BIODEGRADABLE MATERIAL DERIVED FROM THERMOPLASTIC CASSAVA STARCH: REVIEW

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ABSTRACT: Consumption of non-biodegradable materials has had a detrimental effect on humanity and the climate. Non-biodegradable materials are composed of petroleum-based plastic polymers that are harmful to the atmosphere due to their inability to dissolve in landfills. Thermoplastic cassava starch has been recognized as a complete biodegradable material that can be produced by various plants, which is one of the richest resources that is renewable, biodegradable, and readily available at a low cost. Plasticizer, heat, and shear may help convert starch into thermoplastic starch (TPS). This bioplastic is a biodegradable and soluble in water. To be clear, this bioplastic has the restriction that it doesn't have the mechanical characteristics of POM and is also very sensitive to moisture. Hence, this article intends to evaluate the many TPS modifications carried out over the years.

KEYWORDS: *Thermoplastic starch, bio-composite*

1.0 INTRODUCTION

Environmental knowledge and interest have grown steadily in recent years around the world. As well as other enforcement of environmental legislation, This helps to maintain the ecosystem, which is critical in this transformation. [1] The use of non-biodegradable material has led to environmental problems such as water waste, ozone contamination, and landfill problems. Both of these challenges also prompted new studies into the production of biodegradable products such as thermoplastic starch derived from natural resources.

Due to the widespread usage of plastics in a variety of industries, especially the packaging industry, annual production of petroleum-based plastics exceeded 300 million tons until 2015, with approximately 1% being bioplastic [2]. More recently, 50% of the bioplastic preparation is from starch. It is found to help nature by keeping in mind of carbon dioxide emissions and the use of fossil fuel in processing and can have a significant beneficial effect on global warming.

Due to the environmental impact of traditional thermoplastics, the production of biodegradable thermoplastics has accelerated. Biodegradable materials are both safe for the user and the climate. Thus, it is prudent to minimize the usage of non-biodegradable plastic and to encourage the use of biodegradable plastic. Natural fibers have risen in popularity as reinforcement in composite materials over the years, owing to the growing need for renewable, cost-effective, and eco-friendly materials in a variety of applications. Natural fibers often used as reinforcements include flax, kenaf, hemp, jute, coir, sisal, and abaca. However, sugar palm fiber (SPF), a natural fiber, is gaining recognition as a reinforcement in composites, despite the fact that rural populations have known it for decades for its versatile traditional usage.[3]

2.0 THERMOPLASTIC CASSAVA STARCH

Cassava starch is a popular choice for making thermoplastic cassava starch (TPCS) since it is inexpensive and processed in large quantities. As a PLA factor for making flexible packaging films, TPCS and updated TPCS have reasonable properties. [4]. Cassava, technically referred to as Manihot esculenta, is an agricultural crop that belongs to the Euphorbiaceae family. According to Yousefi D.B. et al., (2021)oil palm production dependence on pollination is experiencing issues with decreasing the actual yield. Consequently, alternative methods in commercial plantations such as human-assisted pollination and recently Wireless Sensor Network (WSN it is the sixth highest-ranking starch crop globally and is widely consumed in tropical regions. Cassava starch is the most efficient source of starch when compared to other sources. It has the ability to produce up to 17,000 kg per hectare per year when optimal agricultural techniques are employed [6]. Cassava or its specific name is Manihot esculenta roots are very plentiful in tropical regions, according to Oladunmoye et al., (2014). Cassava is a major source of food in the tropics for people who live in lowland Africa. The feature of the granule affects the pace of hydration and capacity swelling process. Additionally, its final aesthetic appearance was affected by color as well as by the ability to inflate, the capacity to absorb water, and the ability to dissolve.

Thermoplastic cassava starch (TPCS) is being considered as a possible substitute for synthetic thermoplastics since it is both biodegradable and renewable [8]. TPCS is obtained by the extraction of cassava starch, which is generated from the roots of the cassava plant. It serves as a matrix in composite materials. It has been discovered that TPCS improves the mechanical characteristics of composites. Thermoplastic cassava starch is created by altering the starch molecules using physical, chemical, or enzymatic methods to improve its ability to be molded when heated and its mechanical characteristics. Cassava starch that has been modified provides flexibility in its processing, as it can be used in traditional plastic manufacturing techniques such as extrusion and injection molding. This allows for the creation of a wide range of products, including packaging materials, disposable utensils, and even toys [9].

Thermoplastic cassava starch has the benefit of being biodegradable, making it a sustainable substitute for traditional plastics. Thermoplastic cassava starch may be decomposed by microorganisms in the environment, resulting in the formation of natural substances like carbon dioxide and water. The pace of disintegration, however, is contingent upon several elements, including the bioplastic's composition, the circumstances of the disposal location, and the presence of microorganisms (Moura et al., 2021).

Table 1 Summary of cassava starch from various studies.

Type of polymer/tubers	Product/Application	References
Cassava Starch/Palm Wax	Biodegradable material	[10]
Cassava Starch/ Coir Fibre	Biodegradable material	[11]
Cassava Starch/ Kraft	Biodegradable tray with chitosan coating	[12]
Cassava Starch/Orange, sugarcane	Biodegradable tray, packaging material	[13]
Cassava Starch/Sugar Palm	Biodegradable material	[14]
Cassava Starch–Carboxymethyl Cellulose Incorporated with Quercetin and quercetin and tertiary butylhydroquinone(TBHQ).	Active packaging	[15]
Cassava–wheat composite	Bread making	[16]
Cassava starch, glycerol and natural polyphenols extracted from rosemary leaves.	Edible active films	[16]

Konjac glucomannan (KGM)-chitosan-cassava starch-nanosilver films.	Food packaging materials.	[16]
Cassava starch, beeswax, and ethanolic propolis extract	Edible films and coatings	[17]
Cassava starch with ammonium zirconium carbonate(AZC)	Substitute for SBR latex	[18]
Cassava starch-zinc-nanocomposite films	Food packaging	[19]
Cassava starch, essential oil and sodium bentonite nanoclay	Food packaging	[20]
Cassava, potato and sweet potato starch	Food industry	[21]
Cassava starch	Textile Pharmaceutical industries	[22]
Cassava starch	Bioethanol Paper Adhesives	[23]
Cassava starch with carotenoids	Food industry	[24]
Yam and cassava starch with essential oil of oregano	Fruit coating	[25]
Cassava starch, Corn starch and glucose oxidase–peroxidase reagent (GOPOD)	Food processing	[26]
Cassava, corn, potato, sweet potato, glutinous rice, rice, and buckwheat	Ethanol	[27]
Cassava starch with NaOH	Food industry	[28]
Cassava starch hydrolyzed by PoGA15A	Ethanol	[29]

3.0 THERMOPLASTIC STARCH COMPOSITES

Starch is a renewable biopolymer that is widely used in environmentally safe packaging products as a replacement for non-biodegradable petrochemical-based plastic. Although starch in its natural state is not a thermoplastic, it can be transformed into a substance that resembles plastic called thermoplastic starch (TPS). Owing to the hydrophilic nature of the materials, biodegradable composites made of pure thermoplastic starch have inferior mechanical properties and are more hygroscopic than composites made of synthetic polymers [30].

Thermoplastic starch is a biodegradable plastic created by combining starch, a readily available, renewable, non-toxic, and cost-effective raw material derived from agricultural crops, with plasticizers like glycerol, sorbitol, and xylitol. This blending process occurs at high temperatures and involves shear [11].

In the presence of a plasticizer, such as water, glycerol, or sorbitol, thermoplastic starch can be made via extrusion-cooking. The use of starch from various sources most often maize, wheat, potato, and tapioca in the production of TPS biodegradable packaging materials has been the subject of several research studies. Although these biodegradable materials can be beneficial in conjunction with substitute plastics, they are not widely used due to some defects such as brittleness, retro gradation, and hygroscopic properties [31]. Plasticizers are crucial in the production of thermoplastic starch as they enhance the performance of starch. More precisely, they achieve this by decreasing the quantity of hydrogen bonds present in polymer chains while concurrently augmenting the amount of available space. Furthermore, this promotes the mobility of molecular chains and enhances both flexibility and processability. [32].

Diyana et al., (2021) found that thermoplastic starch (TPS), a polymeric substance with a high water or plasticizer content, may be utilized to manufacture starch-based films. The TPS (Thermoplastic Starch) serves a vital role in reducing the impact of synthetic plastic waste. The production method entails the disruption of starch granules using plasticizers that have low water content, together with the application of shear force and heating. Processing starch-based materials has similarities to the processing of conventional polymers [34].

Although TPS has excellent processing capability, it is unsuitable for the majority of typical applications due to a number of drawbacks, including inferior mechanical efficiency, hygroscopic design, and low dimensional stability. TPS's amorphous structure has a propensity to regenerate intermolecular hydrogen bonds when exposed to moisture, resulting in recrystallization (also called retrogradation) and embrittlement. Demonstrated that retrogradation has a detrimental effect on the oxygen and water vapor permeability of TPS films. Enhancing the moisture resistance and mechanical properties of TPS by the use of synthetic polymers has garnered significant interest, allowing for more robust TPS applications. Combining TPS with a hydrophobic polymer increases the total hydrophobicity of the surfaces, where the hydrophobic polymer acts as a barrier, limiting TPS's moisture absorption, and the plasticizer added to TPS may affect the material's mechanical properties [35].

Polymeric nanocomposites including inorganic and organic compounds have been shown to be an important tool for improving the performance of a variety of products and materials, including thermoplastic starch. Due to their superior mechanical properties, huge specific surface region, and high aspect ratio, bio-based cellulose nanomaterials, specifically cellulose nanocrystals (CNCs), cellulose Nano fibrils (CNFs), and micro-fibrillated cellulose (MFC), have been extended in both natural and adapted ways, most notably as an attractive and renewable reinforcement medium for composite materials. Numerous uses of Nano cellulose materials have been identified as cost-effective, including the strengthening of thermoplastic polymers and thermosets by CNCs, the use of MFC in a strongly filled paper in a pilot-scale papermaking system, and the production of highly recyclable superabsorbent [35].

The primary disadvantage of thermoplastic starch composites is the incompatibility of extremely polar thermoplastic starch with nonpolar, resulting in an irreversible decrease in the thermoplastic starch composites' mechanical properties. This incompatibility precludes the forming of strong interfacial hydrogen bonds between thermoplastic starch phases, and numerous studies have been conducted to improve thermoplastic starch compatibility through starch modification, polyethylene modification, and incorporation of a compatibilizer (or coupling agent) into thermoplastic starch composites. The addition of compatibilizers (CA) is a well-established and industrial process for improving the stability and interfacial bonding of immiscible polymer blends [35].

4.0 CONCLUSION

To summarize, TPS is a promising material as a replacement for non-biodegradable plastics. Because of its ecologically beneficial properties, this biopolymer is an ideal choice. TPS's mechanical characteristics and moisture sensitivity may be improved by modifying the material with natural fiber reinforcement and various kinds of polymer. Positive outcomes have been recorded as a consequence of the TPS modification work. This suggests that TPS will likely replace petroleum-based polymers in the near future, particularly in packaging applications. The potential use of TPS as a packaging material is regarded as one of the most promising solutions to the world's abundance of plastic trash.

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REFERENCES

[1] J. Prachayawarakorn, S. Chaiwatyothin, S. Mueangta, and A. Hanchana, "Effect of jute and kapok fibers on properties of thermoplastic cassava starch composites," *Mater. Des.*, vol. 47, 2013, doi: 10.1016/j.matdes.2012.12.012.

[2] M. K. Marichelvam, M. Jawaid, and M. Asim, "Corn and rice starch-based bio-plastics as alternative packaging materials," *Fibers*, vol. 7, no. 4, 2019, doi: 10.3390/fib7040032.

[3] I. Mukhtar, Z. Leman, M. R. Ishak, and E. S. Zainudin, "Sugar palm fibre and its composites: A review of recent developments," *BioResources*, vol. 11, no. 4. 2016. doi: 10.15376/biores.11.4.10756-10782.

[4] A. Bher, I. U. Unalan, R. Auras, M. Rubino, and C. E. Schvezov, "Toughening of poly(lactic acid) and thermoplastic cassava starch reactive blends using graphene nanoplatelets," *Polymers (Basel).*, vol. 10, no. 1, 2018, doi: 10.3390/polym10010095.

[5] M. Yousefi D.B. et al., "Classification of oil palm female inflorescences anthesis stages using machine learning approaches," *Inf. Process. Agric.*, vol. 8, no. 4, 2021, doi: 10.1016/j.inpa.2020.11.007.

[6] R. Jumaidin et al., "Characteristics of cogon grass fibre reinforced thermoplastic cassava starch biocomposite: Water absorption and physical properties," *J. Adv. Res. Fluid Mech. Therm. Sci.*, vol. 62, no. 1, pp. 43–52, 2019.

[7] O. O. Oladunmoye, O. C. Aworh, B. Maziya-Dixon, O. L. Erukainure, and G. N. Elemo, "Chemical and functional properties of cassava starch, durum wheat semolina flour, and their blends," *Food Sci. Nutr.*, vol. 2, no. 2, 2014, doi: 10.1002/fsn3.83.

[8] Sudaryanto, E. Yulianti, Deswita, Wahyudianingsih, D. N. P. Anggreyni, and E. Kartini, "Interfacial properties of solid polymer electrolyte for lithium-ion battery," in *IOP Conference Series: Materials Science and Engineering, 2019*. doi: 10.1088/1757-899X/553/1/012061.

[9] Fakhruddin, R. Irmawaty, R. Djamaluddin, and D. A. Rudy, "Flexural behavior of reinforced concrete beams using PET plastic as partial replacement of coarse aggregate," in *IOP Conference Series: Earth and Environmental Science, 2021*. doi: 10.1088/1755-1315/871/1/012021.

[10] K. Z. Hafila, R. Jumaidin, R. A. Ilyas, M. Z. Selamat, and F. A. M. Yusof, "Effect of palm wax on the mechanical, thermal, and moisture absorption properties of thermoplastic cassava starch composites," *Int. J. Biol. Macromol.*, vol. 194, 2022, doi: 10.1016/j.ijbiomac.2021.11.139.

[11] P. Chotiprayon, B. Chaisawad, and R. Yoksan, "Thermoplastic cassava starch/poly(lactic acid) blend reinforced with coir fibres," *Int. J. Biol. Macromol.*, vol. 156, 2020, doi: 10.1016/j.ijbiomac.2020.04.121.

[12] A. Campos, A. R. Sena Neto, V. B. Rodrigues, B. R. Luchesi, L. H. C. Mattoso, and J. M. Marconcini, "Effect of raw and chemically treated oil palm mesocarp fibers on thermoplastic cassava starch properties," *Ind. Crops Prod.*, vol. 124, no. July, pp. 149–154, 2018, doi: 10.1016/j.indcrop.2018.07.075.

[13] D. C. M. Ferreira, G. Molina, and F. M. Pelissari, "Biodegradable trays based on cassava starch blended with agroindustrial residues," *Compos. Part B*, vol. 185, no. February, p. 107682, 2020, doi: 10.1016/j.compositesb.2019.107682.

[14] R. A. Ilyas et al., "Effect of sugar palm nanofibrillated celluloseconcentrations on morphological, mechanical andphysical properties of biodegradable films basedon agro-waste sugar palm (Arenga pinnata(Wurmb.) Merr) starch," *J. Mater. Res. Technol.*, 2019, doi: 10.1016/j.jmrt.2019.08.028.

[15] W. Tongdeesoontorn, L. J. Mauer, S. Wongruong, P. Sriburi, and P. Rachtanapun, "Physical and antioxidant properties of cassava starch-carboxymethyl cellulose incorporated with quercetin and TBHQ as active food packaging," *Polymers (Basel).*, vol. 12, no. 2, 2020, doi: 10.3390/polym12020366.

[16] S. M. Chisenga, T. S. Workneh, G. Bultosa, and B. A. Alimi, "Progress in research and applications of cassava flour and starch: a review," *Journal of Food Science and Technology,* vol. 56, no. 6. 2019. doi: 10.1007/s13197-019-03814-6.

[17] L. D. Pérez-Vergara, M. T. Cifuentes, A. P. Franco, C. E. Pérez-Cervera, and R. D. Andrade-Pizarro, "Development and characterization of edible films based on native cassava starch, beeswax, and propolis," *NFS J.*, vol. 21, 2020, doi: 10.1016/j.nfs.2020.09.002.

[18] S. Wang, F. Zhang, F. Chen, and Z. Pang, "Preparation of a crosslinking cassava starch adhesive and its application in coating paper," *BioResources*, vol. 8, no. 3, 2013, doi: 10.15376/biores.8.3.3574-3589.

[19] F. A and O. ZD, "Development and Optimisation of Cassava Starch-Zinc-Nanocomposite Film for Potential Application in Food Packaging," *J. Food Process. Technol.*, vol. 7, no. 6, 2016, doi: 10.4172/2157-7110.1000591.

[20] B. Iamareerat, M. Singh, M. B. Sadiq, and A. K. Anal, "Reinforced cassava starch based edible film incorporated with essential oil and sodium bentonite nanoclay as food packaging material," *J. Food Sci. Technol.*, vol. 55, no. 5, 2018, doi: 10.1007/s13197-018-3100-7.

[21] E. Nuwamanya, Y. Baguma, E. Wembabazi, and P. Rubaihayo, "Comparative study of the physicochemical properties of starches from root, tuber and cereal crops," *African J. Biotechnol.*, vol. 10, no. 56, 2011, doi: 10.4314/ajb.v10i56.

[22] N. J. Tonukari et al., "White Gold: Cassava as an Industrial Base," *Am. J. Plant Sci.*, vol. 06, no. 07, 2015, doi: 10.4236/ajps.2015.67103.

[23] H. D. K. C. Wijesinghe and K. D. P. P. Gunathilake, "Characterization and Comparison of Alkali Extracted Starches from Selected Cereals and Tubers," *Asian Plant Res. J.*, 2020, doi: 10.9734/aprj/2020/v5i130096.

[24] E. Atwijukire et al., "Starch quality traits of improved provitamin A cassava (Manihot esculenta Crantz)," *Heliyon*, vol. 5, no. 2, 2019, doi: 10.1016/j.heliyon.2019.e01215.

[25] R. Ortega Toro, J. Martelo-Guzmán, and S. Collazo Bigliardi, "Comparative Study of Active Edible Coatings Based on Yam Starch and Cassava Starch," *Rev. EIA,* vol. 17, no. 34, 2020, doi: 10.24050/reia.v17i34.1408.

[26] H. Mwizerwa, G. O. Abong, M. W. Okoth, M. P. Ongol, C. Onyango, and P. Thavarajah, "Effect of resistant cassava starch on quality parameters and sensory attributes of yoghurt," *Curr. Res. Nutr. Food Sci.*, vol. 5, no. 3, 2017, doi: 10.12944/CRNFSJ.5.3.21.

[27] H. J. Lin et al., "Production of raw cassava starch-degrading enzyme by Penicillium and its use in conversion of raw cassava flour to ethanol," *J. Ind. Microbiol. Biotechnol.*, vol. 38, no. 6, 2011, doi: 10.1007/s10295-010-0910-7.

[28] I. M. Demiate and V. Kotovicz, "Cassava starch in the Brazilian food industry," *Ciência e Tecnol. Aliment.*, vol. 31, no. 2, 2011, doi: 10.1590/s0101-20612011000200017.

[29] Q. S. Xu, Y. S. Yan, and J. X. Feng, "Efficient hydrolysis of raw starch and ethanol fermentation: a novel raw starch-digesting glucoamylase from Penicillium oxalicum," *Biotechnol. Biofuels,* vol. 9, no. 1, 2016, doi: 10.1186/s13068-016-0636-5.

[30] N. A. Sarsari, S. Pourmousa, and A. Tajdini, "Physical and mecha*nical properties of walnut shell flour-filled thermoplastic starch composites,"* BioResources, vol. 11, no. 3, 2016, doi: 10.15376/biores.11.3.6968-6983.

[31] T. Oniszczuk et al., "Effect of natural fibres on the mechanical properties of thermoplastic starch," *Int. Agrophysics*, vol. 30, no. 2, 2016, doi: 10.1515/intag-2015-0080.

[32] Z. N. Diyana, R. Jumaidin, M. Z. Selamat, and M. S. M. Suan, "Thermoplastic starch/beeswax blend: Characterization on thermal mechanical and moisture absorption properties," *Int. J. Biol. Macromol.*, vol. 190, no. August, pp. 224–232, 2021, doi: 10.1016/j.ijbiomac.2021.08.201.

[33] Z. N. Diyana, R. Jumaidin, M. Z. Selamat, R. H. Alamjuri, and F. A. Yusof, "Extraction and Characterization of Natural Cellulosic Fiber from Pandanus amaryllifolius Leaves," *Polymers (Basel).*, vol. 13, no. 23, p. 4171, 2021, doi: https://doi.org/10.3390/polym13234171.

[34] X. Jiang, Y. Bai, X. Chen, and W. Liu, "A review on raw materials, commercial production and properties of lyocell fiber," *Journal of Bioresources and Bioproducts*, vol. 5, no. 1. 2020. doi: 10.1016/j.jobab.2020.03.002.

[35] A. Kaboorani, N. Gray, Y. Hamzeh, A. Abdulkhani, and Y. Shirmohammadli, "Tailoring the low-density polyethylene - thermoplastic starch composites using cellulose nanocrystals and compatibilizer," *Polym. Test.*, vol. 93, 2021, doi: 10.1016/j.polymertesting.2020.107007.