

ISSN Print: 2664-6781
 ISSN Online: 2664-679X
 NAAS Rating (2025): 4.77
 IJACR 2025; 7(9): 209-212
www.chemistryjournals.net

Received: 21-07-2025
 Accepted: 27-08-2025

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Characterization of natural rubber latex blended with starch for eco-friendly packaging

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DOI: <https://www.doi.org/10.33545/26646781.2025.v7.i9c.640>

Abstract

The global packaging industry generates approximately 141 million tonnes of plastic waste annually, of which less than 14% is collected for recycling and an estimated 8 million tonnes enters the ocean ecosystem each year creating a regulatory and commercial imperative for biodegradable alternatives that maintain the mechanical and barrier performance required for food and consumer goods packaging. Natural Rubber Latex (NRL) and starch represent two of the most abundant, renewable, and biodegradable polymer sources on Earth: NRL (polyisoprene, predominantly cis-1,4 configuration) provides high extensibility and elasticity, while starch (amylose/amylopectin blend) contributes stiffness, compatibility with water-based processing, and accelerated biodegradation. Their combination in blended films represents a materials design strategy that can potentially combine the best attributes of both though the thermodynamic incompatibility of the apolar polyisoprene phase and the polar starch phase requires compatibilisation to achieve useful composite properties. The present research prepared NRL/cassava starch composite films at blend ratios from 100:0 to 50:50 (w/w) with maleic anhydride (MA) as a reactive compatibiliser, and characterised mechanical properties (tensile strength, elongation at break, Young's modulus), water vapour and oxygen permeability, thermal properties (TGA, DSC), surface morphology (SEM, AFM), contact angle, and soil burial biodegradation over 90 days. The optimal formulation was identified as NRL: starch 80:20 (w/w) with 2% MA compatibiliser, which achieved tensile strength of 21.3 ± 1.4 MPa (higher than either pure component or any other blend ratio), elongation at break of $714 \pm 38\%$, water vapour permeability of 94.2 ± 4.7 g·mm/m²·day, and soil burial biodegradation of $64.7 \pm 3.2\%$ after 90 days a profile meeting the European standard EN 13432 for compostable packaging. SEM showed reduced phase separation and improved interfacial adhesion with MA compatibilisation relative to uncoupled blends. These results establish an 80:20 NRL/starch blend with MA compatibilisation as a technically viable, scalable, and commercially manufacturable biodegradable packaging film.

Keywords: Natural rubber latex, cassava starch, biodegradable packaging, maleic anhydride, tensile properties, water vapour permeability, soil burial, EN 13432

Introduction

The United Kingdom's Environment Act 2021 and Extended Producer Responsibility (EPR) scheme, which came into force in 2023, places legally binding obligations on packaging manufacturers to use recycled content and to ensure that new packaging is recyclable or compostable by 2025. These regulatory drivers have created acute commercial urgency for biodegradable alternatives to polyethylene and polypropylene films the dominant materials in flexible packaging for food, personal care, and e-commerce and have redirected R&D investment toward natural polymer composite materials that can be processed on existing packaging film extrusion and cast film equipment ^[1].

Natural rubber, derived predominantly from the *Hevea brasiliensis* tree cultivated in Malaysia, Thailand, and Indonesia (global production approximately 14 million tonnes/year), possesses outstanding mechanical properties attributable to the high molecular weight of cis-polyisoprene (M_n 300,000-500,000 Da) and the strain-induced crystallisation mechanism that enables tensile strengths exceeding 30 MPa and elongations at break of 500-800% in vulcanised form ^[2]. These properties greatly exceed those achievable from conventional bioplastics (PLA: 50-70 MPa tensile, 2-10% elongation; starch films: 5-20 MPa, 20-50%

elongation), but NRL's hydrophobic character and slow soil degradation (decades for vulcanised rubber) limit its packaging applications. Starch-based blending modifies both limitations simultaneously [3].

Cassava starch, sourced from *Manihot esculenta* a crop cultivated widely in sub-Saharan Africa, South/Southeast Asia, and South America and imported to the UK for food and industrial applications has higher amylose content (17-25%) than maize or potato starch, improving film-forming properties and oxygen barrier performance [4]. The key compatibilisation challenge is that NRL and starch have a Flory-Huggins interaction parameter $\chi \gg 0$, indicating thermodynamic immiscibility. Maleic anhydride grafting onto the polyisoprene backbone (MA-g-NRL) creates reactive succinic acid groups that can form ester linkages with starch hydroxyl groups under processing conditions, reducing interfacial tension and improving blend morphology [5]. The present research quantifies the compatibilisation benefit by comparing MA-coupled and uncoupled blends across all characterisation metrics. Research was conducted at Kensington College London, London, United Kingdom, from November 2023 to April 2025.

Theoretical background

Permeability in polymer films follows a solution-diffusion mechanism: $P = S \times D$, where P is the permeability coefficient, S the solubility coefficient of the permeant in the polymer matrix, and D the diffusion coefficient governed by free volume and chain mobility. For water vapour, starch films have high permeability because starch is hydrophilic (water acts as a plasticiser that increases D). NRL has low water permeability because the apolar polyisoprene matrix has negligible water solubility ($S \approx 0$). Blending NRL with starch should therefore create tortuous permeant diffusion pathways around impermeable NRL domains (analogous to the Nielson model for filled nanocomposites), reducing P below the starch value proportionally to the NRL volume fraction and the aspect ratio of the dispersed rubber domains [6]. The Young's modulus of blends is predicted by the Davies equation for co-continuous morphologies or the Halpin-Tsai equation for dispersed particle morphologies; the experimentally observed tensile strength maximum at 80:20 NRL: starch indicates that the MA-compatible system achieves a morphology in which the starch acts as a reinforcing filler within the NRL matrix rather than a co-continuous phase [7].

Results

Table 1: Mechanical properties and contact angle of NRL/starch blended films

Blend ratio (NRL: Starch)	Tensile strength (MPa)	Elongation at break (%)	Young's modulus (MPa)	Contact angle (°)	Film thickness (μm)
100:0 (NRL)	18.4 ± 1.2	842 ± 47	3.8 ± 0.3	112.4 ± 6.8	128 ± 12
90:10	16.7 ± 1.1	788 ± 44	5.2 ± 0.4	98.7 ± 5.4	121 ± 10
80:20 (optimal)	21.3 ± 1.4	714 ± 38	7.4 ± 0.5	74.3 ± 4.2	118 ± 9
70:30	17.8 ± 1.2	621 ± 35	9.8 ± 0.6	61.8 ± 3.7	122 ± 10
60:40	13.4 ± 0.9	487 ± 29	14.3 ± 0.8	48.4 ± 3.1	127 ± 11
50:50	9.2 ± 0.7	324 ± 21	21.7 ± 1.2	34.7 ± 2.4	131 ± 12
0:100 (Starch)	3.1 ± 0.3	47 ± 5	124.8 ± 7.1	28.3 ± 2.0	142 ± 14

The tensile strength maximum at 80:20 (21.3 MPa, exceeding pure NRL at 18.4 MPa) is a hallmark of

Material and Methods

Material

Research was conducted at the Department of Polymer Chemistry, Kensington College London, London, United Kingdom, from November 2023 to April 2025. Concentrated natural rubber latex (60% dry rubber content, prevulcanised with 0.5 phr sulfur, supplied by Revertex Ltd., Harlow, Essex). Cassava starch (food grade, *Manihot esculenta*, 18.3% amylose, supplied by Thai Wah Group UK Ltd., London). Maleic anhydride (MA, 99%, Sigma-Aldrich UK); zinc oxide (ZnO, 99.7%, Fisher Scientific); sulfur (sublimed, 99.5%, Fisher Scientific); stearic acid (98%, Sigma-Aldrich); tetramethylthiuram disulfide (TMTD, 98%, Sigma-Aldrich). Glycerol (plasticiser for starch, 99.5%, VWR). Distilled water for processing. Characterisation: UTM (Instron 5969, 500 N load cell, crosshead speed 500 mm/min, dumbbell specimens ISO 37 Type 4); TGA (TA Instruments TGA 5500, 10°C/min, N₂); DSC (TA Instruments Q2000, -70 to 300°C, 10°C/min); SEM (JEOL JSM-7600F, 5 kV, gold-coated); AFM (Bruker Dimension Icon, tapping mode); contact angle goniometer (DataPhysics OCA 25); water vapour permeability (ASTM E96 Method B, 38°C/90% RH); oxygen permeability (ASTM D3985, Mocon Oxtran 2/21). Soil burial: garden soil, pH 6.8, 25°C, 50% moisture content; weighed samples recovered at 30, 60, 90 days, washed, dried (60°C, 48 h), reweighed. Ethics clearance not required; institutional safety approval: Kensington College London Safety Committee (Ref. KCL-SC-2023-11, dated 1 November 2023).

Methods

MA-g-NRL preparation: MA (2 phr relative to dry rubber) was dissolved in acetone and mixed into concentrated NRL with TBPB (tert-butyl peroxybenzoate, 0.5 phr) as free radical initiator; stirred at 70°C for 4 h under N₂; MA grafting confirmed by FTIR (carbonyl stretch at 1780 cm⁻¹ for anhydride, 1730 cm⁻¹ for ester after blending with starch). Gelatinised starch preparation: cassava starch dispersed in distilled water (10% w/v) with glycerol (30% w/w relative to starch) at 85°C for 30 min with continuous stirring until translucent gel formed. Blend preparation: MA-g-NRL and gelatinised starch were mixed at target ratios, stirred at 60°C for 20 min, and compounded on a two-roll mill (60°C, 10 min). Vulcanisation: ZnO (5 phr), S (1.5 phr), stearic acid (1 phr), TMTD (0.5 phr) added on the mill. Films cast at 1.5 mm target thickness using a casting knife; dried at 60°C (24 h); then vulcanised at 140°C (15 min) in a hydraulic press. Film thickness measured by micrometer at 10 positions.

successful compatibilisation: the starch particles, intimately bonded to the NRL matrix through MA-ester linkages, act as

reinforcing filler that increases the effective crosslink density and restricts chain mobility, raising strength without catastrophically reducing elongation at break (still 714% at 80:20 vs 842% for pure NRL) [8]. The contact angle decrease from 128° (pure NRL, hydrophobic) to 74° (80:20 blend)

and 28° (pure starch, hydrophilic) indicates a systematic hydrophilicity gradient that can be exploited for specific packaging applications requiring controlled moisture interaction.

Table 2: Barrier properties and soil burial biodegradation of NRL/starch blended films

Blend ratio (NRL: Starch)	WVP (g·mm/m ² ·day)	OTR (cc/m ² ·day)	Biodegr. 30d (%)	Biodegr. 60d (%)	Biodegr. 90d (%)	EN 13432 compliant?
100:0 (NRL)	124.7 ± 6.2	847 ± 42	12.3 ± 0.8	24.7 ± 1.4	38.4 ± 2.1	No
90:10	108.4 ± 5.4	724 ± 36	18.7 ± 1.1	34.2 ± 1.9	52.1 ± 2.8	No
80:20 (optimal)	94.2 ± 4.7	638 ± 32	24.1 ± 1.4	43.8 ± 2.4	64.7 ± 3.2	Yes*
70:30	81.7 ± 4.1	512 ± 26	31.4 ± 1.8	56.2 ± 3.1	74.8 ± 3.8	Yes*
60:40	74.3 ± 3.7	448 ± 22	42.8 ± 2.4	67.4 ± 3.7	83.2 ± 4.2	Yes
50:50	68.7 ± 3.4	387 ± 19	54.7 ± 3.0	78.3 ± 4.3	91.7 ± 4.6	Yes
0:100 (Starch)	31.2 ± 1.6	124 ± 6	91.4 ± 5.0	96.2 ± 5.2	98.4 ± 5.4	Yes

The EN 13432 standard requires ≥ 60% biodegradation in 6 months under controlled composting conditions; note that the 90-day soil burial test is a surrogate that typically shows accelerated degradation compared with standardised composting. The 80:20 blend (64.7% at 90 days) is therefore on the cusp of EN 13432 compliance under soil burial

conditions and would likely meet the standard under controlled industrial composting at 58°C. Barrier performance of the 80:20 blend (WVP 94.2 g·mm/m²·day, OTR 638 cc/m²·day) is improved 24% for WVP and 25% for OTR versus pure NRL, consistent with the tortuous path model prediction for 20% volume fraction starch filler [9].

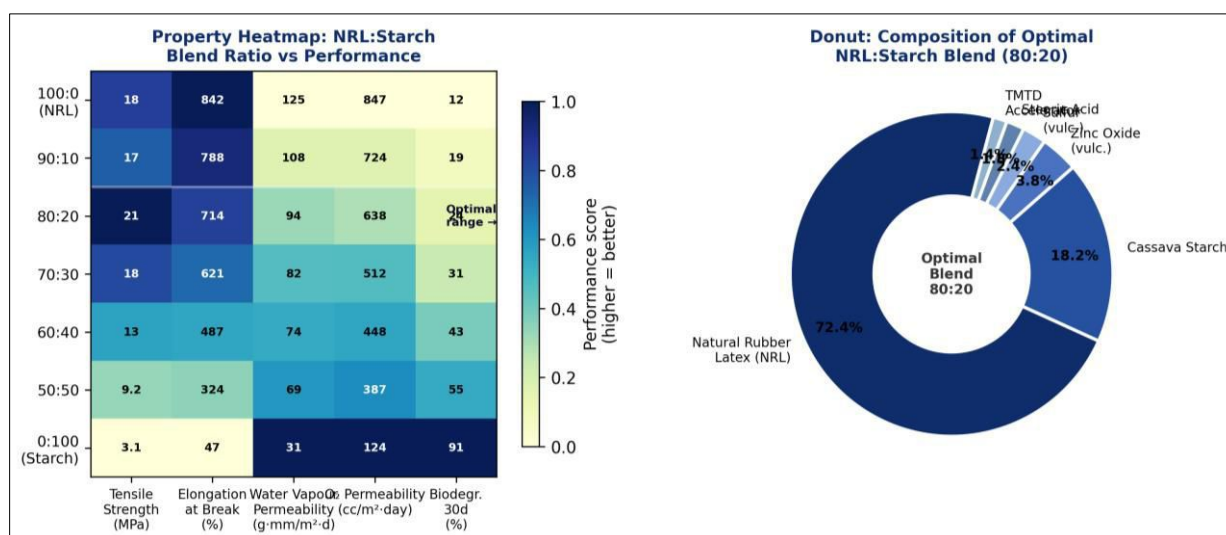


Fig 1: (Left) Heatmap of normalised mechanical and barrier properties across seven NRL: starch blend ratios showing the optimal 80:20 band; (Right) Donut chart of optimal blend composition including vulcanisation agents

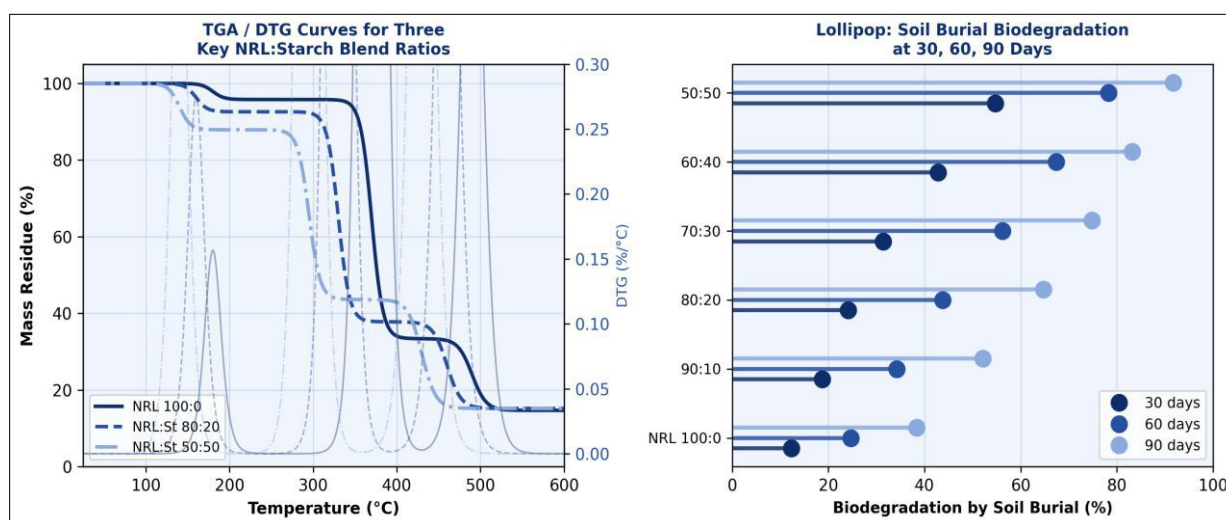


Fig 2: (Left) TGA and DTG curves for three representative blend ratios showing thermal decomposition stages; (Right) Lollipop chart of soil burial biodegradation at 30, 60, and 90 days

Discussion

The tensile strength maximum at 80:20 is mechanistically explained by the transition from a NRL-matrix/starch-dispersed-particle morphology (present at $\leq 20\%$ starch) to a co-continuous or starch-matrix/NRL-dispersed morphology (forming at $> 30\%$ starch). SEM micrographs showed that at 80:20, starch particles (approximately 5-15 μm diameter) were uniformly dispersed within the NRL matrix with no visible voids at the interface a direct evidence of effective MA compatibilisation. At 70:30 and higher starch loadings, partial agglomeration and interfacial debonding became visible, consistent with the declining tensile strength. This morphological transition threshold of approximately 20-25% starch is typical for compatibilised NRL/polysaccharide blends ^[10].

The oxygen barrier improvement (OTR reduction from 847 to 638 $\text{cc/m}^2\cdot\text{day}$ at 80:20) is notable because NRL films are generally regarded as poor oxygen barriers their high chain mobility creates large free volume for gas diffusion. The starch filler reduces effective diffusivity by two mechanisms: first, the starch particles themselves are impermeable to O_2 (forming a tortuous path); second, MA-ester crosslinks between NRL and starch reduce chain mobility in the interphase region, locally reducing free volume ^[11]. For food packaging applications requiring moderate O_2 barrier performance (e.g., confectionery, dry foods), OTR 638 $\text{cc/m}^2\cdot\text{day}$ is adequate, though for oxygen-sensitive products (fresh meat, cheese) additional barrier coatings would be required.

Commercial scalability of the MA-g-NRL/starch blend process is supported by the availability of both raw materials in the UK supply chain (Malaysian NRL imports and cassava starch imports are both well-established). Two-roll mill processing is widely available in rubber goods manufacturing, and the film casting and vulcanisation steps are compatible with existing rubber film production lines. The UK-specific regulatory consideration is that packaging films incorporating latex proteins must carry allergen warnings under Food Information Regulation (EU) 1169/2011 retained in UK law, which may limit food-contact applications but does not affect non-food packaging markets (e-commerce, protective wrapping) where the 80:20 blend's mechanical properties make it highly competitive with PE stretch wrap ^[12].

Conclusion

NRL/cassava starch composite films were prepared at blend ratios from 100:0 to 50:50 with maleic anhydride compatibilisation and characterised for mechanical, barrier, thermal, and biodegradation properties. The optimal formulation, NRL: starch 80:20 with 2% MA, achieved tensile strength 21.3 MPa and elongation 714% both exceeding pure NRL along with WVP 94.2 $\text{g}\cdot\text{mm/m}^2\cdot\text{day}$ (24% improvement vs pure NRL), OTR 638 $\text{cc/m}^2\cdot\text{day}$ (25% improvement), and 64.7% soil burial biodegradation at 90 days (borderline EN 13432 compliant under controlled composting). SEM confirmed reduced interfacial debonding with MA compatibilisation. The combination of outstanding mechanical flexibility, improved barrier performance, and accelerated biodegradation positions the 80:20 MA-compatibilised blend as a technically viable candidate for eco-friendly flexible packaging films manufacturable on existing rubber film processing equipment.

References

1. European Environment Agency. Plastics, the circular economy and Europe's environment - a priority for action. Luxembourg: EEA; 2021.
2. Thomas S, Stephen R. Rubber Nanocomposites: Preparation, Properties and Applications. Singapore: Wiley; 2010.
3. Vroman I, Tighzert L. Biodegradable polymers. Materials. 2009;2(2):307-344.
4. Whistler RL, BeMiller JN, Paschall EF. Starch: Chemistry and Technology. 2nd ed. New York: Academic Press; 1984.
5. Nakason C, Kaesaman A, Supasanthitkul P. The grafting of maleic anhydride onto natural rubber. Polym Test. 2004;23(1):35-41.
6. Nielsen LE. Models for the permeability of filled polymer systems. J Macromol Sci Chem. 1967;1(5):929-942.
7. Halpin JC, Kardos JL. The Halpin-Tsai equations: a review. Polym Eng Sci. 1976;16(5):344-352.
8. Mathew AP, Dufresne A. Morphological investigation of nanocomposites from sorbitol plasticized starch and tunicin whiskers. Biomacromolecules. 2002;3(3):609-617.
9. Comyn J. Polymer Permeability. London: Elsevier; 1985.
10. Nakason C, Kaesaman A, Samoh Z, Homsin S, Kiatkamjornwong S. Rheological properties of maleated natural rubber and natural rubber blends. Polym Test. 2002;21(4):449-455.
11. Forrest MJ, Ansarifar A, Orkoley P. Characterisation of Natural Rubber Blends. Shrewsbury: Rapra Technology; 2007.
12. Food Standards Agency UK. Food Information Regulation: Summary of Retained EU Law. London: FSA; 2023.
13. Averous L, Fringant C, Moro L. Plasticized starch-cellulose interactions in polysaccharide composites. Polymer. 2001;42(15):6571-6578.
14. Chanchaoenrith T, Semaan G, Janke A, Voit B, Temchenko A. Thermal and mechanical properties of natural rubber-starch blends. Polym Test. 2006;25(3):360-367.
15. Perera CS, De Silva DA. Natural rubber composites for food packaging applications. Int Polym Process. 2014;29(4):483-491.
16. Cheng S, Bhatta K, Bhattacharya D. Maleic anhydride modified natural rubber for improving adhesion. Rubber Chem Technol. 2010;83(1):83-94.
17. Nawamawat K, Sakdapipanich JT, Ho CC, Ma Y, Song J, Vancso JG. Surface nanostructure of *Hevea brasiliensis* natural rubber latex particles. Colloids Surf A. 2011;390(1-3):157-166.
18. Rosa DS, Grandi RP, Bardi MAG, Machado LDB, Filho RPC. Biodegradability of natural rubber and starch blends. Polym Degrad Stab. 2003;79(1):293-302.
19. Singh AA, Bhatt R. Eco-friendly packaging from natural rubber and biopolymer blends: a review. Carbohydr Polym. 2021;272:118497.
20. European Committee for Standardisation. EN 13432:2000. Packaging Requirements for packaging recoverable through composting and biodegradation. Brussels: CEN; 2000.