulose for paper egg trays or still importing new paper egg trays. Over the years, new egg trays have been imported to Suriname from different countries, namely: China (CN), Hong Kong (HK), India (IN), Jamaica (JM), Netherlands (NL), Pakistan (PK), Taiwan (TW), United States of America (US), South Africa (ZA). (General Bureau of Statistics Suriname, 2024)

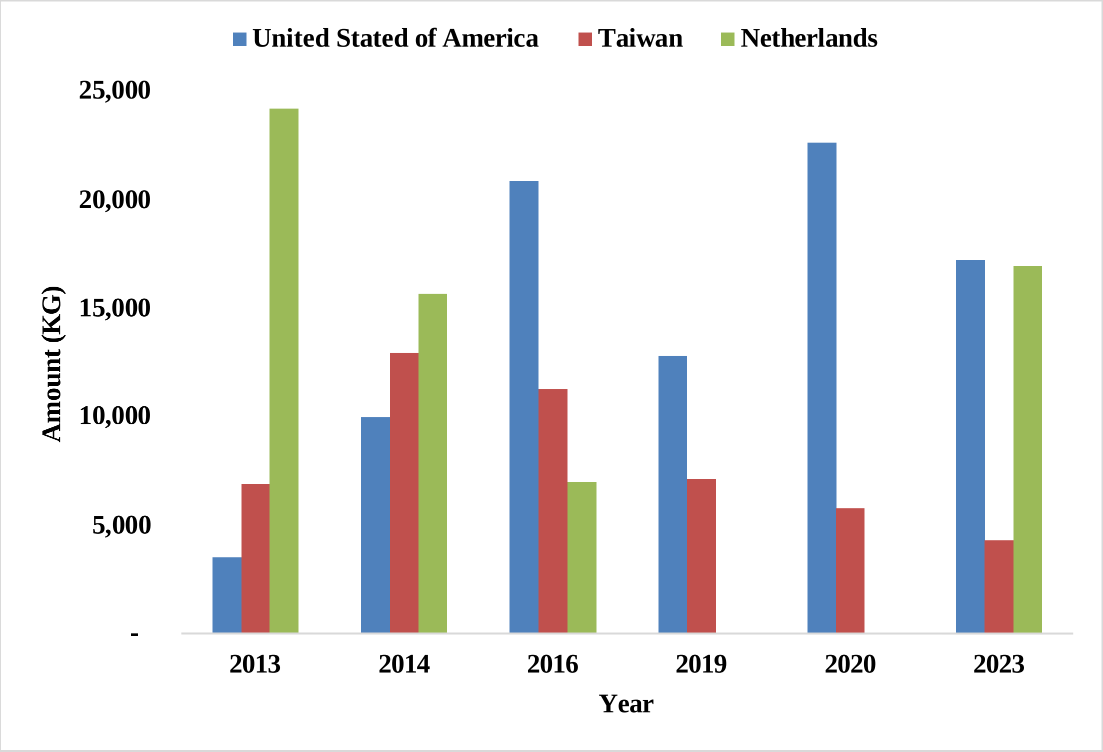


Figure 1: Imports of egg trays by Suriname in net weight (KG) and period 2013-2023

Note: Due to the Disclosure Prevention Policy (DPP), there is no data for the years 2015,2017, 2018, 2021 and 2022, including export data. (General Bureau of Statistics Suriname)

In Figure 1, only the countries with available data for three years or more are included. The trading statistic number 48,195,010 is used by the Bureau of Statistics in Suriname to record the amount of imported or exported packaging for eggs. All this material also ends up as solid waste. It is therefore important for Suriname to recycle and reprocess wastepaper at a higher level. Currently, only a few small private companies are paying attention to this issue.

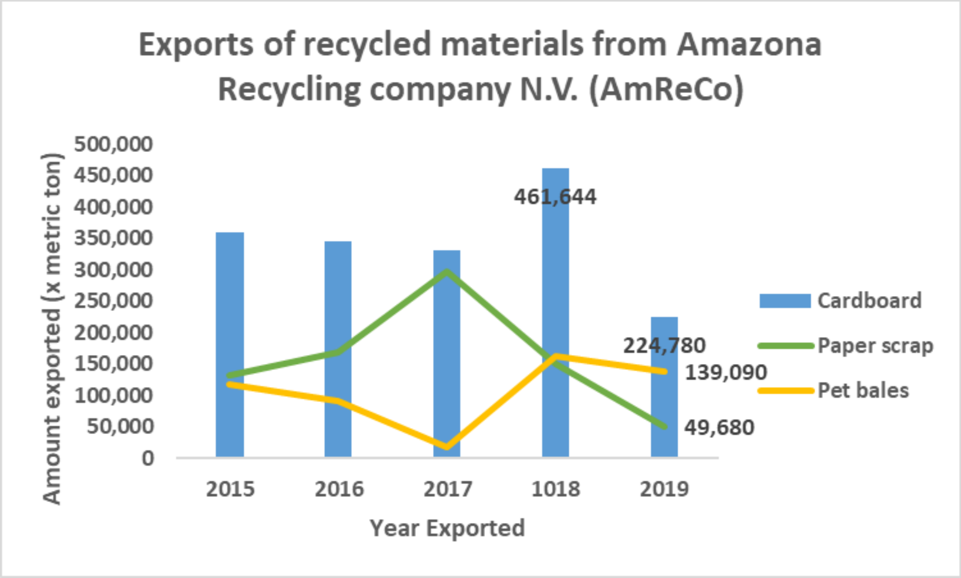


Figure 2: Facts and Figures Waste Processing in Suriname (AmReCo, 2009)

As illustrated in Figure 2, data on a mix of various waste cardboard has been documented. Distinguishing between different types of cardboard based on their specific purposes will facilitate the production of new paper materials from waste. Recycling and reusing the cardboard helps to achieve the sustainable development goal number fifteen, “Life on Land " which brings Suriname closer to the world we want by 2030. Furthermore, it brings Suriname closer to realizing the reuse and recycling policy activity outlined in the integrated waste management plan (IWMP) for Suriname (IWMP final report, 2022). Thus, reusing old material is an important principle of green chemistry, “use renewable feedstocks”, and the circular economy.

This study has developed an approach to transform waste cardboard, coconut fibers, and starch into sustainable and biodegradable paper pulp to substitute the import of egg trays.

1.2 Problem Statement

In Suriname, over 272,846 metric tons of waste cardboard are exported to other countries, where it is recycled into various paper products (AmReCo, 2009). These molded paper products are then imported by Suriname to be used for packaging and storage. Instead of exporting used corrugated cardboard as waste, Suriname can utilize it for the local production of paper molded products. There is a local company, “Green Pack Suriname,” that produces molded products, i.e., egg trays. However, their starting material is “pre-used” cardboard and newspapers, which are comparatively clean, have steady quality, and are easy to recycle. Until now, the excess used, corrugated cardboard in Suriname has not been used properly. The challenge at hand is to convince larger companies of the advantage of the feasibility and efficiency of utilizing this waste cardboard and coconut fibers as starting materials for producing sustainable and functional paper pulp.

1.3 Main and sub research questions

Main research question:

Can paper pulp, derived from used, corrugated cardboard, modified cassava or maize starch, and modified coconut fiber, be utilized to manufacture paper pulp that can be used to produce paper products in Suriname?

Sub-questions:

1. How does the presence of modified starch-binding agents affect the quality of paper pulp?
2. What is the potential of modified starch, coconut fiber, and cardboard in making paper pulp, and how does this affect the properties of paper pulp products?
3. What ratio of modified starch and modified coconut fiber should be utilized to produce paper pulp products with better properties?

Objective

In this research, the aim is to produce paper pulp products from waste cardboard and coconut fiber fibers. The feasibility of this production process will be investigated, and the influence of coconut fibers together with modified cassava and maize starch will be studied. The performance and quality of the locally produced paper pulp will be evaluated in accordance with the requirements for export.

1.4 Relevance of the project

In Suriname, cardboard and other wastepaper are usually dumped by residents in the streets in their neighborhoods. This can lead to enormous environmental pollution, or this cardboard waste gets burned or ends up legalized in open dumping places (Zuilen L.F., 2006). Dumping waste in the streets is normally illegal. The economic circumstances in Suriname have prompted an increase in boxes sent from family members abroad, containing essential food and other items to support their loved ones during challenging economic periods. Moreover, supermarkets offer cardboard boxes instead of handbags for multiple purchases, thereby increasing the amount of cardboard packaging in households. It is a common practice for residents to burn their cardboard boxes and other household waste in their backyards, which also creates air pollutants. Supporting recycling and reuse initiatives is a way to address waste cardboard effectively. There is a local company that started collecting specific types of waste, such as cardboard. However, the large amount of collected waste cardboard is not used locally but rather exported to other countries. (AmReCo, 2009). This research project will study the feasibility of using waste cardboard and modified coconut fibers to produce stable molded products, which could significantly reduce waste management costs in Suriname, create local job opportunities, sustainable manufacturing, and decrease reliance on imported paper products.

To the broader impacts of this study include:

- Producing paper pulp from biowaste and cardboard using a methodology that is harmless to the environment.
- Providing the Surinamese community with insights and practical examples of structural waste recycling and waste management by the collection of used cardboard. This will conserve the environment by using the waste cardboard and coconut fibers and thus close the cycle towards a circular economy.
- Obtain fundamental insights for the utilization of coconut fibers, maize, and cassava starch as additives in production processes.

1.5 Thesis outline

The thesis contains five chapters, references, and the appendix.

Chapter 1 gives a general overview of the background and motivation of this study and contains the project definition and objectives. In Chapter 2, the existing research and theories about the preparation of paper pulp from cardboard with modified or even unmodified coconut fiber and starch are described. Additionally, an overview of methodologies and analyses is given to determine key properties of the paper pulp. Chapter 3 gives an overview of the materials that were needed and describes the methods that were applied to prepare and analyze the samples during the experiments. In chapter 4, the results are reported and interpreted, and it is discussed how they align with the research questions. Chapter 5 presents the conclusion and recommendations, followed by the references that cite relevant literature and sources discussed in the chapters, followed by the appendix.

Chapter 2: Literature Review

2.1 Corrugated Cardboard

Used, corrugated cardboard can be very useful because cellulose fibers can be recycled up to seven times (Ozola, et al., 2019). Glucose molecules from the cellulose polymers are connected by β-1,4-glycosidic bonds (Figure 3). The pyranose formed glucose units consist of a six-carbon ring with hydroxyl groups attached at different positions.

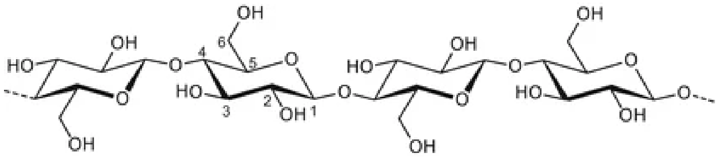


Figure 3: Structural representation of a cellulose molecule. (Heinze, 2015)

In the manufacturing process, the cellulose fibers are converted into a paper pulp using water. Binders or other additives, such as starches, can be used for better performance and adhesion of the cardboard.

Corrugated cardboard has two or more flat sheets and consists of a crimped sheet in between, like a sandwich model. The number of layers depends on the application of the packaging.

2.2 Coconut fibers

The coconut fiber from the plants with the official name "*Cocos Nucifera*", which belong to the family "Arecaceae (Palm)" is about 30 wt % of the 1–2 kg in weight coconut fruit. There are about 300 types of coconuts, and therefore, the mesocarp consists of fibers that can vary in length and thickness. Coconut fibers are distinguished by brown and white fibers. White fiber is soft, smooth, and flexible, made from young green coconut fibers. Brown fiber (Figure 4), from fully ripe (mature) coconuts, does not go through the same process. The best fibers come from mature coconuts, while lower-quality ones are from immature or very ripe nuts. Both types are important for making coconut-based products because they contain a substantial amount of lignocellulosic polymer, enhancing their strength and longevity. However, due to their slow decomposition rate of almost 9 years, these fibers can harm the environment when disposed of through practices like open burning or soil contamination. It has been noted that fibers near fully ripe nuts yield higher-quality fibers, which are favored for fiber collection processes. The fibers are a mixture of different ecotypes.

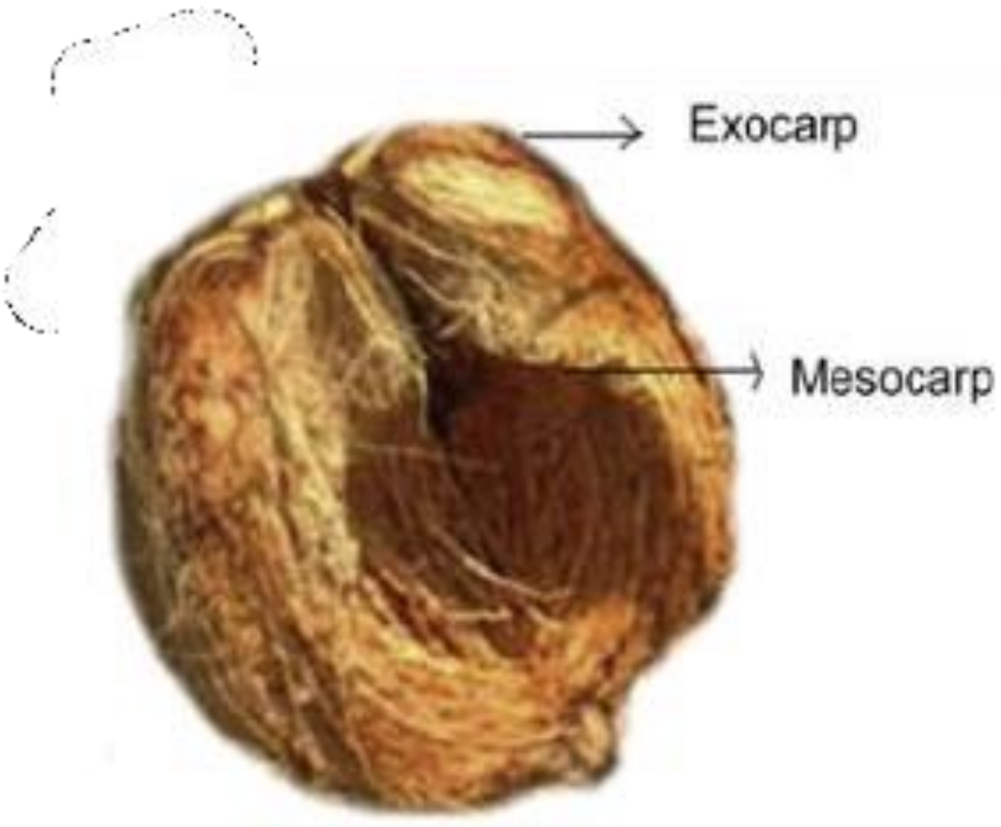


Figure 4: Coconut Husk 12-14 months

The chemical composition of the fibers regulates how they interact with polymer structures, significantly influencing the properties of the composite. “Coconut husk fibers contain cellulose, lignin, and hemicellulose in the following chemical compositions: cellulose 26.6%, hemicellulose 27.7%, lignin 29.4%, water 8%, and other materials ranging from 8.3%.” (Ningtyas et al., 2022; Mishra & Basu, 2020). Different types of treatments of coconut fibers, for example, lignin etching and grafting of functional groups, can affect the fiber’s structure, properties, and self-bonding strength. To form a strong linkage bond, it is important to know these properties and how they can be affected. Miao et al. (2023) compared several studies that showed the impact of chemical treatment methods, particularly NaOH solutions, which give a better and effective mechanism for changing fiber bonding properties and enhancing fiber strength, leading to instantaneous severe lateral swelling of the fibers. Wang et al. (2019) reported that the strength of single fibers is more influential in determining mechanical strength compared to the role of inter-fiber bonding. The stiffness of lignin-rich fibers poses challenges in their plastic deformation, hindering effective inter-fiber contact and cross-linking during the hot-pressing process. Research executed by Shah et al. (2016) also confirmed that lignin serves as a dual barrier, both physical and chemical, in the hindrance of pulping solution penetration into raw materials. This lignin resistance slows down fiber release and affects the efficiency of pulping processes such as the Kraft and Organosolv methods. Several studies have examined ways to improve the chemical reactivity of coconut fibers. Mishra et al. (2020) compared the effect of different NaOH concentrations on the coconut fiber structure used in experiments from different references. They reported that a treatment with 5% NaOH primary removes the less thermally stable hemicellulose and gives a more thermally stable lignin-cellulose complex. This increased stability has been shown to support the production of molded products, such as egg trays, from Organosolv pulp derived from tender coconut fibers (Jincy, et al., 2015).

Pulp refining is an approach where the fiber properties are modified to obtain a higher pulp quality. This increases the strength of the fiber-fiber bonds and flexibility which leads to stronger paper properties. Chemically modifying fibers can alter their surface properties, water absorption, and barrier behavior, making them more suitable for packaging applications. In this study, coconut fibers were chemically treated using a mixture of ethanol, acetic acid, and sulfuric acid to modify the fiber surface, reduce lignin interference, and enhance fiber–fiber bonding during pulping. Reducing lignin or disrupting its structure improves pulp quality and contributes to higher tensile strength in the final product (Zhang et al., 2013; Gharehkhani et al., 2015). While processes such as Organosolv are known for efficiently removing lignin and allowing recovery of organic solvents, they are discussed here as reference methods in the literature and were not applied in this study. Furthermore, Bui et al. (2020) exposed coconut fibers to a sodium hydroxide 10% and a calcium hydroxide $Ca(OH)_2$ saturated solution to determine their chemical stability. Alcohol and water mixtures significantly influence the physical structure of coconut fibers. Lower alcohol concentrations promote greater swelling, increasing pore volume and enzyme accessibility. Recent studies on organosolv pretreatment commonly use ethanol concentrations in the range of 60–80 wt%, supporting the use of high alcohol concentrations for the effective lignin solubilization (Chu et al., 2021; (Nair et al., 2023). The degraded fibers, which will be used in the process, are important to determine their biodegradability and environmental impact and are therefore highly relevant for the Life Cycle Assessment (LCA). By understanding how the coconut fibers break down under different chemical conditions helps to estimate the environmental impact of the final molded pulp product and the eco-friendly waste management approaches. Their results show that the mass loss of the modified fiber is almost equal to half of the mass loss when using raw coconut fibers. The mass loss was 37% and 20% in sodium and calcium hydroxide, respectively, for the raw fibers. These findings describe and give insight into how coconut fibers respond to various chemical treatments in other studies and are referenced here for context. Treatments such as NaOH, $Ca(OH)_2$, and Organosolv pretreatment were not part of the chemical modification used in this research, which instead applied an ethanol, acetic acid, sulfuric acid modification method.

2.3 Starch

Starch is a promising natural and renewable plant-based polysaccharide that has proven to make a successful contribution when used in biodegradable products (Giuri et al., 2018). The characteristics of starches can differ considerably based on the plant source from which they are derived. Different plant species, such as maize, wheat, potatoes, rice, tapioca, and cassava, are employed in starch production. In Figure 5, starch is chemically fractionated into two glucan polymers, amylose 20-30 wt%, and amylopectin 70-80 wt% (Cornejo-Ramírez et al., 2018; Buléon et al., 1998). The variety in the hydroxyl groups is the main reason that they behave hydrophobically. This behavior is a limitation for the development of starch-based materials.

Table 1 summarizes the properties of certain native starches (i.e., Cassava and Maize) from two distinct studies by Zambelli et al. (2024) and Alcázar-Alay et al. (2015).

Table 1: Composition of Amylose and Amylopectin for Maize and Cassava Starch

Origin of Starch	**Amylose (%)**	**Amylopectin (%)**
Cassava	15-25*	75-85*
	8-25 / 23.7**	N.A.
Maize	25-30*	70-75*
	25.8-32.5 / 28.5**	N.A.

**Zambelli et al. (2024) and **Alcázar-Alay et al. (2015)*

The addition of starch in the paper pulp process will be helpful because of its binding effects. Thermoplastic behavior is also characteristic of starch under high temperatures, but because of its brittleness and water solubility, it needs a plasticizer in the process. The brittleness of starch can be improved by the incorporation of plant-based fibers. (Lomelí-Ramírez et al., 2014)".

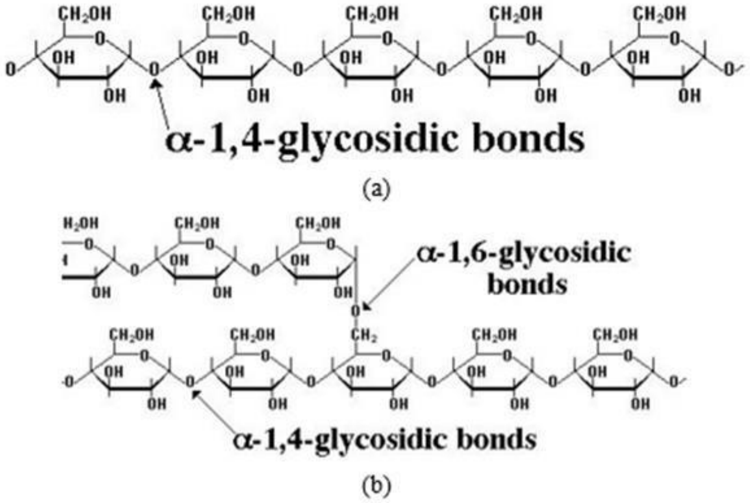
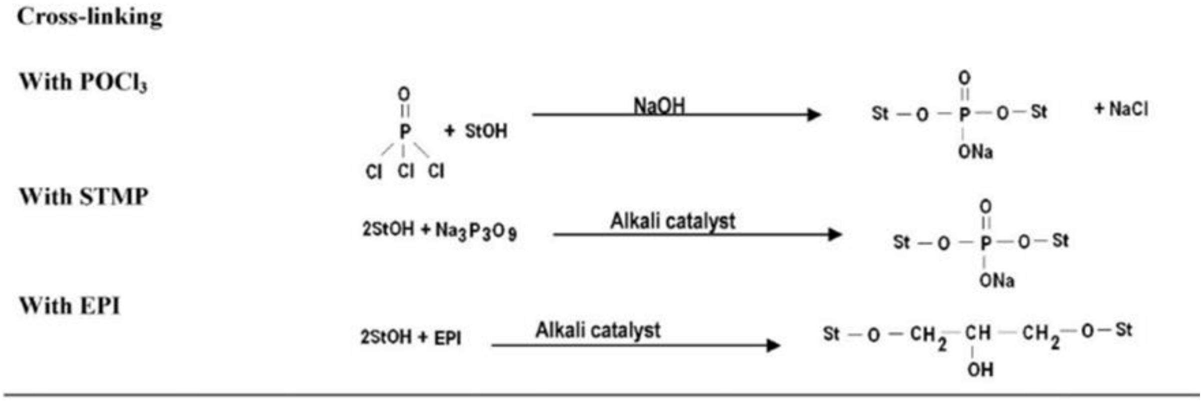


Figure 5: Starch structure with (a) amylose and (b) amylopectin

Chemical modification in which new functional groups are introduced into the starch molecule to change their chemical behavior, resulting in modified starch molecules.

The reaction conditions, such as modifying reagents, concentration of the reactants, reaction time, type of catalyst used, pH, and temperature, determine the chemical and functional properties of a modified starch molecule. By chemically modifying the starches, it produces water-resistant starch types that do not break down quickly. Crosslinked starch is a low-cost structural transformation by the crosslinked method, which is commonly used in the papermaking industry. Crosslinking treatment is intended to create intra- and intermolecular bonds at random locations in the starch grain, which stabilizes and strengthens the starch grain. Crosslinkers are bifunctional or multifunctional reagents that can form intermolecular bonds with the hydroxyl groups, forming ester or ether linkages. This enables the starch granules to show a reduction in swelling under cooking conditions due to better resistance at a temperature of 95 °C. “Some main agents that are already used for cross-linking are sodium trimeta-phosphate (STMP), monosodium phosphate (SOP), sodium tripolyphosphate (STPP), epichlorohydrin (EPI), phosphoryl chloride ($POCl_3$), a mixture of adipic acid and acetic anhydride, and vinyl”. (Singh et al., 2007). In aqueous slurry, $POCl_3$ is an efficient cross-linking agent at pH > 11 in the presence of a neutral salt. The starch crosslinking reactions with some main agents are shown in Figure 6. At higher temperatures for cross-linking processes, STMP is an efficient material that can be used in aqueous slurry at warm temperatures with moisture starch. Because of the poor solubility, the chance of disintegration, and the less uniform distribution of EPI, the $POCl_3$ and STMP are preferred as crosslinking agents. (Singh et al., 2007).



St = Starch; $POCl_3$ = Phosphorus oxychloride; STMP = Sodium tri-meta phosphate.

Figure 6: Some common starch chemical modification reactions (Singh et al., 2007)

In the study by Koo et al. (2010) they investigated the effect of cross-linking on the chemical properties of maize starch. Their study showed how cross-linked maize starch resulted in decreased solubility, swelling factor, and paste clarity. They also showed the strong correlation between the swelling factor with the degree of cross-linking, with lower swelling factors associated with higher degrees of cross-linking. The chemically modified starch showed a decrease in the solubility in water due to the cross-linked bonds of starch, and swelling factor at all temperatures. (Koo et al. 2010). This will be used as an internal sizing agent to modify the characteristics, especially the absorbency and moisture content of the egg trays to liquids. The mechanical properties of egg trays, as depicted in Table 2, have been previously investigated (Amoo et al., 2019).

Table 2: Mechanical properties of egg trays with increasing percentage of starch added

	Paper egg trays (Control)	**Internal application of starch on Paper egg trays**		
	0%	10%	20%	30%
Water absorption Capacity (%)	272.40 ± 5.12	279.0 ± 1.71	282.80 ± 1.29	292.60 ± 0.96
Moisture content (%)	4.10 ± 0.30	5.0 ± 0.67	5.20 ± 0.18	5.68 ± 0.08
Thickness Swelling degree (%)	72.80 ± 2.5	75.40 ± 2.36	82.0 ± 1.29	90.20 ± 0.82

For the crosslinking method, the trisodium citrate acts as a crosslinking agent in starch-based systems. It facilitates the formation of bonds between starch molecules, improving the starch's ability to absorb water by changing its gelatinization. The trisodium citrate is created by using sodium hydroxide, $NaOH$, to neutralize the citric acid, $C_6H_8O_7$ and then letting them form crystals (Figure 7).

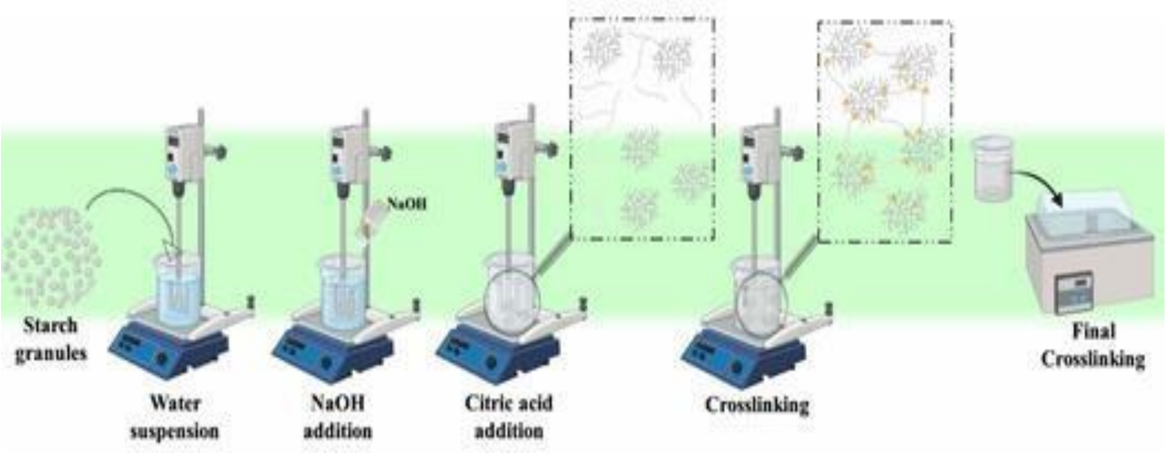


Figure 7: Schematic illustration showing how starch chains (amylose and amylopectin) rearrange during the crosslinking process in starch hydrogel production

Adding trisodium citrate to wet starch stabilizes it and inhibits gelatinization. Affecting the gelatinization process, trisodium citrate modifies the water-absorbing capacity of starch-based products. It reduces the amount of water absorbed by starch or alters the texture and consistency of the final product. For the paper pulp, waste corrugated cardboard can be mixed with coconut fibers to increase the quality of the molded products, and starch as a sizing agent that helps to strengthen, bind particles, and provide moisture content to the product (Robert et al., 2019b and Czechowski et al., 2020).

To avoid inadequate performance from the unmodified starch, the starch in this work will undergo modification by using the crosslinking method. This should result in better moisture content and stability of the paper egg (Jiang et al., 2020). Amylose has more proportional relationships with pasting and gel texture properties, whereas amylopectin is predominant in regular (about 20–35% amylose) and waxy (<15% amylose) varieties. Maize starch has a higher proportional relationship with firmness. For this examination, it is important to maintain the plaque and gel structure. With the modified starch molecules, the aim is to offer the maximum firmness to the final product.

Chapter 3: Materials and Methods

This section contains materials, chemicals, and methods to produce paper pulp. It also gives an analysis of the quality of the paper pulp. Waste cardboard used in this work was collected from the Amazona Recycling Company (AmReCo). The coconut fibers that formed the composite of biowastes were collected as waste products from a local coconut farmer in the Coronie district. The cassava and maize powder used were collected from a local supermarket. Section 3.3 Pre-Work describes the initial work, which is divided into four parts showing how the different components were prepared before combining them together in different mixing percentages. Thereafter, the drying process in the sun was used to prevent charring and allowing the removal of moisture from the samples. The data analysis of the molded pulp samples is given in Section 3.5 Sample Analysis & Accuracy.

All the samples were labeled with different abbreviations. This consists of the initials from the name of the component in combination with the treatment of the component.

The samples that consist of modified or unmodified components, respectively M or U, are written before the abbreviation to distinguish them.

3.1 Materials

- Waste Cardboard (WC)
- Cassava Starch (CS)
- Maize Starch (MS)
- Blender
- Digital weighing balance
- Thermometer

3.2 Chemicals

- Sodium hydroxide
- Acetic acid 70%
- Sulfuric acid 0.5%
- Ethanol 60%
- Trisodium Citrate (12.8 mg/mL)

3.3 Pre-Work

3.3.1 Preparation of Waste Cardboard (paste)

Used cardboard papers were cut into smaller pieces (Figure 8) using a paper cutter, and the pieces were soaked in water using a plastic bucket. After 24 hours, the soaked pieces of paper were removed and blended using a household electric blender. Figure 9 shows the wet form of the waste cardboard paste produced.

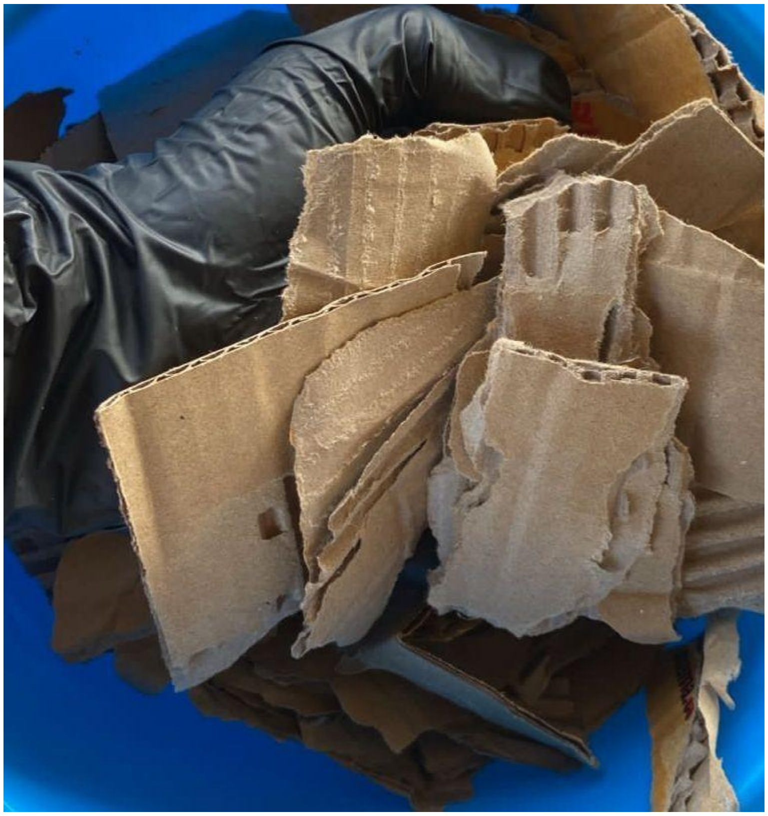


Figure 8: Shredded waste cardboard

Figure 9: Blended waste cardboard after soaking for 24 hours in tap water

3.3.2 Segmentation of the coconut fiber

Removing the fibers from coconuts is a critical process. The fibers were segmented from the exocarp, and only the fibers from the mesocarp part were used. The fibers shown in Figure 10 were washed with water to remove any dirt, cut with scissors into small pieces, and then chopped with a household electric blender to receive smaller parts.

Figure 10: Coconut fibers directly segmented from the exocarp (a) and smaller chopped coconut fibers (b)

3.3.3 Modification of Coconut fibers

The modified coconut fibers were prepared by mixing the coconut fiber particles (50 grams) with 60% ethanol (500mL), 70% Acetic acid (50 mL) and 0.5% Sulfuric acid (50 mL). The Erlenmeyer was placed on a hotplate covered by a watch glass (Figure 11). After 15 minutes of monitoring the temperature, it reached 140°C. After 20 minutes the solution cooled down to room temperature. This was first washed with 70% fresh acetic acid and then with distilled water using a Buchner Filter.

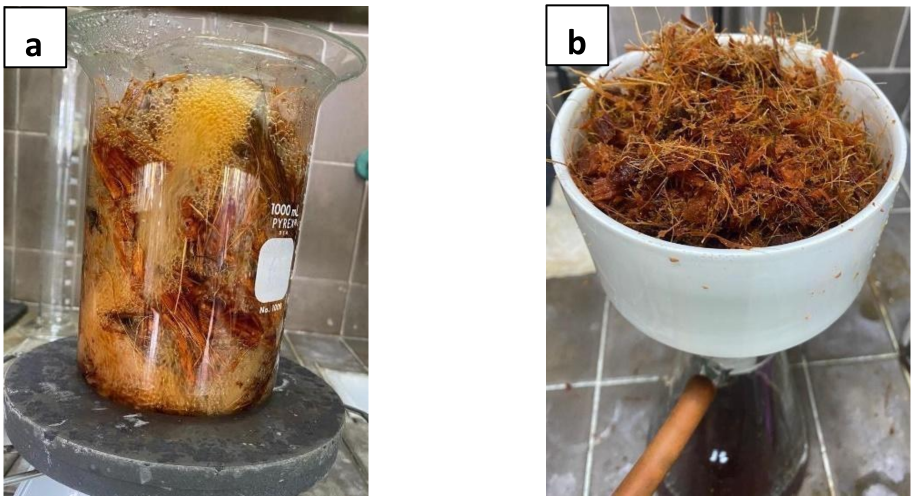


Figure 11: The setup during the modification process of the coconut fibers (a) extracting and (b) filtering

3.3.4 (Un) Modified starches

The experimental procedure below describes how both the modified and unmodified cassava and maize starches were prepared.

Unmodified Starches (Cassava and Maize)

The unmodified starch binding agent was prepared by dissolving 105 g powder in 1.5 mL water and heating to form a thick starch paste. This procedure was also carried out to prepare the unmodified starch.

Modified Starches (Cassava and Maize) prepared according to Da Costa et al. (2025)

Starch powder (35 g) was dissolved in 500 mL of water and heated. After the starch was dissolved, NaOH (13 g/L) was added and stirred for three hours at a temperature ranging between 40-45 °C (Figure 12a). The pH was determined using litmus paper (Figure 12b). Then, citric acid ($C_6H_8O_7$) (19.4 g/L) was added to form the crosslinking agent (trisodium citrate, $Na_3C_6H_5O_7$), considering the reaction's stoichiometric balance. Chemical crosslinking occurred with the system under mechanical agitation at room temperature (~ 25 °C) for 24 hours. The gel was heated in a water bath at 90 °C for 30 min and stabilized at room temperature (~ 25 °C) for 30 min.

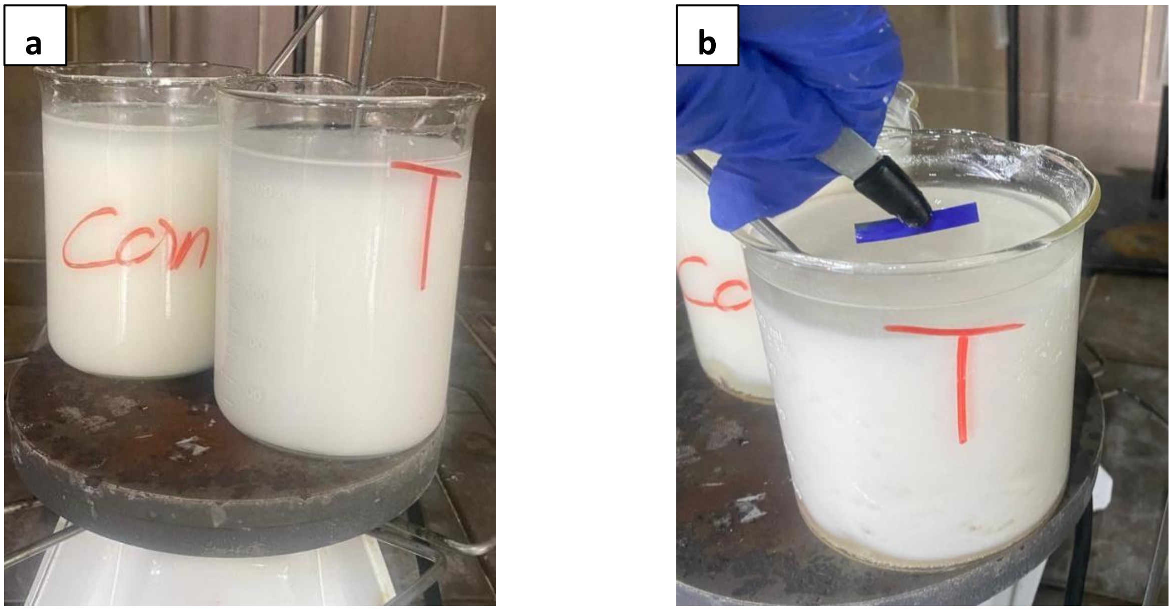


Figure 12: (a) Modified Maize (left) and Cassava (right) Starches. (b) pH determination

3.4 Preparation of the molded pulp

After the pre-work, the different components, as shown in Figure 13; waste cardboard paste, (un) modified coconut fibers, (un) modified cassava, and (un) modified maize starches were used to produce the end molded pulp samples in different mixing percentages. The general overview of the experimental work is shown in Figure 14.

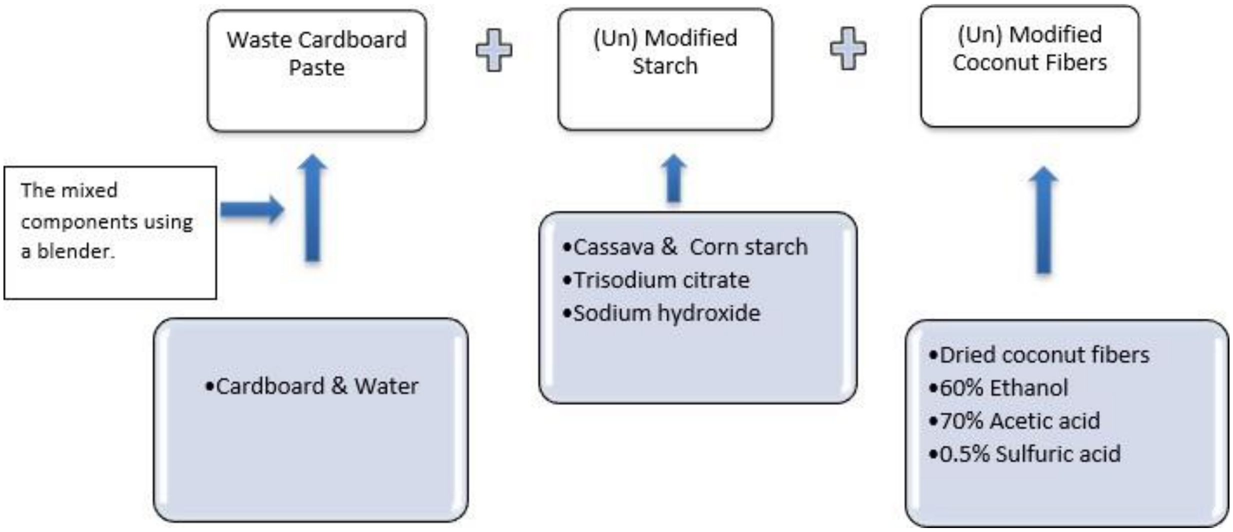


Figure 13: Main substance in the formation of paper pulp

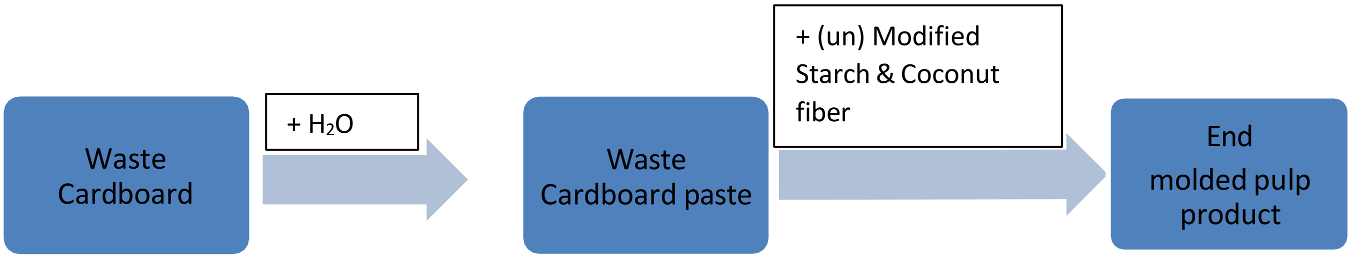


Figure 14: General flowchart to produce the paper pulp product

For each sample a total wet weight of 100 grams was placed in the plastic container. The containers were pressed together manually for the removal of water (Figure 15a). The samples were left to sun dry (Figure 15b)

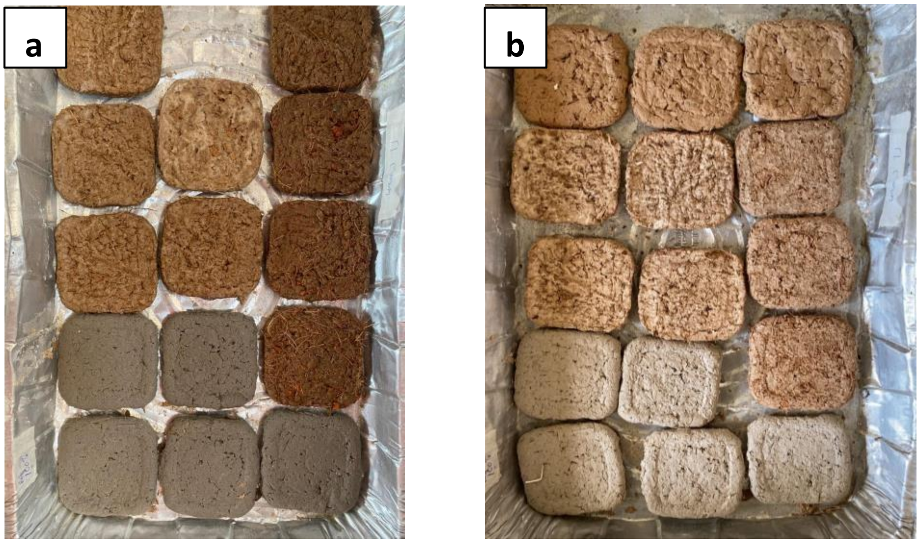


Figure 15: (a) The molded samples before sun-drying. (b) The sun-dried molded sample

Waste cardboard (WC) was mixed thoroughly with the coconut fibers and starches according to the proportions shown in table 3. The thesis employs abbreviations for additives to label the samples. The terms "Unmodified (U)" and "Modified (M)" preceded with the corresponding additives: Coconut fibers are labeled as (CF), Cassava starch as (CS), and Maize starch as (MS).

Table 3: Overview of the samples prepared

Sample #	**Board Composition**	**Mix Proportion (%)**
Reference (control experiment)		
1	WC	100
1 additive		
2	WC: UCS	75:25
3	WC: UMS	75:25
4	WC: MCS	75:25
5	WC: MMS	75:25
6	WC: UCS	85:15
7	WC: UMS	85:15
8	WC: MCS	85:15
9	WC: MMS	85:15
10	WC: UCF	90:10
11	WC: MCF	90:10
12	WC: UCF	50:50
13	WC: MCF	50:50
2 additives		
14	WC: UCS: UMS	75:12.5:12.5
15	WC: MCS: MMS	75:12.5:12.5
16	WC: UCS: UMS	85:7.5:7.5
17	WC: MCS: MMS	85:7.5:7.5
18	WC: UCS: UCF	75:15:10
19	WC: UMS: UCF	75:15:10
20	WC: MCS: MCF	75:15:10
21	WC: MMS: MCF	75:15:10
3 additives		
22	WC: UCS: UMS: UCF	75:7.5:7.5:10
23	WC: UCS: UMS: UCF	70:10:10:10
24	WC: UCS: UMS: UCF	85:5:5:10
25	WC: MCS: MMS: MCF	75:7.5:7.5:10
26	WC: MCS: MMS: MCF	70:10:10:10
27	WC: MCS: MMS: MCF	85:5:5:10

3.5 Sample Analysis & Accuracy

The analysis and accuracy of the synthesized molded pulp were done by taking the following tests and comparing them with the literature references. All presented numerical data were rounded to the nearest whole number to improve readability and simplify the presentation of results.

Water absorption capacity (WAC)

After preparing the samples, they were air-dried at room temperature for 24 hours. The air-dried samples were weighed and immersed in a glass bowl with tap water at room temperature for another 24 hours. After 24 hours of immersion, the wet samples were re-weighed, and the water absorption capacity was calculated using equation 1, as shown in Appendix A- Calculations.

$$WAC\ (\%) = \frac{W_1 - W_0}{W_0} \times 100\%$$

Equation 1

Where: W_1= the final weight of samples (after immersion), and

W_0 = Initial weight of samples (before immersion)

Moisture content (MC)

After preparing the samples, they were left to air dry at room temperature for a minimum of 24 hours. The air-dried sample's initial weight was weighed (M_0), dried at 120 °C for 4 hours, allowed the oven-dried sample to cool to room temperature, and then weighed again (M_1). The moisture content values were obtained by implementing equation 2 as shown in Appendix A- Calculations.

$$MC\ (\%) = \frac{M_0 - M_1}{M_0} \times 100\%$$

Equation 2

Swelling Degree (SD)

The determination of the swelling degree was conducted through the following steps for each sample. The initial length, width, and thickness of the samples were measured. The samples were then submerged in a glass bowl containing water at neutral pH and at regular time intervals of 1 minute, 15 minutes, and 30 minutes. The size of the samples was re-measured after every time interval to assess the extent of swelling. The example calculations using equation 3 for the % thickness swelling are presented in Appendix A- Calculations.

$$Swelling\ ratio\ in\ Thickness\ (\%) = \frac{T_w - T_d}{T_d} \times 100\%$$

Equation 3

Where: T_w= the weight of the swollen samples (after immersion), and

T_d = the weight of the dry samples (before immersion)

Chapter 4: Results and Discussion

The results of the tested molded products are reported in this chapter. The Water Absorption Capacity (WAC), Moisture Content (MC), and Thickness Swelling Degree (T-SD) are measured to determine the quality of the different percentage mixtures.

4.1 Water absorption capacity

Water absorption was conducted to determine the resistance offered by the material to absorb water and its capability to withstand wet conditions. The water absorption capacity was measured in duplicate for all 27 samples, shown in Table 3 and the average results and Standard Error (SE) are shown in Figure 16-Figure 18.

Figure 16 gives the water absorption capacity results for the following mixtures:

1. The 85% waste cardboard: 15% (un) modified starches,
    - Sample 6, WC: UCS
    - Sample 7, WC: UMS
    - Sample 8, WC: MCS
    - Sample 9, WC: MMS
    - Sample 16, WC: UCS: UMS (85%: 7.5%: 7.5%)
    - Sample 17, WC: MCS: MMS (85%: 7.5%: 7.5%)

2. The 75% waste cardboard: 25% (un) modified starches
    - Sample 2, WC: UCS
    - Sample 3, WC: UMS
    - Sample 4, WC: MCS
    - Sample 5, WC: MMS
    - Sample 14, WC: UCS: UMS (85%: 12.5%: 12.5%)
    - Sample 15, WC: MCS: MMS (85%: 12.5%: 12.5%)

3. The 75% Waste cardboard: 15% (un)modified starches: 10% (un) modified Coconut fibers.
    - Sample 18, WC: UCS: UCF
    - Sample 19, WC: UMS: UCF
    - Sample 20, WC: MCS: MCF
    - Sample 21, WC: MMS: MCF
    - Sample 22, WC: UCS: UMS: UCF
    - Sample 25, WC: MCS: MMS: MCF

Starch was added to the pulp mixtures to improve the bonding and cohesion between the fibers (F). The 100% waste cardboard control sample in this experiment results indicate a WAC of 278% which is within the range of 272.20 ± 5.12% reported by Kehinde et al. (2019) for their control sample.

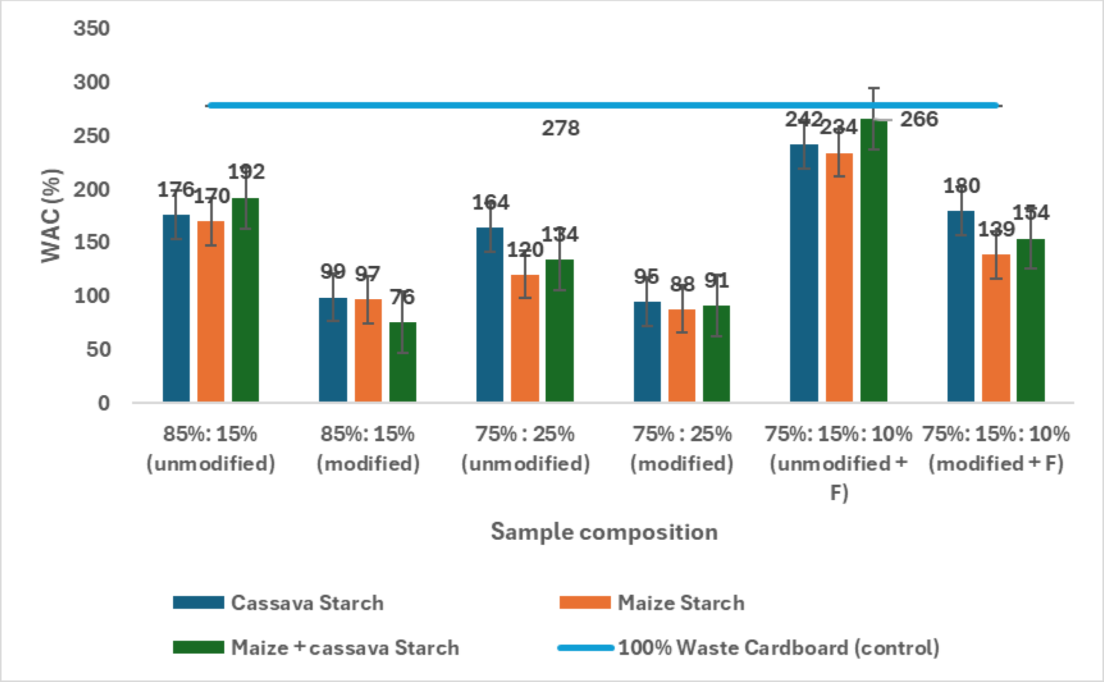


Figure 16: Water Absorption Capacity of Cardboard Mixtures at 75% and 85% Concentrations, with Different Starch and Fiber (F) Modifications

Comparing the water absorption capacity data for the different percentage mixtures and components, it was observed from Figure 16 that the 100% waste cardboard yielded the highest value of 278% for the samples without any fibers included. During the WAC test, it was observed that the 100% cardboard sample was the only sample that immediately started to crumble after being placed in water (Figure A1). Almost all mixtures, Figure 16, exhibit a WAC lower than 200% except for the sample 18 (WC: UCS: UCF, ratio 75%:15%:10%), sample 19 (WC: UMS: UCF, ratio 75%:15%:10%) and sample 22 (WC: UCS: UMS: UCF ratio 75%:7.5%: 7.5%: 10%) from table 3, containing both unmodified maize starch, cassava starch and coconut fibers. In general, the addition of either maize or cassava lowers the water absorption capacity. The increase in WAC of this sample was partially attributed to the presence of coconut fibers. Anggono et al. (2025) discuss how the inclusion of coconut coir fibers in recycled paper composites enhances water absorption capabilities. They highlight that the presence of fiber content generates more voids and cracks within the material, leading to an open structure that promotes higher water uptake. Their study results indicate that increased fiber ratios correlate with greater water absorption capacity, showing how the fiber structure helps absorb water. Despite the higher water absorption, this sample did not break apart during the water absorption test compared to the 85%:15% composition without fibers, which became brittle immediately after 5 minutes during the water absorption test (Figure A4 and Figure A5). Comparing the samples from the 85%: 15% with the 75%: 25% respectively waste cardboard: starch (either modified or unmodified), Figure

16 shows a decrease in WAC for a higher percentage of starch, when using cassava or maize separately. The decrease in water absorption due to the presence of a higher amount of starch results in reducing the pore size of waste cardboard and increasing the surface hydrophobicity. Another observation from the water absorption test was that the 75:25% sample, consisting of 75% cardboard and 25% starch, remained more compact compared to the 85:15% sample, which contains 85% cardboard and 15% starch. Comparing these samples, it can be concluded that the higher cardboard proportion in the 85:15% sample led to greater swelling and less stable paper

pulp. The results in Figure 16 show the lowest water absorption capacity in each sample where only maize starch was used as a binding agent, compared to the samples where only cassava starch was used as a binding agent. The difference in WAC between maize and cassava might be associated with the composition of amylose and amylopectin. Zambelli et. al. (2024) and Alcázar-Alay et al. (2015) showed that cassava starches have around 23.7% amylose fractions which is lower compared to the 28.5% in maize starch. The study of Da Costa et al. (2025) found that the "starch sample with high amylose content had low water absorption due to the greater stiffness of the hydrogel structure that resisted swelling". The results in this study also show that lower WAC was obtained for the sample mixtures where cassava and maize starch were used separately in the samples.

Figure 17 gives the water absorption capacity results for:

1. The 70% waste cardboard: 20% (un) modified starches: 10% (un) modified Coconut fibers
    - Sample 23, WC: UCS: UMS: UCF (70%: 10%: 10%: 10%)
    - Sample 26, WC: MCS: MMS: MCF (70%: 10%: 10%: 10%)

2. The 85% Waste cardboard: 10% (un) modified starches: 5% (un)modified Coconut fibers.
    - Sample 24, WC: UCS: UMS: UCF (85%: 5%: 5%: 5%)
    - Sample 27, WC: MCS: MMS: MCF (85%: 5%: 5%: 5%)

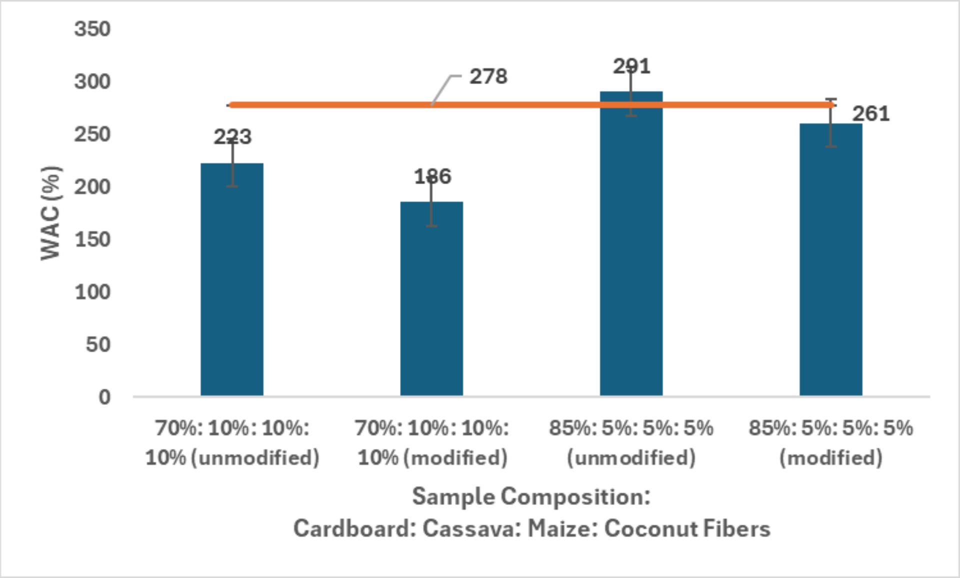


Figure 17: Water Absorption Capacity of Cardboard Mixtures at 70% and 85% Concentrations, with Different Starch and Fiber Modifications

From Figure 17, it could be observed that coconut fiber concentration was held constant at 10%. The cassava: maize starches were combined in different percentages of 10%: 10% and 5%: 5%. The unmodified samples of both ratios give a higher WAC compared to the lower WAC for these modified starches. The study by Kehinde et al. (2019) found that using cassava as a sizing agent at concentrations of 10%, 20%, and 30% showed a WAC of respectively 279 ±1.71%, 282.80 ±1.29% and 292.60 ±0.96% where a higher cassava concentration led to a higher WAC. During this experiment, there was no sample where only 10% cassava was added. Sample 24, the unmodified 85%: 5%: 5%: 5% (WC: UCS: UMS: UCF) that consists of a total concentration of 10% starch (5% maize and 5% cassava) results in a WAC of 291% which is higher than the 10% concentrated cassava starch only sample from the study by Kehinde et al. (2019). Comparing sample 26 and sample 27 that consist of two different modified starch ratios of 10%: 10% and 5%: 5% it could be observed that the higher the total modified starch amount used, the lower the WAC. This is in line with observation in Figure 16. Amoo et al. (2019) reported a significantly lower WAC of 253.20 ± 8.14% for their optimized 30-cell paper egg tray formulation, indicating improved water resistance and making the packaging more suitable for practical applications where moisture exposure is expected.

Figure 18 gives the water absorption capacity results for:

1. The 50% waste cardboard: 50% modified Coconut fibers
    - Sample 12, WC: UCF
    - Sample 13, WC: MCF
2. The 90% Waste cardboard: 10% (un)modified Coconut fibers.
    - Sample 10, WC: UCF
    - Sample 11, WC: MCF

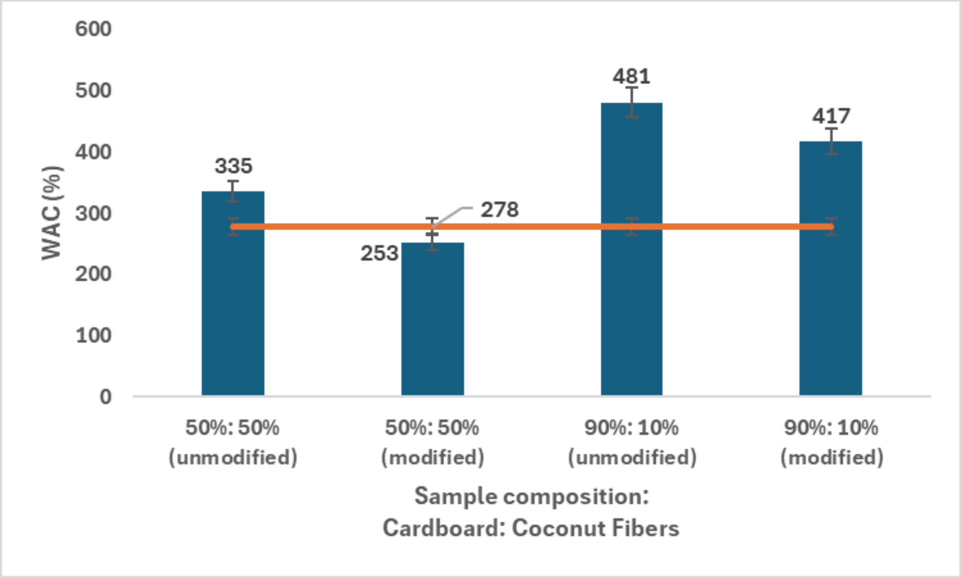


Figure 18: Water Absorption Capacity of Cardboard Mixtures at 50% and 90% Concentrations, with Different Fiber Modifications

Figure 18 shows that the lowest water absorption capacity is in the sample with the composition of cardboard waste: Coconut fiber in the mixing ratio of 50%: 50%. Both samples with the modified and unmodified 10% coconut fibers resulted in a higher WAC. Comparing the 10% modified and unmodified coconut fibers from Figure 18 with the other samples in Figure 16 and Figure 17, where also 10% coconut fibers and the starches were used, it could be observed that the absence of starch in the samples from Figure 18 resulted in the highest WAC > 400%. The increase of the WAC, as also shown in Figure 16, clearly shows that for the unmodified and modified samples, the presence of coconut fibers increases the amount of water the sample absorbs compared to the samples of cardboard and starch without the coconut fibers. According to a study done by Radhakrishnan et al. (2023), coconut fibers primarily consist of cellulose and other plant-derived fibers known for their high-water absorption capacity, resulting in increased water uptake. The free hydroxyl group present in cellulose easily binds with water molecules and can make them adhere to the cellulose, thereby improving the hydrophilic properties of the component. These results showed that the cardboard content has a great impact on the WAC. After adding the sample compositions of either the modified or unmodified 90%:10% cardboard: coconut fibers to water, it was observed that these samples easily break apart (see Figure A2 and Figure A3). From the components added, coconut fiber increases the WAC, while maize and cassava starches decrease the WAC. The higher percentage of amylose present in maize starch resulted in a lower WAC compared to cassava starch, due to the detrimental effect on the porous structure of the hydrogel. Da Costa et al. (2025). It can therefore also be concluded that the lower obtained WAC in Figure 16 with either the modified or unmodified starch / coconut fibers components is due to the presence of amylose-rich starches. According to the study by Da Costa et al. (2025), the higher amount of amylose content is related to a higher crosslinking degree. A higher amylose content does play a crucial role during the crosslinking process, allowing more crosslinks between the linear structures of the maize starch. In figure 18, sample 13 clearly has the lowest WAC compared with all other samples, including those with starch.

4.2 Moisture content

This section shows the average results and SE for duplicate measurement from the moisture content analysis of the 27 samples in Table 3. Based on the findings of Amoo et al. (2019), they reported a MC of 4.48 ± 0.19% specified for paper egg trays.

On the horizontal line from Figure 19, the 100% waste cardboard sample showed 13% of the moisture content, which can arise from several factors, such as the cellulose content of the cardboard or the porous structure of this material. Silveira et al. (2021) showed the correlation between moisture content and cardboard ratios whereby they found the most representative moisture classes of 10%-13%. This study found a moisture content between 8.3% and 15.1% for the 100% cardboard samples.

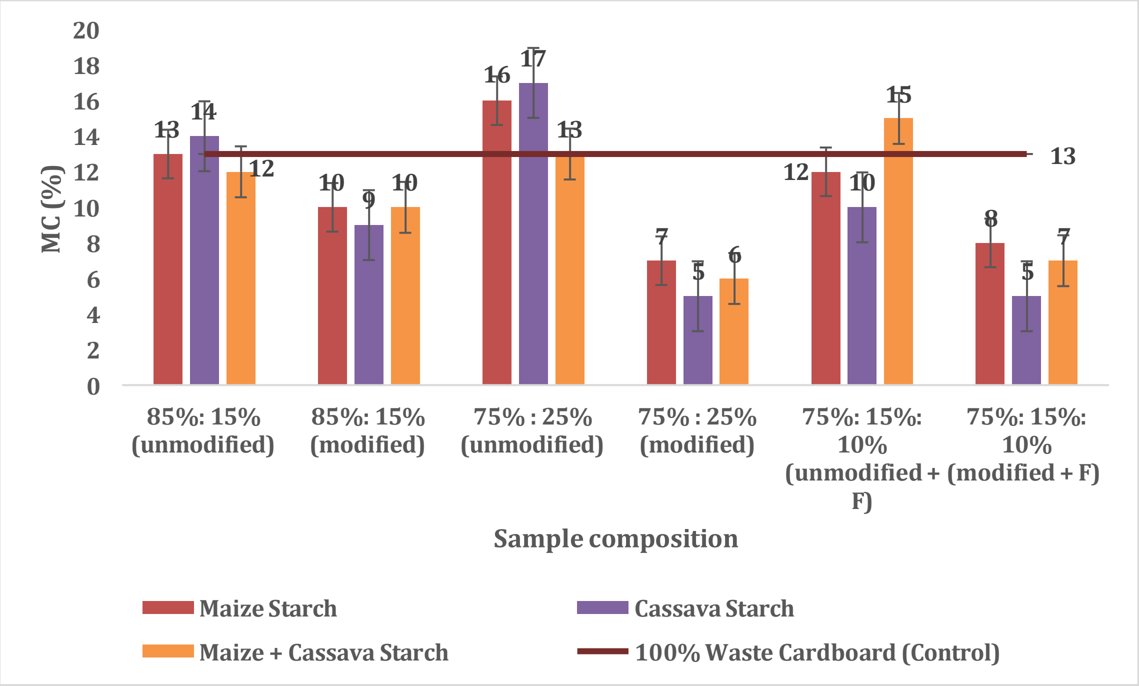


Figure 19: Moisture Content of Cardboard Mixtures at 75% and 85% Concentrations, with Different Starch and Fiber Modifications

Figure 19 shows a greater increase in the moisture content for the unmodified samples where only starches are included, compared with the 100% waste cardboard, control experiment. Additionally, an increase in the starch content, looking at 85%: 15% and 75%: 25%, respectively, waste cardboard and unmodified starch samples resulted in a slight rise in the moisture content. The presence of starch increases the moisture content in the samples due to its hydrophilic behavior. After the modification of the starches, a decrease in moisture content can be observed when comparing the modified samples of 85%:15% and 75%:25%. When examining the outcomes for the identical ratio of cardboard coupled with modified starch, it becomes evident that the 75%:25% ratio exhibits significantly lower moisture content, despite having a higher starch concentration compared to the 85%:15% ratio. The difference between samples with modified and unmodified starch clearly demonstrates how the way starch is treated through crosslinking plays a key role in reducing the hydrophilic characteristics.

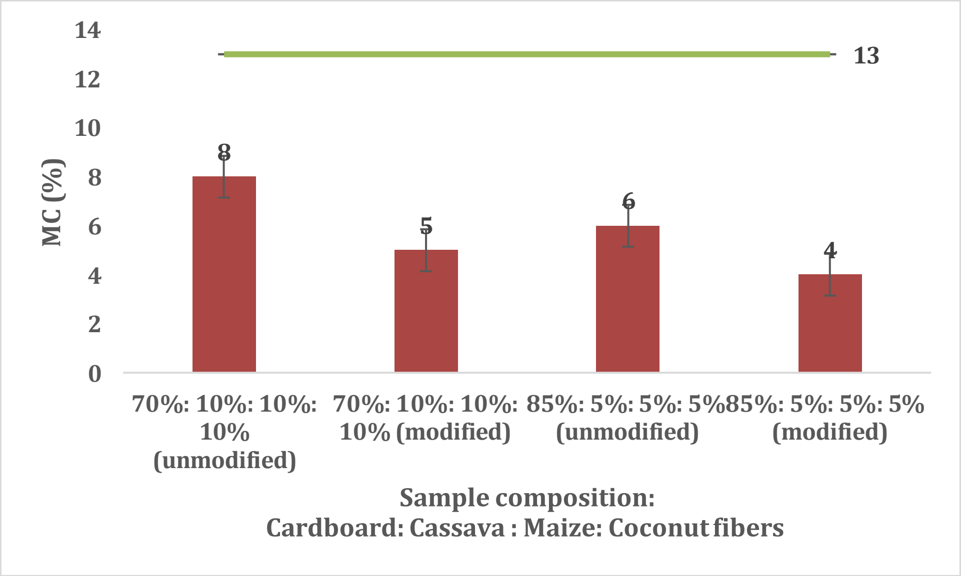


Figure 20: Moisture Content of Cardboard Mixtures at 70% and 85% Concentrations, with Different Starch and Fiber Modifications

Figure 20 shows that adding coconut fibers as a third additive to the composition for both the unmodified and modified samples results in lower moisture content. While the study from Silveira et al. (2021) showed a moisture content of 15.4% and 16.3% for the samples containing 85% cardboard, it is important to note that the 85% cardboard in this experiment was combined with starch and coconut fibers and these samples resulted in lower moisture content of 6% and 4% for respectively unmodified and modified samples (Figure 20). While the 85% cardboard samples with only starch included resulted in a higher moisture content of 9%- 10% and 12%- 14% for respectively unmodified and modified samples (Figure 19), close to the results obtained by Silveira et al. (2021). The hydrophilic nature of starch and fibers leads to more water absorption.

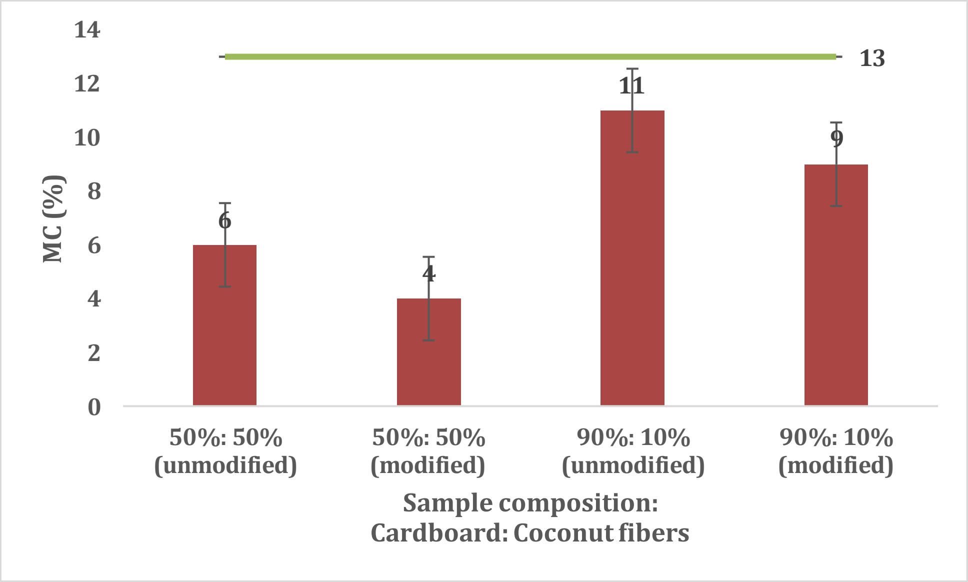


Figure 21: Moisture Content of Cardboard Mixtures at 50% and 90% Concentrations, with Different Fiber Modifications

The samples consisting of a 50% cardboard and 50% coconut fibers composition, excluding starch, also exhibit a lower moisture content compared to 90% coconut fibers and 10% starch mixture. When comparing the unmodified samples to the control sample containing only waste cardboard with a moisture content of 13%, it can be inferred that the addition of coconut fibers leads to a slight decrease in moisture content.

The results from Figure 19 to Figure 21 have testified that the addition of starches only results in an increase in moisture content. When comparing the results for the compositions 75% cardboard, 15% starch, and 10% coconut fiber, and 70% cardboard, 10% starch, and 10% coconut fiber (both unmodified), as shown in Figure 19 and Figure 20, it is evident that varying the starch concentration also alters the moisture content. The lowest MC was found for sample 13 and sample 27, both showing a value of 4%, indicating good dryness and strong capacity for resistance to microbial growth and improved shelf life. According to the study by Amoo et al. (2019), the with a optimum MC for molded pulp egg trays reported of 4.48 ± 0.19%, sample 4, sample 20, and sample 26 which demonstrated an MC of 5%, can be considered to have desirable moisture conditions for practical use.

4.3 Thickness swelling degree

The thickness swelling degree data in this section were from the average results and SE for duplicate measurement of the 27 samples in Table 3. The average values and SE for the results are presented in Figure 22 - Figure 24. The thickness swelling degree value of 32% obtained for the 100% waste cardboard, the control experiment, represents the maximum value recorded in the study.

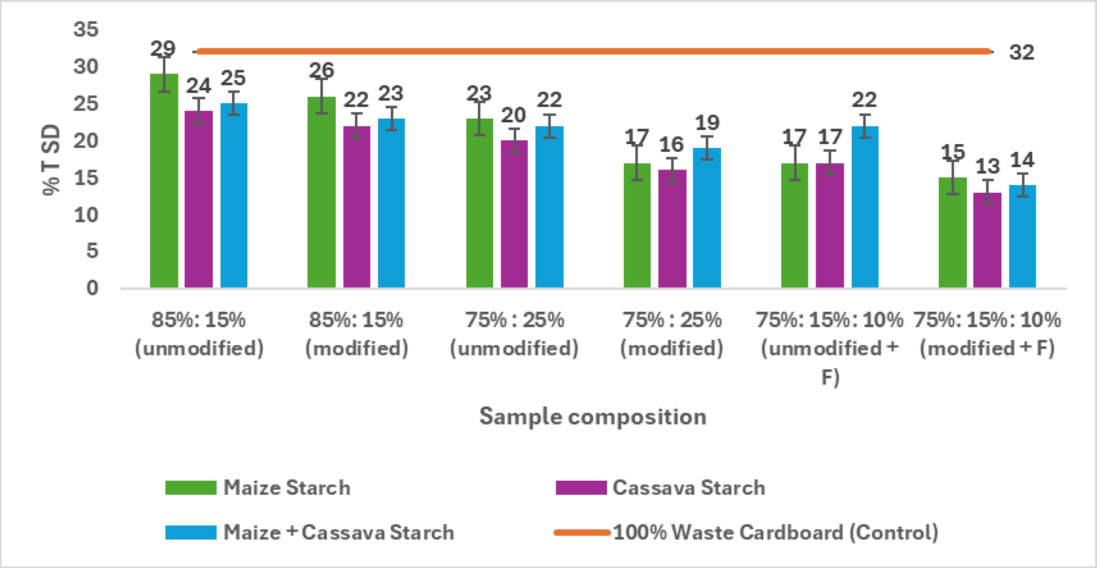


Figure 22: Thickness Swelling Degree (T-SD) of Cardboard Mixtures at 75% and 85% Concentrations, with Different Starch and Fiber Modifications

A thickness swelling degree of 13% is achieved for the modified samples where all three additives are present in sample 20 with ratio 75%: 15%:10% (WC: MCS: MCF) using cassava starch as the binding agent. Figure 23 shows the modified starch and coconut fibers (sample 25) with a ratio of 70%: 10%: 10%: 10% (WC: MCS: MMS: MCF). Sample 20 and sample 25 exhibited the same thickness swelling degree comparable to the unmodified sample, which uses a 50%:50% ratio of cardboard to coconut fibers. Decreasing the amount of cardboard samples does have a positive effect on reducing the thickness swelling degree of the unmodified samples.

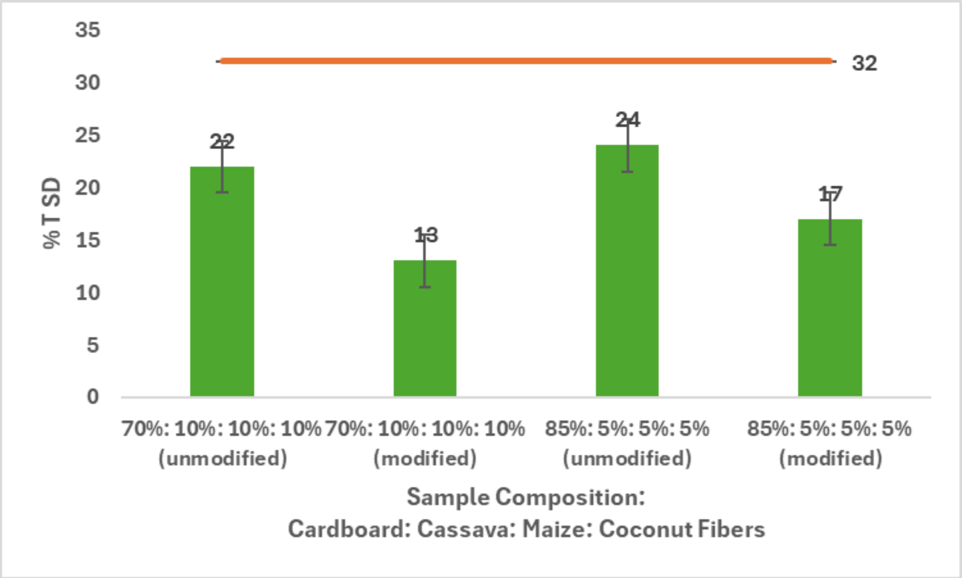


Figure 23: Thickness Swelling Degree (T-SD) of Cardboard Mixtures at 70% and 85% Concentrations, with Different Starch and Fiber Modifications

Reducing the thickness swelling degree of the samples after the modification involving at least one or more additives, including maize or cassava starch, or even coconut fibers, is evident in Figures 23 and 24. This suggests that the incorporation of these additives has a notable impact on reducing the swelling behavior of the samples.

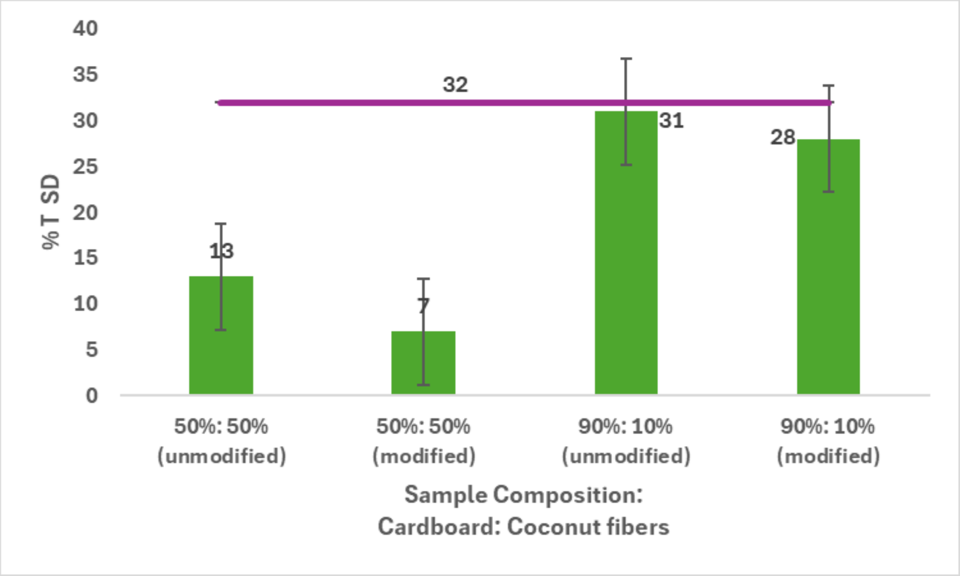


Figure 24: Thickness Swelling Degree (T-SD) of Cardboard Mixtures at 50% and 90% Concentrations, with Different Fiber Modifications

From Figure 24, samples containing unmodified coconut fibers and a higher percentage of waste cardboard (90%:10%) showed the highest thickness swelling compared with the control sample, that consists only of waste cardboard. The higher swelling degree is attributed to the poor interfacial bonding between the waste cardboard and the coconut fibers, and the presence of empty spaces exposing hydrophilic behavior.

The presence of cellulose, a component found in waste cardboard, could potentially be a contributing factor to the observed increase in the thickness swelling degree of the batch, as indicated by the obtained results for respectively 100% waste cardboard and the 90%: 10%. This suggests that the cellulose content within the cardboard material may have played a role in influencing the thickness swelling behavior.

According to George et al. (2001), the presence of three hydroxyl (−OH) groups within cellulose molecules enhanced their strong attraction to water molecules. The hydrogen bonds linking these hydroxyl groups to cellulose molecules are responsible for chain breaking under high humidity conditions. Intermolecular hydrogen bonding from these hydroxyl parts and water molecules results in composite swelling. (Kamarudin et al., 2022). The lowest T-SD value was obtained for sample 20 (75%:15%:10%), which achieved a T-SD of 13%.

4.4 General discussion of the measured properties

This study investigates the possibility of transforming waste corrugated cardboard and coconut fibers into paper pulp. The focus was on the feasibility and quality of the resulting materials for sustainable packaging applications in Suriname. The experimental results show that the proportions and types of additives strongly influence the WAC, MC, and T-SD of the pulp.

The presence of maize and cassava starches not only serves as a binding agent, but the modification also improved the hydrophobic properties of the pulp, thereby reducing the WAC in several mixtures. The sample compositions are critical in determining the final pulp performance. Figure 16-Figure 18 shows how the addition of coconut fibers and starch influences the WAC, with the presence of coconut fibers increasing the WAC due to their porous and hydrophilic nature. First, mixtures containing unmodified cassava or maize (or both) starch at ratios of 75%: 25% (sample 2–5, 14 and 15) consistently showed lower WAC values ranging from 88%–163%. In contrast, compared mixtures in which the starch was combined with coconut fibers at ratios of 75%: 15%: 10% (sample 18-21, 22 and 25) resulted in higher WAC values ranging from 139%-266%, because the fibers increased the water uptake of the pulp. Finally, when the modified mixtures are evaluated with respect to the unmodified samples, it becomes evident that chemical modification of both the starch and the coconut fibers reduces the WAC. This reduction is clearly visible in the modified 75%: 15%: 10% mixture shown in Figure 16 and the modified mixtures presented in Figure 17.

In addition to water absorption, moisture content also varies across the different mixtures. As shown in Figure 20 and Figure 21, the incorporation of coconut fibers has a clear influence on the MC. The modified 50%: 50% (WC: MCF) mixture in sample 13 showed the lowest MC of 4%, compared to the modified 90%: 10% (WC: MCF) mixture in sample 11 with a higher MC of 9%. Sample 11 resulted in a higher MC because the amount of coconut fiber was lower, waste cardboard amount was higher, and no starch was present. These findings confirm that the moisture content is strongly affected by the proportion of coconut fibers in the mixture. For the samples containing cardboard, starch, and coconut fibers, the modified sample 27, with a ratio of 85%: 5%: 5%: 5% (WC: MCS: MMS: MCF) achieved the lowest moisture content (MC) of 4% (Figure 20). The following sample values were within the limit of 4% - 6% for the moisture content:

- Unmodified 85%: 5%: 5%: 5% (WC: UCS: UMS: UCF, sample 24)→ MC: 6%
- Modified 85%: 5%: 5%: 5% (WC: MCS: MMS: MCF, sample 27)→ MC: 4%
- Unmodified 50%: 50% (WC: UCF, sample 12)→ MC: 6%
- Modified 50%: 50% (WC: MCF, sample 13)→ MC: 4%
- Modified 75%: 25% (WC: MCS, sample 4)→ MC: 5%
- Modified 75%: 15%: 10% (WC: MCS: MCF, sample 20)→ MC: 5%
- Modified 70%: 10%: 10%: 10% (WC: MCS: MMS: MCF, sample 26)→ MC: 5%

The lowest T-SD was obtained for the 50%: 50% sample cardboard: coconut fibers and 75%: 15%: 10%. For this experiment, none of the resulting thickness swelling degrees exceeded the standard of 70%, as specified for an egg tray in the study conducted by Amoo et al., 2017.

The standard error presented in Figure 17 - Figure 24 provides important insights into the reliability and precision of the measurements for water absorption capacity, moisture content, and thickness swelling degree. The SE could be calculated using the two replicates, which results in small error bars in all the graphs. But using only two replicates limits the reliability of the estimate. For further research on the method described for the transformation of wastepaper into paper pulp, it is important to make more batches for the samples and analyze them more than two times.

Chapter 5: Conclusion and Recommendation

The findings of this research indicate that it is indeed feasible to produce paper pulp from a combination of used, corrugated cardboard, modified cassava starch, and modified coconut fiber. The experimental results showed that these materials can yield paper pulp with adequate properties suitable for manufacturing paper products in Suriname. The presence of modified starch binding agents, whose crosslinked structure increases hydrophobicity and improves fiber bonding, contributed to improved pulp quality by reducing WAC, lowering MC, and decreasing T-SD compared with the mixtures containing the unmodified starch.

The combination of modified starch, modified coconut fiber, and cardboard demonstrates strong potential for producing stable biodegradable paper pulp. Together, these components improve the key properties such as the MC and reduce the swelling, making the paper pulp suitable for various molded packaging products, including trays and other sustainable packaging applications. The samples and tests showed promising results, among all the tested mixtures, the best performing composition was sample 20, with a 75%: 15%: 10% ratio of cardboard: modified cassava starch: modified coconut fiber. This sample produced a low MC of 5% and the lowest T-SD value of 13%, indicating the most balanced and stable performance compared to the other mixtures.

Future research should focus on optimizing the ratios of fibers and starches to further enhance the mechanical properties and performance characteristics of the pulp. To obtain a reliable estimate of variability, at least three to five replicates per sample are recommended. This helps to calculate a meaningful standard error and assess the consistency of the chosen method. In addition, future studies should evaluate other key mechanical properties such as tensile strength, bending strength, and burst strength, to determine whether the produced pulp meets the requirements for practical packaging applications. Research on the biodegradability and durability of the produced paper pulp will also be crucial for its application in commercial activities and gives insight into the impact on the environment.

References

Alcázar-Alay, S. C., & Meireles, M. A. A. (2015). Physicochemical properties, modifications and applications of starches from different botanical sources. *Food Science and Technology (Campinas), 35*(2), 215–236. https://doi.org/10.1590/1678-457X.6749

Amazona Recycling Company N.V. (2009). Facts and figures of waste disposal in Suriname [Web page]. Retrieved February 2023, from http://www.amazonarecycling.sr/statisticsENG.html

Amoo, K., Onilude, M. A., & Omoniyi, T. E. (2016). Fibre characteristics of paper and paper egg tray used in Southwestern Nigeria. *International Journal of Engineering Research and Reviews, 4*(4), 53-60.

Amoo, K., Onilude, M. A., & Omoniyi, T. E. (2017). Characterisation of paper egg trays used in Southwestern Nigeria. *International Journal of Scientific & Engineering Research*, *8*(3), 1048–1054.

Amoo, K., Onilude, M. A., & Omoniyi, T. E. (2019). Efficacy of cassava gel, Polyvinyl acetate and Hydroxyethyl cellulose as sizing agents for 30-cell paper egg tray. *Scientific African, 5*, e00140. https://doi.org/10.1016/j.sciaf.2019.e00140

Anggono, A. D., Darmawan, A. S., & Yulianto, A. (2025). Development and Performance Analysis of Coconut Coir Waste-Based Recycle Papers for Cooling Pad Applications. *Engineering Proceedings*, *18* (1), 84. https://doi.org/10.3390/engproc2025084018

Basel Convention Regional Centre for Training and Technology Transfer for the Caribbean (BCRC-Caribbean). (2021). Replacing single use plastic commodities in the economy of Suriname [Web page]. Retrieved January 2024, from https://www.bcrc-caribbean.org/our-news-events/replacing-single-use-plastic-commodities-in-the-economy-of-suriname-2/

Bui, H., Sebaibi, N., Boutouil, M., Levacher, D. (2020). Determination and Review of Physical and Mechanical Properties of Raw and Treated Coconut Fibers for Their Recycling in Construction Materials. *Fibers, 8(6), 37*. https://doi.org/10.3390/fib8060037

Buléon, A., Colonna, P., Planchot, V., Ball, S., (1998). Starch granules: structure and biosynthesis. *International Journal of Biological Macromolecules*, 23(2), 85–112. https://doi.org/10.1016/s0141-8130(98)00040-3

Chu, Q., Tong, W., Chen, J., Wu, S., Jin, Y., Hu, J., & Song, K. (2021). Organosolv pretreatment assisted by carbocation scavenger to mitigate surface barrier effect of lignin for improving biomass saccharification and utilization. *Biotechnology for Biofuels*, *14*(1), 136. https://doi.org/10.1186/s13068-021-01988-w

Cornejo-Ramírez, Y. I., Martínez-Cruz, O., Del-Toro-Sánchez, C. L., Wong-Corral, F. J., Borboa-Flores, J., & Cinco-Moroyoqui, F. J. (2018). The structural characteristics of starches and their functional properties. *CYTA- Journal of Food, 16*(1), 1003–1017. https://doi.org/10.1080/19476337.2018.1518343

Czechowski, L., Kmita-Fudalej, G., & Szewczyk, W. (2020). The Strength of Egg Trays under Compression: A Numerical and Experimental Study. *Materials, 13*(10), 2279. https://doi.org/10.3390/ma13102279

Da Costa, T. B., Camani, P. H., Ferreira, R. R., Barbosa, R. F. S., & Rosa, D. D. S. (2025). Enhancing corn starch hydrogels for effective sorption of potentially toxic metals: The role of Amylose and Amylopectin content. *Journal of Polymers and the Environment*. https://doi.org/10.1007/s10924-025-03495-7

Feiner, G. (2006). Additives: Phosphates, salts (sodium chloride and potassium chloride), citrate, lactate and hydrocolloids. *In Meat products handbook: Practical science and technology* (pp. 72-88). Woodhead Publishing. https://doi.org/10.1533/9781845691721.1.72

General Bureau of Statistics Suriname. (n.d.). *Statistieken en publicaties*. Algemeen Bureau voor de Statistiek in Suriname. Retrieved April 2024, from https://statistics-suriname.org/

George, J., Sreekala, M. S., & Thomas, S. (2001). A review on interface modification and characterization of natural fiber reinforced plastic composites. *Polymer Engineering and Science, 41*(9), 1471–1485. https://doi.org/10.1002/pen.10846

Gharehkhani, S., Sadeghinezhad, E., Kazi, S. N., Yarmand, H., Badarudin, A., Safaei, R. M., & Zubir, M. N. M. (2015). Basic effects of pulp refining on fiber properties—A review. *Carbohydrate Polymers, 115*, 785–803. https://doi.org/10.1016/j.carbpol.2014.08.047

Giuri, A., Colella, S., Listorti, A., Rizzo, A., & Corcione, C. E. (2018). Biodegradable extruded thermoplastic maize starch for outdoor applications. *Journal of Thermal Analysis and Calorimetry, 134*, 549–558. https://doi.org/10.1007/s10973-018-7404-7

Heinze, T. (2015). Cellulose: Structure and properties. In Advances in Polymer Science (pp. 1–52) Springer. https://doi.org/10.1007/12_2015_319

Jiang, T., Duan, Q., Zhu, J., Liu, H., & Yu, L. (2020). Starch-based biodegradable materials: Challenges and opportunities. Advanced Industrial and Engineering Polymer Research, 3(1), 8–18. https://doi.org/10.1016/j.aiepr.2019.11.003

Jincy P. J., Ravindranath, A. D., & Sarma, U. S. (2015). Eco-friendly organosolv process for pulping of tender coconut fibre. *CORD, 31*(1):13-23. https://doi.org/10.37833/cord.v31i1.64

Kamarudin, S. H., Norizan, M. N., Fadil, F., Osman, S., & Ahmad, S. (2022). Water absorption and thickness swelling characteristics of the bionanocomposites. *In Composites science and technology* (pp. 159–180). Springer. https://doi.org/10.1007/978-981-16-8578-1_9

Kehinde, A., Onilude, M. A., & Omoniyi, T. E. (2019). Efficacy of cassava gel, polyvinyl acetate and hydroxyethyl cellulose as sizing agents for 30-cell paper egg tray. *Scientific African, 5*, e00140. https://doi.org/10.1016/j.sciaf.2019.e00140

Koo, S., Lee, K., & Lee, H. (2010). Effect of cross-linking on the physicochemical and physiological properties of corn starch. *Food Hydrocolloids*, *24*(6-7), 619–625. https://doi.org/10.1016/j.foodhyd.2010.02.009

Lomelí-Ramírez, M. G., Kestur, S. G., Manríquez-González, R., Iwakiri, S., de Muniz, G. B., & Flores-Sahagun, T. S. (2014). Bio-composites of cassava starch-green coconut fiber: Part II-Structure and properties. Carbohydrate Polymers, 102, 576–583. https://doi.org/10.1016/j.carbpol.2013.11.020

Main, N. M., Talib, R. A., Ibrahim, R., Rahman, R. A., & Mohamed, A. Z. (2014). Suitability of coir fibers as pulp and paper. *Agriculture and Agricultural Science Procedia*, *2*, 304–311. https://doi.org/10.1016/j.aaspro.2014.11.043

Miao, Y., Xiang, S., Wei, Y., Long, X., Qiu, J., & Miao, Y. (2023). Physical Properties of Pulp and Paper: A Comparison of Forming Procedures. *Forest Products Journal*, *73*(2), 175-185. https://doi.org/10.13073/FPJ-D-23-00007

Mishra, L., & Basu, G. (2020). Coconut Fibre: Its structure, properties and applications. In *Handbook of natural fibres* (2nd ed., p. 838). Elsevier. https://doi.org/10.1016/B978-0-12-818398-4.00010-4

Nair, L. G., Agrawal, K., & Verma, P. (2023). Organosolv pretreatment: an in-depth purview of mechanics of the system. *Bioresources and Bioprocessing*, *10*(1), 50. https://doi.org/10.1186/s40643-023-00673-0

Ningtyas, K. R., Agassi, T. N., & Putri, P. G. (2022). Utilization of waste cellulose raw material for making paper pulp. *IOP Conference Series: Earth and Environmental Science*, *1012*(1), 012091. https://doi.org/10.1088/1755-1315/1012/1/012091

Ozola, Z. U., Vesere, R., Kalnins, S. N., Blumberga, D. (2019). Paper waste recycling: Circular economy aspect. *Environmental and Climate Technologies*, *23*(3), 260–273. https://doi.org/10.2478/rtuect-2019-0094

Preparation of an integrated waste management plan (IWMP) for Suriname; Final report (2022). DM1040/2021 (pp. 2-15). Ministerie van ruimtelijke ordening & milieu.

Radhakrishnan, S., Krishna, J. S., Dwivedi, S. P., Gupta, S., Gupta, P., & Chaudhary, V. (2023). Experimental investigation of mechanical and physical properties of coconut shell and eggshell filler-based bio-fiber reinforced epoxy hybrid composites. *Biomass Conversion and Biorefinery*. https://doi.org/10.1007/s13399-023-05037-4

Robert, U. W., Etuk, S. E., Umoren, G., & Agbasi, O. E. (2019). Assessment of thermal and mechanical properties of composite board produced from coconut (Cocos nucifera) husks, waste newspapers, and cassava starch. *International Journal of Thermophysics*, *40*(9), 1-11. https://doi.org/10.1007/s10765-019-2547-8

Samuel, H. S., Ekpan, F. M., & Ori, M. O. (2024). Biodegradable, recyclable, and renewable polymers as alternatives to traditional petroleum-based plastics. *Asian Journal of Environmental Research.*, *1*(3), 152–165. https://doi.org/10.69930/ajer.v1i3.86

Shah, N., Mewada, R. K., & Mehta, T. (2016). Crosslinking of starch and its effect on viscosity behaviour. *Reviews in Chemical Engineering*, *32*(2), 211-227. https://doi.org/10.1515/revce-2015-0047

Silveira, A., Cardoso, J., Correia, M. J., & Martinho, G. (2021). Moisture measurement in paper and cardboard packaging waste bales for recycling. *Applied Sciences*, *11*(10), 4586. https://doi.org/10.3390/app11104586

Singh, J., Kaur, L., McCarthy, O. J. (2007). Factors influencing the physico-chemical, morphological, thermal and rheological properties of some chemically modified starches for food applications—A review. *Food Hydrocolloids*, *21*(1), 1–22. https://doi.org/10.1016/j.foodhyd.2006.02.006

United Nations Industrial Development Organization (UNIDO). (2018). Provision of consultancy services for the design and assessment of the BAT-BEP solid waste demonstration project in Paramaribo, Suriname. (RFP-7000002034/CZ/AB; File: IS-327, Version 02) UNIDO.

Wang, Q., Xiao, S., Shi, S. Q., & Cai, L. (2019). Mechanical property enhancement of self-bonded natural fiber material via controlling cell wall plasticity and structure. *Material & Design*. https://doi.org/10.1016/j.matdes.2019.107763

Zambelli, R. A., Pereira da Rocha, A., & Gama de Mendonca, L. (2024). Importance of starch characterization. In *Standardized procedures and protocols for starch* (pp. 1–32). Humana Press. https://doi.org/10.1007/978-1-0716-3866-8_1

Zhang, S. Y., Fei, B. H., Yu, Y., Cheng, H. T., & Wang, C. G. (2013). Effect of the amount of lignin on tensile properties of single wood fibers. *Frontiers of Materials Science, 7(1)*, 56-60. https://doi.org/10.1007/s11632-013-0106-0

Zuilen, L. F. (2006). Planning of an integrated solid waste management system in Suriname: A case study in greater Paramaribo with focus on households (Doctoral dissertation, Ghent University). Ghent University Academic Repository. http://hdl.handle.net/1854/LU-467952

Appendix A- Calculations

This section provides an overview of the data and calculations of the samples analyzed.

Water Absorption Capacity

Example calculation of sample 1 (WAC$_1$) using Equation 1:

$$WAC_1\,(\%) = \frac{53-14}{14} \times 100\%$$

$$WAC_1\,(\%) = 279\%$$

Moisture content

Example calculation of sample 1 (MC$_1$) using Equation 2

$$MC_1\,(\%) = \frac{15-13}{15} \times 100\%$$

$$MC_1\,(\%) = 13\%$$

Thickness Swelling Degree

Example calculation using Equation 3:

$$\text{T-SD}_1\,(\%) = \frac{1.6-1.2}{1.2} \times 100\%$$

$$\text{T-SD}_1\,(\%) = 33\%$$

The average of the WAC, MC and T-SD was calculated by substituting the data from **Error! Reference source not found.** into Equation 4.

$$Average\,(\%) = \frac{result\ 1 + result\ 2}{2} \qquad \textit{Equation 4}$$

The average water absorption capacity, moisture content and thickness swelling degree from the duplicate measurements are plotted in **Error! Reference source not found. - Error! Reference source not found.**.

Example calculation

$$Average\,WAC\,(\%) = \frac{279\% + 277\%}{2} = 278\%$$

Table A 1: Data from the duplicated testing

Sample	WAC	MC	T-SD
1	279	13	31
	277	13	33
2	174	11	29
	178	14	29
3	169	12	23
	171	15	24
4	100	9	23
	97	12	28
5	98	9	21
	95	9	21
6	190	12	27
	193	12	24
7	78	8	23
	73	8	21
8	473	11	29
	491	10	33
9	421	7	23
	413	12	33
10	241	15	17
	244	8	17
11	233	7	17
	235	13	17
12	185	12	13
	175	6	17
13	143	5	16
	136	5	9
14	269	19	20
	263	12	23
15	227	9	15
	220	6	27
16	292	4	27
	291	8	21
17	156	5	8
	153	10	15
18	189	6	17
	182	6	9
19	259	5	17
	262	2	17
20	256	6	17
	250	3	8
21	167	19	29
	162	14	17
22	117	22	17
	122	13	23
23	96	7	17
	93	7	17
24	87	7	23
	90	3	9
25	143	13	17
	125	13	29
26	92	4	19
	91	9	19
27	341	6	17
	329	6	9

Table A 2: Comparison of Experimental Sample Compositions with Literature Data

Sample composition	**WAC (%)**	**MC (%)**	**T-SD (%)**	**Literature WAC (%)**	**Literature MC (%)**	**Literature T-SD (%)**
Amoo et al. (2017) Control	-	-	-	272.20 ± 5.12	4.10 ± 0.30	72.80 ± 2.5
Amoo et al. (2019)	-	-	-	253.20 ± 8.14	4.48 ± 0.19	<70
Kehinde et al. (2019)	-	-	-	272.40–292.60	4.10–5.68	72.80–90.20
WC (100:0) - Sample 1	278	13	32			
WC: UCS (75:25) -Sample 2	164	17	20			
WC: UMS (75:25) -Sample 3	120	16	23			
WC: MCS (75:25) -Sample 4	95	5	16			
WC: MMS (75:25) -Sample 5	88	7	17			
WC: UCS (85:15) -Sample 6	176	14	24			
WC: UMS (85:15) -Sample 7	170	13	29			
WC: MCS (85:15) -Sample 8	99	9	22			
WC: MMS (85:15) -Sample 9	97	10	26			
WC: UCF (90:10) -Sample 10	481	11	31			
WC: MCF (90:10) -Sample 11	417	9	28			
WC: UCF (50:50) -Sample 12	335	6	13			
WC: MCF (50:50) -Sample 13	253	4	7			
WC: UCS: UMS (75:12.5:12.5)- Sample 14	134	13	22			

WC: MCS: MMS (75:12.5:12.5)-Sample 15	91	6	19			
WC: UCS: UMS (85:7.5:7.5) - Sample 16	192	12	25			
WC: MCS: MMS (85:7.5:7.5) - Sample 17	76	10	23			
WC: UCS: UCF (75:15:10) - Sample 18	242	10	17			
WC: UMS: UCF (75:15:10) - Sample 19	234	12	17			
WC: MCS: MCF (75:15:10) - Sample 20	180	5	13			
WC: MMS: MCF (75:15:10) - Sample 21	139	8	15			
WC: UCS: UMS: UCF (75:7.5:7.5:10)-Sample 22	266	15	22			
WC: UCS: UMS: UCF (70:10:10:10) - Sample 23	223	8	22			
WC: UCS: UMS: UCF (85:5:5:5) - Sample 24	291	6	24			
WC: MCS: MMS: MCF (75:7.5:7.5:10)-Sample 25	154	7	14			
WC: MCS: MMS: MCF (70:10:10:10) - Sample 26	186	5	13			
WC: MCS: MMS: MCF (85:5:5:5) - Sample 27	261	4	17			

Appendix B- Observations

Figure A 1: Control Sample after adding water: 100% waste cardboard

Figure A 2: Sample after adding to water: unmodified 90%:10% cardboard: coconut fibers

Figure A 3: Sample after adding to water: modified 90%:10% cardboard: coconut fibers

Figure A 4: Sample after adding to water: modified 85%:15% cardboard: Starch

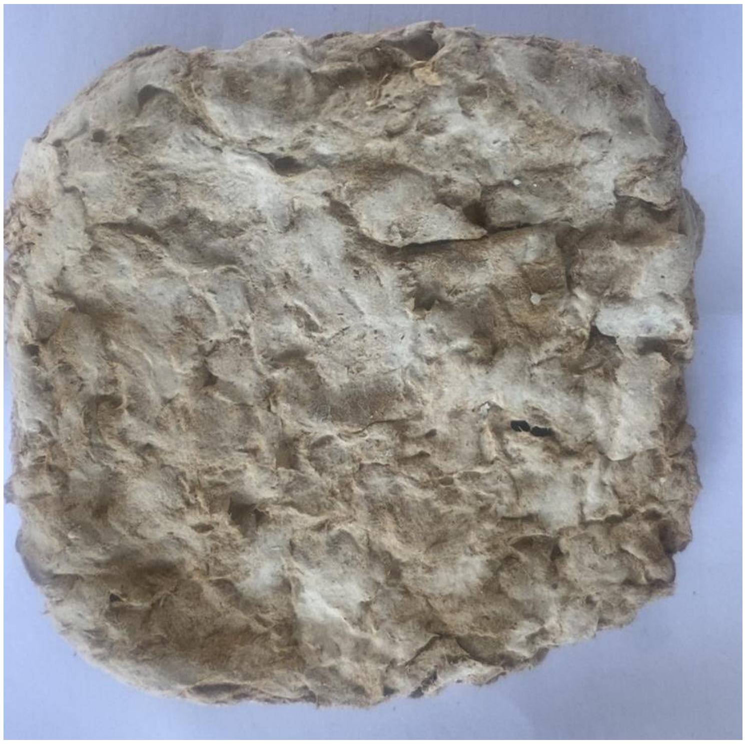


Figure A 5: Sample after adding to water: modified 75%:25% cardboard: starch

Figure A 6: Sample after adding to water: modified 75%:15%:10% cardboard: starch: coconut fibers

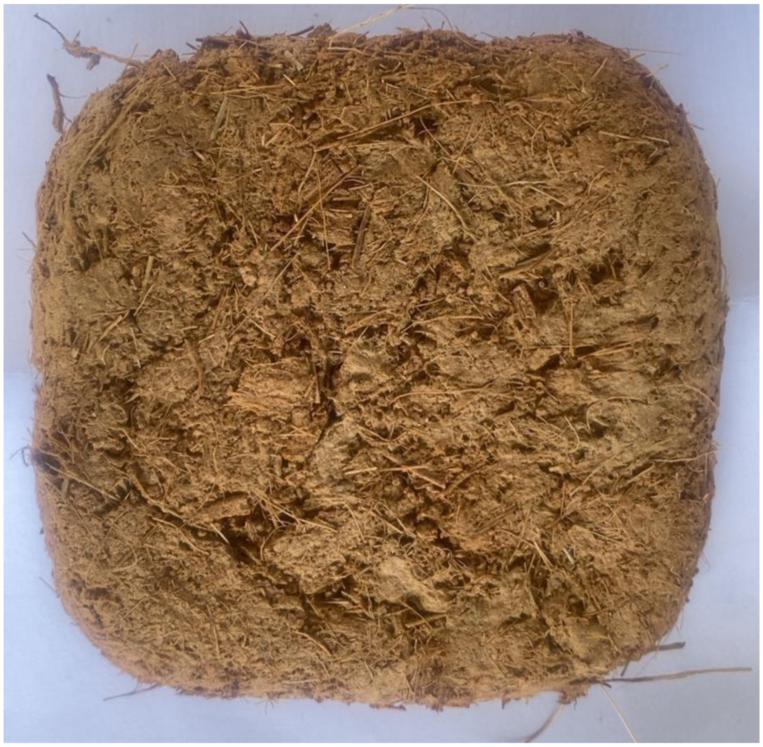


Figure A 7: Sample after adding to water: Modified 70%: 20%: 10%, Cardboard: Starch: Coconut fibers

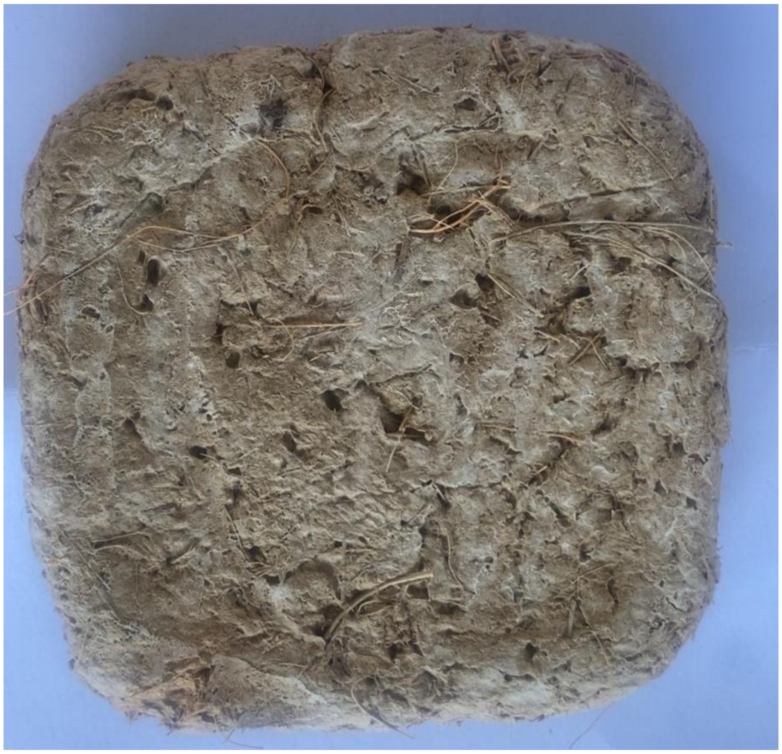


Figure A 8: Sample after adding to water: modified 85%:10%: 5% cardboard: Starch: coconut fibers

Figure A 9: Sample after adding to water: modified 50%:50% cardboard: coconut fibers