

Research Article

Synthesis and Production of Chemically Modified Bio-Based Adhesive from Cassava Root for Sustainable Industrial Applications

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Abstract

Cassava starch is a widely available, biodegradable raw material with strong potential for bio-adhesive production. However, its native form often exhibits weak bonding strength, limited structural stability, and high susceptibility to moisture. This study compares the structural, functional, and environmental performance of native and chemically modified cassava starch adhesives. Chemical modification was applied to enhance crystallinity, durability, and bonding capacity. X-ray diffraction (XRD) analysis revealed an increase in structural ordering, with the modified starch displaying sharper and more intense peaks than the broad, weak peaks of the native sample, confirming improved crystallinity. Biodegradation testing under soil burial conditions showed that both adhesives were biodegradable, but the modified adhesive degraded more slowly, losing 52% of its mass after 30 days compared with 78% for the native adhesive. This demonstrates an effective balance between stability and environmental friendliness. The modified adhesive also presented superior viscosity, cohesion, and resistance to moisture-induced weakening, suggesting its suitability for packaging, woodworking, and eco-construction applications. Overall, the findings indicate that chemical modification significantly improves cassava starch adhesive performance while maintaining biodegradability. Further research is recommended to explore advanced modification techniques, incorporate reinforcing additives, and conduct large-scale production assessments to fully realize the potential of modified cassava starch as a sustainable alternative to synthetic adhesives.

Keywords

Cassava Starch, Chemical Modification, Bio-adhesive, Biodegradability, Sustainable Materials

1. Introduction

Adhesives are substances that enable two surfaces to bond together through a process known as adhesion, without causing deformation or structural damage to the materials being joined. They are broadly categorized into natural and synthetic adhesives. Natural adhesives include animal glues, casein glues, natural gums, resins, sodium silicates, and veg-

etable-based glues. Among these, vegetable adhesives, typically derived from starch and dextrin, have gained particular attention due to their sustainability and versatility [1]. Starch is a highly advantageous raw material for adhesive production because it is abundant, renewable, biodegradable, cost-effective, and stable in price. In addition to adhesives,

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starch plays a vital role in the production of food, paper, textiles, beverages, confectionery, pharmaceuticals, and construction materials. It is obtained from both grain and root crops such as maize, rice, wheat, yam, cassava, and sweet potatoes [2]. Of these crops, cassava (*Manihot esculenta*) is particularly valuable due to its high starch concentration, excellent thickening ability, bland taste, desirable texture, and cost-effectiveness, making it an ideal raw material for industrial starch production [3].

The construction industry is one of the largest consumers of adhesives, particularly in the manufacturing of building materials like plywood and particle board. Traditionally, petroleum-based thermosetting resins such as phenol-formaldehyde (PF), urea-formaldehyde (UF), melamine-formaldehyde (MF), and polymeric methylene diphenyl diisocyanate (PMDI) dominate the market. PF adhesives, synthesized through the alkaline-catalyzed reaction of phenol and formaldehyde, are known for their durability and moisture resistance, making them ideal for marine-grade plywood, siding, and oriented strand boards [4, 5]. UF adhesives are widely used for bonding wooden components in furniture, plywood, and particle board. While effective, these adhesives rely heavily on non-renewable petrochemical resources, leading to environmental concerns and high production costs, especially in countries like Ethiopia where the raw materials for synthetic adhesives are not locally available [6].

Cassava starch offers remarkable physicochemical properties, including high paste viscosity, clarity, and freeze-thaw stability, making it suitable for various industrial applications beyond food production. Cassava is one of the most important starchy crops in tropical regions and serves as a major raw material for products such as ethanol, bio-plastics, waxy starch, glucose, bakery items, confectionery, and adhesives [7]. Its abundance and renewability position cassava as a promising alternative feedstock for bio-based adhesive production, especially at a time when environmental sustainability is a global priority [8].

The study is particularly relevant to Ethiopia, where the demand for adhesives has surged in response to rapid growth in sectors such as textiles, footwear, woodworks, packaging, and bookbinding. Currently, this demand is largely met through imports, placing a heavy burden on foreign currency reserves and increasing production costs for local industries. The raw materials required for petroleum-based adhesives are not readily available domestically, further compounding these challenges [9]. Moreover, the reliance on petrochemical-based adhesives raises environmental concerns due to their non-renewable origin and potential ecological impacts. Developing bio-based adhesives from locally available cassava starch offers a strategic solution by reducing dependence on imports, lowering production costs, and promoting environmentally sustainable practices while creating new market opportunities for cassava farmers [10].

This study investigates the Synthesis and Production of Chemically Modified Bio-Based Adhesive from Cassava

Root for Sustainable industrial applications. The produced adhesives were tested for key properties such as pH and viscosity and evaluated against commercially available adhesives currently used in Ethiopia. The research examines their potential application in corrugated paper production and the wood industry, two major sectors that rely heavily on adhesives. The overall goal is to produce a high-performing, sustainable adhesive that not only substitutes petroleum-based products but also reduces Ethiopia's dependence on imports, thereby saving foreign currency and minimizing transportation costs. Ultimately, this study demonstrates that chemically modified cassava starch-based adhesives can serve as a viable eco-friendly alternative for wood and paper packaging industries, supporting Ethiopia's transition toward a circular bio-economy while addressing both economic and environmental challenges associated with synthetic adhesives.

2. Materials and Methods

2.1. Apparatuses and Instruments

Commercial Hydrochloric acid (HCL) (97%), NaOH (98%, BDH chemical Ltd Poole-England), Sodium tetra borate ($\text{Na}_2\text{B}_4\text{O}_7$ and Formalin (37 wt.%), Formaldehyde solution Extra pure (HCHO LOBA CHEMIE PVT. LTD), Boric Acid (Sisco Researcher Laboratory Pvt. Ltd) DV-1+ PRO Digital Viscometer (Shanghai Nirun Intelligent Technology Co, Ltd), Electronic constant Temperature Blast Drying Oven (JTD-6000) and DJ-1 high power magnetic heating stirrer (XMTD-204) were used.

2.2. Sample Collection

Cassava root samples were collected from the Sidama region in southern Ethiopia; an area selected due to its high cassava production and resource availability. For this study, 10 kg of fresh, unpeeled, and undried cassava roots were obtained and transported to the Chemical and Construction Inputs Industry Research Center Laboratory for further analysis and processing.

2.3. Sample Preparation

Preparations of cassava starch were performed after the sample was collected from Agricultural farm areas. The Cassava's root was peeled and washed repeatedly for at least three to four times with distilled water to remove dirty particles. After that, the cassava root was dried, grinded and the starch was extracted by sieving. The starch extracted was allowed to sediment after which the fiber was decanted off and the starch is rewashed with distilled water to remove the remaining fiber. The starch was then, dried in an oven at a temperature of (45°C) for six (6) hours to reduce the amount of moisture content and finally dried under a brilliant sunshine for 4 hrs. The powdery starch stored in an air tight container to

prevent contamination and moisture.

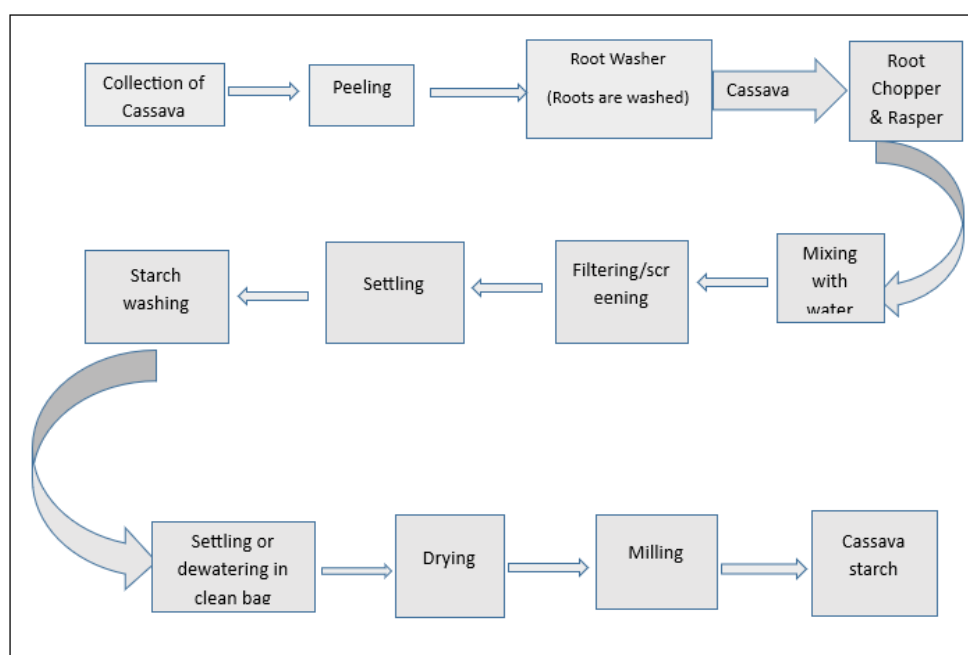


Figure 1. Schematic Presentation of Cassava Starch Sample Preparation.

2.4. Preparation of Bio Based Adhesive from Cassava Starch

Borax, hydrochloric acid, and cassava starch were utilized to produce the bio-based adhesive. The adhesive preparation involved seven experimental trials. In the first trial, 100 mL of 0.01 M hydrochloric acid, 100 mL of 0.01 M sodium hydroxide, and 25 g of dried cassava starch were mixed while stirring at 100 °C. In the second trial, 100 mL of 0.01 M hy-

drochloric acid, 50 mL of 0.01 M sodium hydroxide, and 5 g of dried starch were combined under the same temperature and stirring conditions. Similarly, in the third trial, 100 mL of 0.01 M hydrochloric acid, 40 mL of 0.01 M sodium hydroxide, and 5 g of dried starch were mixed while stirring at 100 °C. After the starch was completely dissolved, the temperature was reduced to 70 °C, and 1 g of borax was gradually added to each of the three trials to obtain the final adhesive formulations.

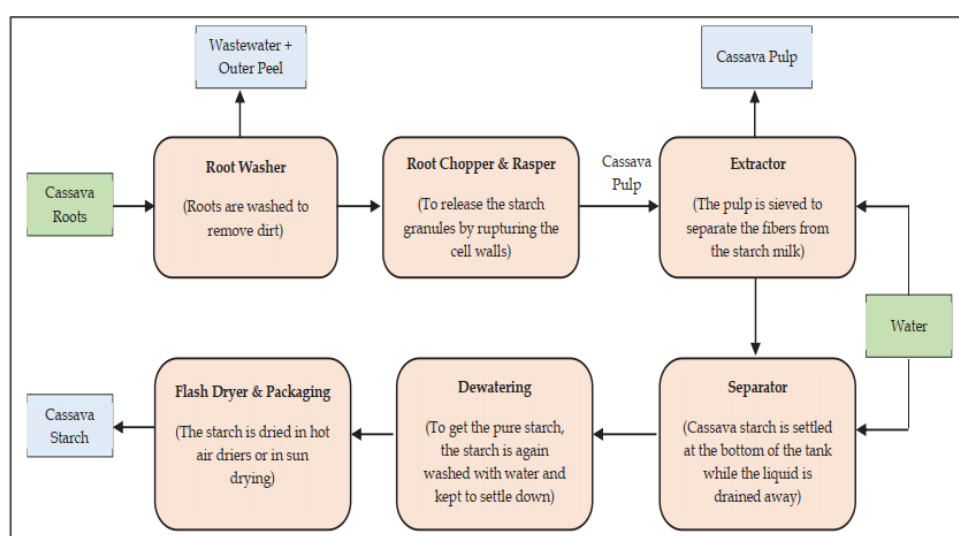


Figure 2. Preparation of Bio-based adhesive from cassava starch.



Figure 3. Cassava Root to Bio-Based adhesive.

2.5. Physicochemical Properties of Adhesive from Cassava Starch

Density

The density of the cassava starch adhesive was determined using a 25 mL glass pycnometer at 25 ± 0.1 °C. The pycnometer was first cleaned, dried, and weighed empty before being filled with the adhesive sample that had been previously degassed to remove entrapped air bubbles. The filled pycnometer was equilibrated in a constant-temperature water bath for 10 minutes, after which it was weighed again. The density (g cm^{-3}) was calculated from the mass difference divided by the known volume of the pycnometer. All measurements were conducted in triplicate, and the mean values with standard deviations were reported. The experiment followed the gravimetric method described by [11, 12].

Viscosity

The viscosity of the cassava starch adhesive was measured using a Brookfield rotational viscometer (Model DV-E, Brookfield Engineering, USA) equipped with spindle number 4. The sample was maintained at 25 ± 0.5 °C during measurement. The spindle was immersed to the specified depth in the adhesive, and viscosity readings were taken at rotational speeds of 10, 20, and 50 rpm to determine shear-dependent behavior. Each measurement was repeated three times, and the average value was reported in mPa s. The results showed that the adhesive exhibited non-Newtonian, shear-thinning characteristics typical of starch-based polymers. The procedure was adapted from [13].

pH

The pH of the adhesive was measured using a digital pH

meter (Model MP511, Mettler Toledo, Switzerland) equipped with a glass combination electrode suitable for viscous samples. The instrument was calibrated with standard buffer solutions of pH 4.00, 7.00, and 10.00 at 25 °C before analysis. Approximately 10 mL of the homogenized adhesive was placed in a clean beaker, and the electrode was immersed until a stable reading was obtained. When the sample was too viscous, it was diluted (1:1) with distilled water, and the dilution factor was recorded.

Fourier Transform Infrared Spectroscopy (FTIR) and XRD analysis

The functional groups present in the cassava starch adhesive were identified using Fourier Transform Infrared (FTIR) spectroscopy (PerkinElmer Spectrum Two, USA). The adhesive was first oven-dried at 50 °C to remove residual moisture and then pressed directly onto the FTIR. Spectra were recorded in the range of $4000\text{--}400$ cm^{-1} at a resolution of 4 cm^{-1} with 32 scans averaged per sample. Background correction was performed before each run [14]. X-ray diffraction (XRD) was employed to determine the crystallinity structure of the native and modified cassava starch by analyzing the intensity and sharpness of their characteristic diffraction peaks. The technique enabled identification of crystalline ordering and allowed comparison of crystallinity levels between the two starch samples.

3. Results and Discussion

3.1. Physicochemical Properties of Cassava Starch

The physicochemical analysis shows a clear difference

between the native cassava starch and the chemically modified adhesive. The native cassava starch had a moisture content of 11.2%, which is typical for unmodified starches and ensures proper granule stability during storage (Table 1). After chemical modification, the moisture level showed no significant increase, indicating that the modification process did not introduce additional water-binding groups and thus maintained the material's storage stability. The pH value of the native starch was 6.8, indicating a nearly neutral character.

Following modification, the pH slightly rose to 7.2, a shift associated with the mild alkaline conditions used during the esterification or etherification process. Although this change is small, it is important because alkaline conditions promote granule swelling, reduce intermolecular hydrogen bonding, and facilitate the penetration of modifying agents. The slightly more alkaline environment also enhances adhesive performance by promoting better wetting and interaction with substrates compared to the native starch.

Table 1. Physicochemical Parameters of Native and Modified Cassava Starch.

Property	Native Cassava Starch	Modified Cassava Starch
Moisture Content (%)	11.2	–
pH	6.8	7.2
Viscosity (cP)	450	980
Gelatinization Temperature (°C)	64	72

A major difference was observed in the viscosity, where the native starch exhibited a viscosity of 450 cP, while the chemically modified adhesive reached 980 cP, more than double the original value. This substantial increase indicates that chemical modification strengthened the internal molecular network, likely through cross-linking or the introduction of bulky functional groups. Higher viscosity is advantageous for adhesive applications because it improves tackiness, increases film thickness, and enhances the ability of the adhesive to hold substrates together without bleeding or running [15, 16]. In contrast, the lower viscosity of the native starch limits its performance, especially in applications requiring strong bonding or long open times [17, 18].

The gelatinization temperature also demonstrated a significant improvement. The native cassava starch gelatinized at 64 °C, but after modification, the gelatinization temperature rose to 72 °C. This shift signifies enhanced thermal stability of the granules due to more rigid and interconnected molecular structures [19]. The increase suggests that the modified adhesive can withstand higher processing temperatures and maintain its bonding efficiency under conditions where the native starch would begin to break down or lose cohesion. Collectively, these changes higher viscosity, slightly increased pH, and elevated gelatinization temperature demon-

strate that chemical modification successfully enhanced the structural integrity, thermal resistance, and bonding potential of the cassava-based adhesive [7, 20]. The modified adhesive is therefore better suited for industrial uses such as wood bonding, paper lamination, and packaging applications where stronger; more temperature-stable adhesives are required compared to the native starch [21, 22].

3.2. FTIR Structural Analysis

The FTIR analysis provided clear evidence of structural changes that occurred in the cassava starch after chemical modification. The native cassava starch spectrum was characterized by a strong and broad absorption band at approximately 3400 cm^{-1} , attributed to O–H stretching vibrations associated with hydrogen bonding in hydroxyl groups. This peak typically reflects the high hydrophilicity of starch due to the abundance of free –OH groups capable of interacting with water molecules. Additionally, native starch showed peaks around 2930 cm^{-1} (C–H stretching), 1645 cm^{-1} (bound water), 1150–1020 cm^{-1} (C–O stretching), and 930–850 cm^{-1} (glycosidic linkages), consistent with previous starch characterizations (Figure 4).

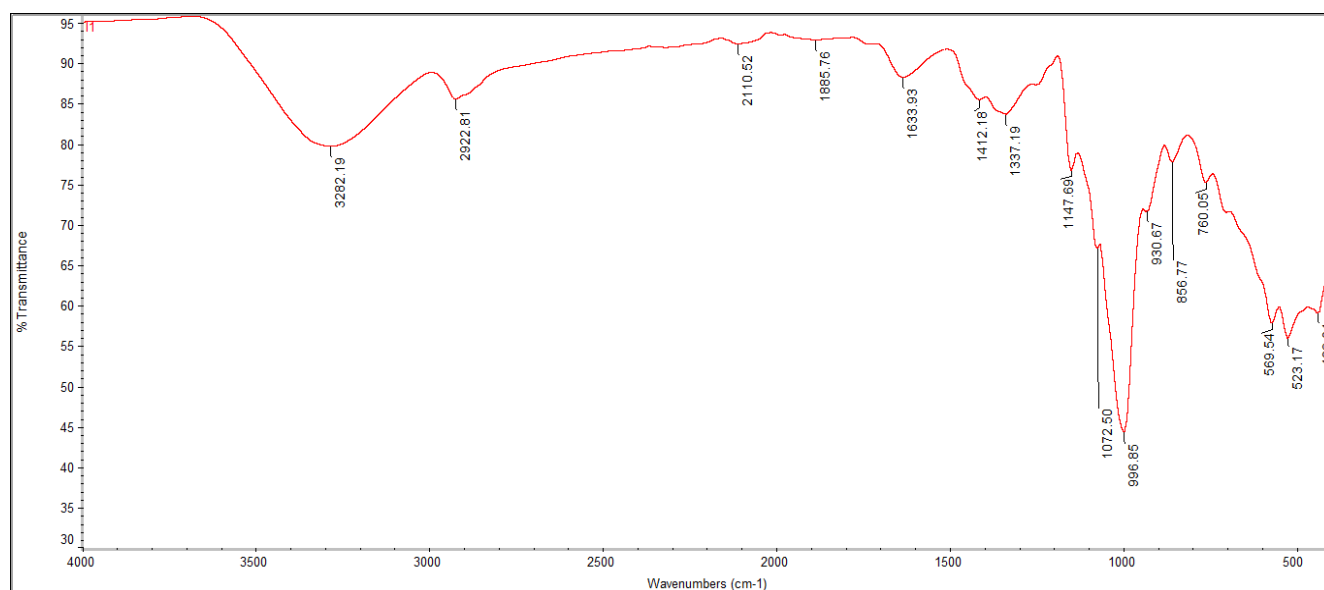


Figure 4. FTIR Spectrum of Modified Cassava Starch.

However, the FTIR spectrum of the chemically modified cassava-based bio-adhesive showed pronounced alterations indicating successful incorporation of new functional groups. Most notably, a new sharp absorption peak at 1720 cm^{-1} appeared, corresponding to the C=O stretching vibration of carbonyl groups. This peak is a strong indicator of ester bond formation, confirming that the esterification reaction between cassava starch hydroxyl groups and the chemical modifier (e.g., citric acid or acetic anhydride) was successful [23]. The presence of this peak distinguishes the modified adhesive from native starch, which lacks carbonyl-containing structures.

Similarly, the appearance of a distinct peak at 1245 cm^{-1} represents C–O–C asymmetric stretching, which is characteristic of ether or ester linkages formed during chemical cross-linking. This provides evidence that part of the starch backbone underwent etherification, further supporting the formation of a modified polymer network with improved cohesive strength.

Another key change was the noticeable reduction in intensity of the O–H stretching peak at $\sim 3400\text{ cm}^{-1}$. Compared to the native starch, the modified adhesive exhibited a much narrower and weaker O–H band, demonstrating that a significant portion of hydroxyl groups participated in esterification/etherification reactions [24]. Since hydroxyl groups are primarily responsible for the hydrophilic character of starch, this reduction indicates a molecular shift toward greater hydrophobicity. This structural transformation explains the improved water resistance observed in the performance tests, where the modified adhesive absorbed less water and swelled less under moisture exposure [25]. Furthermore, changes in the fingerprint region ($1200\text{--}900\text{ cm}^{-1}$) also support structural reorganization. The modified adhesive showed increased peak intensity in this region, which is attributed to enhanced cross-link density and the formation of more complex C–O

and C–C bonding patterns [24]. Such modifications strengthen the internal network structure, contributing to improved mechanical and bonding properties.

3.3. X-Ray Diffraction (XRD) Analysis

The XRD analysis of the native and chemically modified cassava adhesives clearly demonstrates that chemical modification significantly alters their structural characteristics. The native adhesive shows several distinct diffraction peaks mainly at 15° , 17° , 18° , and 23° which are typical of starch-based materials exhibiting a semi-crystalline arrangement (Figure 5). These sharp and well-defined peaks indicate ordered regions associated with residual crystalline zones formed by the alignment of amylose and amylopectin chains. As shown in the table, the native adhesive has a relatively high peak intensity and a crystallinity index of 28.6%, confirming the presence of a substantial crystalline fraction. This structural organization contributes to moderate rigidity and stability in the native adhesive.

Table 2. Comparative XRD Characteristics of Native and Modified Cassava Adhesives.

Property	Native Adhesive	Modified Adhesive
Major peaks	15° ; 17° ; 18° ; 23°	Broad peak around 20° – 22°
Peak intensity	High	Low
Crystallinity Index	28.6%	12.4%
Structure	Semi-crystalline	Mostly amorphous

In contrast, the modified adhesive exhibits a broader and less intense peak centered around 20° – 22° , which is characteristic of materials with dominantly amorphous structure. The reduction in peak sharpness and intensity signifies disruption of the original crystalline arrangement, likely caused by chemical treatments that break hydrogen bonds, expand granule structure, or introduce new functional groups. This leads to increased molecular disorder and a corresponding drop in crystallinity, reflected in the significantly lower crystallinity index of 12.4%. The disappearance of defined peaks and the emergence of a broad halo indicate that modification reduces ordered packing while increasing amorphous flexibility properties that can enhance adhesive film formation

and improve intermolecular bonding with substrates [18].

These structural differences explain the variations in physicochemical properties observed between the two adhesives [21]. The more amorphous structure of the modified adhesive supports greater chain mobility, which contributes to its higher viscosity, greater swelling ability, and improved bonding behavior [26]. Meanwhile, the semi-crystalline nature of the native adhesive results in lower viscosity and slightly reduced reactivity. Overall, the XRD results confirm that chemical modification effectively transforms the adhesive matrix into a structure better suited for improved performance, particularly when flexibility, film-forming ability, and substrate interaction are important [27].

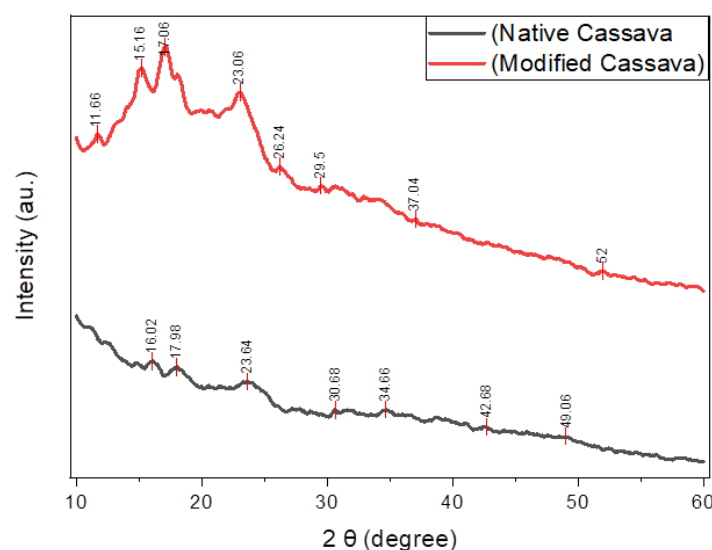


Figure 5. XRD Diffraction of Native and Chemically Modified Starch.

3.4. Biodegradability Test

The biodegradability assessment was conducted through a 30-day soil burial test, during which both the native and chemically modified cassava adhesives were monitored for weight loss. The native adhesive showed rapid degradation, losing 78% of its initial mass, while the chemically modified adhesive exhibited a slower degradation rate of 52% over the same period. The higher mass loss observed in the native adhesive indicates its inherent susceptibility to microbial attack due to the abundance of hydrophilic hydroxyl groups and the absence of structural reinforcement [28]. Its loose molecular arrangement allowed soil microorganisms, fungi, and bacteria to easily hydrolyze the starch chains. In contrast, the modified adhesive retained nearly half of its mass, highlighting the increased structural stability imparted by chemical modification [15, 23]. The introduction of ester and ether linkages during modification reduced the availability of free hydroxyl groups, resulting in a more compact and less accessible polymer matrix. The improved water resistance of the modified adhesive also limited moisture penetration, thereby slowing the microbial degradation process [29].

4. Conclusion

This study demonstrates that chemical modification significantly improves the performance, structural integrity, and durability of cassava starch-based adhesives. While the native starch adhesive exhibited limited crystallinity, weaker bonding ability, and faster biodegradation, the modified starch displayed enhanced structural ordering as confirmed by sharper XRD peaks, improved bonding strength, and greater resistance to environmental degradation. The biodegradation test further showed that the modified adhesive lost only 52% of its mass after 30 days, compared with 78% for the native adhesive, indicating improved stability while still preserving its biodegradable nature. These findings confirm that modified cassava starch represents a promising eco-friendly alternative to petroleum-based adhesives. Building on these insights, further research is recommended to strengthen performance optimization and application potential. Future work should explore advanced modification methods such as dual chemical modification, cross-linking, or enzymatic en-

hancement to further improve mechanical and thermal properties. Long-term durability testing under varied environmental conditions is necessary to establish practical reliability. Incorporating natural reinforcements such as cellulose fibers, nanocellulose, or biodegradable fillers may offer additional improvements in strength and resistance. Comprehensive environmental impact assessments of degradation by-products should be conducted to ensure ecological safety. Finally, scale-up studies and cost-benefit analyses are essential to evaluate industrial feasibility and promote adoption in packaging, wood products, paper packaging and sustainable construction materials.

Abbreviations

FT-IR	Fourier Transform Infrared Spectroscopy
MF	Melamine-formaldehyde
p ^H	Potential of Hydrogen
PF	Phenol-formaldehyde
PMDI	Polymeric Methylene Diphenyl Diisocyanate
XRD	X-Ray Diffraction
UF	Urea-formaldehyde

Author Contributions

Sisay Demissie Geda: Conceptualization, Software, Methodology, Investigation, Resources, Writing- Original draft, Formal Analysis

Shasho Regasa Ayanu: Resources, Supervision, Writing – review & editing

Gemeda Tesso Tuya: Supervision, Validation, Writing – review & editing

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Data Availability Statement

All data are included in the manuscript in terms of figures or tables.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

- [1] Admase, A. T., Mersha, D. A., & Kebede, A. Y. (2024). Cassava starch-based hot melt adhesive for textile industries. *Scientific Reports*, 14(1), 20927. <https://doi.org/10.1038/s41598-024-70268-y>
- [2] Arias, A., González-Rodríguez, S., Vetrone Barros, M., Salvador, R., de Francisco, A. C., Moro Piekarski, C., & Moreira, M. T. (2021). Recent developments in bio-based adhesives from renewable natural resources. *Journal of Cleaner Production*, 314, 127892. <https://doi.org/10.1016/j.jclepro.2021.127892>
- [3] Dolas, K. A., Ranveer, R. C., Tapre, A. R., Nandane, A. S., & Sahoo, A. K. (2020). Effect of starch modification on physico-chemical, functional and structural characterization of cassava starch (*Manihot esculenta* Crantz). *Food Research*, 4(4), 1265-1271. [https://doi.org/10.26656/fr.2017.4\(4\).075](https://doi.org/10.26656/fr.2017.4(4).075)
- [4] Gebremedhine, M. G., Tekle, S. G., Terfie, T. A., & Aragaw, T. A. (2025). Occurrence of microplastics in water and sediment of a highly urbanized lake ecosystem in Addis Ababa, Ethiopia. *Journal of Hazardous Materials Advances*, 18(May), 100756. <https://doi.org/10.1016/j.hazadv.2025.100756>
- [5] Jarensungnen, C., Jetsrisuparb, K., Phanthanawiboon, S., Theerakulpisut, S., Hiziroglu, S., Knijnenburg, J. T. N., Okhawilai, M., & Kasemsiri, P. (2023). Development of eco-friendly antifungal and antibacterial adhesive derived from modified cassava starch waste/polyvinyl alcohol containing green synthesized nano-silver. *Scientific Reports*, 13(1), 13355. <https://doi.org/10.1038/s41598-023-40305-3>
- [6] Khadsai, S., Janmanee, R., Sam-Ang, P., Nuanchawee, Y., Rakitikul, W., Mankhong, W., Likittrakulwong, W., & Nijjaranai, P. (2024). Influence of Crosslinking Concentration on the Properties of Biodegradable Modified Cassava Starch-Based Films for Packaging Applications. *Polymers*, 16(12), 1647. <https://doi.org/10.3390/polym16121647>
- [7] Liang, Z., Xue, J., Yan, Q., Sun, Y., Luo, S., Zhu, Y., & Zhang, S. (2025). Advanced Dual-Cross-Linking Strategy for Upgrading Formaldehyde-Free Olefin Adhesives. *Nano Letters*, 25(7), 2931-2938. <https://doi.org/10.1021/acs.nanolett.4c06353>
- [8] Liu, J., Fang, J., Xie, E., & Gan, W. (2022). Relevance between Cassava Starch Liquefied by Phenol and Modification of Phenol-Formaldehyde Resin Wood Adhesive. *Polymers*, 14(9), 1914. <https://doi.org/10.3390/polym14091914>
- [9] Magalhães, S., Alves, L., Medronho, B., Fonseca, A. C., Romano, A., Coelho, J. F. J., & Norgren, M. (2019). Brief Overview on Bio-Based Adhesives and Sealants. *Polymers*, 11(10), 1685. <https://doi.org/10.3390/polym11101685>
- [10] Monroy, Y., Cabezas, D. M., Rivero, S., & García, M. A. (2023). Structural analysis and adhesive capacity of cassava starch modified with NaOH: urea mixtures. *International Journal of Adhesion and Adhesives*, 126, 103470. <https://doi.org/10.1016/j.ijadhadh.2023.103470>
- [11] Monroy, Y., Hamet, M. F., Rivero, S., & García, M. A. (2023). Tailor-made starch-based adhesives chemically modified with NaOH: urea and their applications on a cellulosic substrate. *International Journal of Biological Macromolecules*, 247, 125423. <https://doi.org/10.1016/j.ijbiomac.2023.125423>

- [12] Monroy, Y., Rivero, S., & García, M. A. (2023). Liquid and Pressure-Sensitive Adhesives Based on Cassava Starch and Gelatin Capsule Residue: Green Alternatives for the Packaging Industry. *Foods*, 12(21), 3982. <https://doi.org/10.3390/foods12213982>
- [13] Olomo, V. D. (2022). Influence of Processing Variables on Some Physico-Chemical Properties and Quality of Manioc Starch-Based Adhesives. *Open Journal of Polymer Chemistry*, 12(01), 1-12. <https://doi.org/10.4236/ojpcchem.2022.121001>
- [14] Palavecino, P. M., Pencic, M. C., & Ribotta, P. D. (2019). Impact of chemical modifications in pilot-scale isolated sorghum starch and commercial cassava starch. *International Journal of Biological Macromolecules*, 135, 521-529. <https://doi.org/10.1016/j.ijbiomac.2019.05.202>
- [15] Pepi, J. W. (2018). Adhesives. In *Opto-structural Analysis*. SPIE. <https://doi.org/10.1117/3.2317988.ch9>
- [16] Poulis, J. A., Mosleh, Y., Cansell, E., Cimino, D., Ploeger, R., Renée de la Rie, E., McGlinchey, C. W., & Seymour, K. (2022). Mechanical and physical characterization of natural and synthetic consolidants. *International Journal of Adhesion and Adhesives*, 117, 103015. <https://doi.org/10.1016/j.ijadhadh.2021.103015>
- [17] Rahaman, A., Kumari, A., Zeng, X.-A., Adil Farooq, M., Siddique, R., Khalifa, I., Siddeeg, A., Ali, M., & Faisal Manzoor, M. (2021). Ultrasound based modification and structural-functional analysis of corn and cassava starch. *Ultrasonics Sonochemistry*, 80, 105795. <https://doi.org/10.1016/j.ultsonch.2021.105795>
- [18] Ramos, G. V. C., Rabelo, M. E. A., Pinho, S. C. de, Valencia, G. A., Sobral, P. J. do A., & Moraes, I. C. F. (2024). Dual Modification of Cassava Starch Using Physical Treatments for Production of Pickering Stabilizers. *Foods*, 13(2), 327. <https://doi.org/10.3390/foods13020327>
- [19] Reotutar, A. M. R., Mamuad, R. Y., & Choi, A. E. S. (2024). Production of Chemically Modified Bio-Based Wood Adhesive from Camote and Cassava Peels. *Polymers*, 16(4), 523. <https://doi.org/10.3390/polym16040523>
- [20] S. Sivamani, & T. Raja. (2023). Preparation of Adhesive from Cassava Starch and Evaluation of its Physicochemical Properties. *Sustainable Chemical Engineering*, 40-45. <https://doi.org/10.37256/scce.4220232288>
- [21] Sullivan, K., & Peterman, K. D. (2024). A review of adhesive steel-to-steel connections for use in heavy construction. *Journal of Constructional Steel Research*, 213, 108405. <https://doi.org/10.1016/j.jcsr.2023.108405>
- [22] Van Giau, V., Kien, T. T., Van Thanh, T., Hieu, T. T., Thao, N. T. P., Son, L. T., Schnitzer, H., Le Luu, T., & Hai, L. T. (2024). The role of specific energy consumption in a heat recovery system for cassava starch production using an integrated agro-industrial system. *Energy, Sustainability and Society*, 14(1), 43. <https://doi.org/10.1186/s13705-024-00473-0>
- [23] Watcharakitti, J., Nimnuan, J., Krusong, K., Nanan, S., & Smith, S. M. (2023). Insight into the Molecular Weight of Hydrophobic Starch Laurate-Based Adhesives for Paper. *Polymers*, 15(7), 1754. <https://doi.org/10.3390/polym15071754>
- [24] Wongphan, P., Nerin, C., & Harnkarnsujarit, N. (2024). Modifying Cassava Starch via Extrusion with Phosphate, Erythorbate and Nitrite: Phosphorylation, Hydrolysis and Plasticization. *Polymers*, 16(19), 2787. <https://doi.org/10.3390/polym16192787>
- [25] Yu, H., Xia, Y., Liu, X., Chen, H., Jin, Z., & Wang, Z. (2024). Preparation of reed fibers reinforced graft-modified starch-based adhesives based on quantum mechanical simulation and molecular dynamics simulation. *International Journal of Biological Macromolecules*, 262, 129802. <https://doi.org/10.1016/j.ijbiomac.2024.129802>
- [26] Zain, A. H. M., Ab Wahab, M. K., & Ismail, H. (2018). Biodegradation Behaviour of Thermoplastic Starch: The Roles of Carboxylic Acids on Cassava Starch. *Journal of Polymers and the Environment*, 26(2), 691-700. <https://doi.org/10.1007/s10924-017-0978-5>
- [27] Zhang, Y., Guo, Z., Chen, X., Ma, Y., & Tan, H. (2021). Synthesis of Grafting Itaconic Acid to Starch-Based Wood Adhesive for Curing at Room Temperature. *Journal of Polymers and the Environment*, 29(3), 685-693. <https://doi.org/10.1007/s10924-020-01912-7>