Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Monosodium Glutamate-Modified Polyamides: Thermal Properties, Water Uptake, and Mass Loss during Compost Exposure

Yu Tung Hsu
Chinese Culture University
Chiu Chun Lai
lqj2@ulive.pccu.edu.tw

Chinese Culture University
Ming Chih Kuo
Chinese Culture University
Kang-Yun Chu
Chinese Culture University

Research Article

Keywords: Bio-based polyamides, Monosodium glutamate, Hot-melt adhesives, Thermal properties, Biodegradability

Posted Date: November 17th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11611421/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Monosodium Glutamate-Modified Polyamides: Thermal Properties, Water Uptake, and Mass Loss during Compost Exposure

[1]Yu-Tung Hsu, [1] Chiu-Chun Lai[*], [1]Ming-Chih Kuo, [1]Kang-Yun Chu

[1]Department of Textile Engineering, Chinese Culture University, Taipei City, Taiwan

[*] Corresponding author: Chiu-Chun Lai

Tel: +886-2-28610511#33401

Email: lqj2@ulive.pccu.edu.tw

Abstract

Novel bio-based polyamide hot-melt adhesives modified with monosodium glutamate (MSG) were successfully synthesized via a sustainable melt polycondensation approach. The structural, thermal, physical, and biodegradable properties of these copolymers were systematically evaluated using FTIR, DSC, TGA, contact angle measurements, and composting tests. FTIR confirmed successful MSG incorporation into the polymer backbone without disrupting its fundamental structure. Although adding MSG and modifying aliphatic carbon chain lengths slightly altered initial thermal stability and melting temperatures, optimized formulations—particularly those with 10 wt % MSG (such as HOG10 and HSG10)—exhibited balanced crystallization behavior and robust thermal profiles. Furthermore, physical characterizations demonstrated that MSG incorporation and shorter dicarboxylic acid segments enhanced surface hydrophilicity and water absorption. Crucially, compost exposure tests revealed that increasing MSG content and aliphatic chain flexibility significantly accelerated environmental weight loss and degradation rates. This study provides a promising, eco-friendly pathway for developing bio-renewable polyamide adhesives with tailored thermal and biodegradable performance.

Keywords：Bio-based polyamides, Monosodium glutamate, Hot-melt adhesives, Thermal properties, Biodegradability

Introduction

Polyamides (PAs) represent one of the earliest commercialized and most robust synthetic polymers, finding widespread applications in engineering plastics, industrial fibers, automotive interiors, and protective textiles due to their exceptional mechanical strength, wear resistance, and chemical stability. Among them, Polyamide 66 (PA66) is the most prominent, characterized by a high concentration of repeating methylene-to-amide ratios and uniform interchain spacing. These structural features promote extensive intermolecular hydrogen bonding, conferring high rigidity and tensile strength [1, 2]. However, this high degree of crystallinity and hydrogen bonding often leads to inherent drawbacks, including high brittleness, poor impact resistance, and elevated melting temperatures that complicate thermal processing and increase the risk of thermal degradation or discoloration [3].

In response to global environmental concerns and the imperative to reduce dependency on fossil-derived feedstocks, the development of bio-based and sustainable polyamides has gained substantial academic and industrial interest. Renewable resources such as vegetable oils and plant-derived derivatives offer promising alternatives for synthesizing eco-friendly polymers. In particular, long-chain polyamides derived from dimer fatty acids have emerged as exceptional candidates for hot-melt adhesives, functional coatings, and flexible packaging [4]. Due to their longer aliphatic segments and lower density, dimer acid-based polyamides typically exhibit reduced melting points, lower moisture permeability, and enhanced processability compared to conventional PA66, making them ideal for compounding with heat-sensitive natural materials.

Despite their favorable processing characteristics and bio-derived nature, conventional polyamides often suffer from slow environmental degradation rates, limiting their end-of-life circularity. To address this limitation, incorporating natural, biodegradable additives into the polymer backbone represents an effective modification strategy. Monosodium glutamate (MSG), a naturally occurring, water-soluble, and cost-effective amino acid salt, contains active functional groups capable of participating in polymer structuring [5].

This study aims to synthesize and characterize a novel series of bio-based polyamide hot-melt adhesives modified with monosodium glutamate (MSG). By introducing MSG into various polyamide formulations, the effects of MSG concentration, aliphatic carbon chain length, and acid-to-amine molar ratios on the structural, thermal, physical, and biodegradable properties of the resulting copolymers were systematically investigated. This approach provides a sustainable pathway for developing high-performance, eco-friendly polyamide adhesives with tailored thermal and degradation characteristics.

Materials and Methods

Adipic acid ($C_6H_{10}O_4$, molecular weight [Mw]:146.14 g/mol), sebacic acid ($C_{10}H_{18}O_4$, Mw: 202.25 g/mol), and C36 dimer acid ($C_{36}H_{68}O_4$, Mw: 560.91 g/mol) were used as dicarboxylic acid components. 1,6-Hexanediamine ($C_6H_{16}N_2$, Mw: 116.20 g/mol) served as the diamine monomer. Monosodium glutamate (MSG, $C_5H_8NO_4Na$, Mw: 169.11 g/mol) was incorporated

as a bio-based modifying agent. Antioxidant 4500 was supplied by Chang Jiang Chemical Co., Ltd. (Taiwan). High-purity nitrogen gas (N_2, Mw:28.01 g/mol) was used as an inert protective atmosphere during the polymerization process. All reagents and chemicals were used as received without further purification.

Synthesis of MSG-Modified Polyamide Copolymers

illustrated in Figure 1, with the detailed feed ratios and sample codes summarized in Table 1. The bio-based polyamides were prepared via a melt polycondensation technique. Predetermined amounts of dicarboxylic acid components—including 1,6-hexanediamine (HMDA) and various dicarboxylic acids as specified in Table 1—along with a catalytic amount of Antioxidant 4500, were charged into a four-necked round-bottom flask equipped with a mechanical stirrer, a nitrogen inlet, and a vacuum system. To remove residual oxygen and moisture, the reaction system was evacuated and purged with high-purity nitrogen gas. The mixture was then heated to 190 °C under a continuous nitrogen atmosphere, and pre-polymerization was carried out for 3 hours with constant mechanical stirring.

Following the pre-polymerization stage, a specified weight percentage of monosodium glutamate (MSG)—ranging from 0 to 20 wt% as detailed in Table 1—was introduced into the molten mixture. The subsequent polycondensation reaction was continued at 190 °C for an additional 1 hour. Upon completion, the resulting polymer melt was extruded into a 25 °C water bath for rapid strand solidification. The solidified strands were pelletized into small fragments, dried in an oven at 70 °C for 24 hours to remove residual moisture, and stored in a desiccator prior to further characterization.

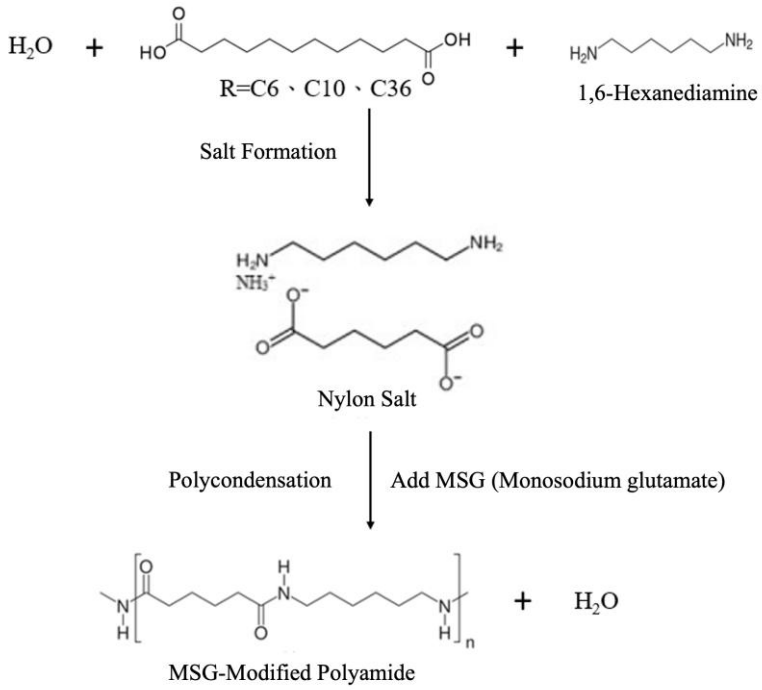


Figure 1. Schematic illustration of the synthesis route for the monosodium glutamate (MSG)-modified polyamide copolymers.

Table 1. Sample codes and feed ratios of the synthesized polyamide copolymers.

Sample code	Molar ratio				Weight percentage (%)	Appearance
	Hexamethylenediamine (H)	C_{36} Dimer Acid (O)	Sebacic acid (S)	Hexanedioic acid (A)	Monosodium glutamate (G)	
HOG	1	1	-	-	0	Transparent
HOG5	1	1	-	-	5	Transparent
HOG10	1	1	-	-	10	Pale yellow translucent
HOG20	1	1	-	-	20	Yellow translucent
HA	1	-	-	1	0	Gray
HAG10	1	-	-	1	10	Dark yellow
HSG10	1	-	1	-	10	Orange-yellow
HOG10	1	1	-	-	10	Yellow translucent
HhSG10	1.1	-	1	-	10	White
HSG10	1	-	1	-	10	Orange-yellow
HshG10	1	-	1.1	-	10	Pale yellow

Characterization and Measurements

Fourier Transform Infrared Spectroscopy (FTIR)

The chemical structures and functional groups of the synthesized polyamide copolymers were analyzed using a Fourier Transform Infrared (FTIR) spectrometer (Spectrum Two, PerkinElmer Co., Ltd.). The spectra were recorded in the wavenumber range of 4000 to 400 cm^{-1} at room temperature.

Differential Scanning Calorimetry (DSC)

The thermal properties, including the melting temperature (Tm) and melting enthalpy (ΔHm), of the copolymers were evaluated using a Differential Scanning Calorimeter (DSC Q20, TA Instruments). Samples were first heated from 30℃ to 300℃ at a heating rate of 10℃/min under a nitrogen atmosphere to eliminate thermal history. They were subsequently cooled to 30℃ at 10℃/min and reheated to 300℃ at the same rate to record data from the second heating scan.

Thermogravimetric Analysis (TGA)

The thermal stability and degradation behavior of the synthesized products were investigated using a Thermogravimetric Analyzer (TGA Q50, TA Instruments). Samples were placed on a platinum pan and heated from 30℃ to 600℃ at a heating rate of 10℃/min under a continuous nitrogen purge.

Water Absorption Test

To determine the water absorption capacity, approximately 5 g of each sample was dried in an oven at 80℃ for 24 hours until a constant weight (W_d, dry weight) was achieved. The dried samples were then immersed in ultrapure water for 24 hours and 48 hours at room

temperature. After immersion, the surface moisture was gently removed using filter paper, and the wet weight (W_w) was recorded. The water absorption rate was calculated using the following equation:

$$\text{Water absorption (\%)} = \frac{Ww - Wd}{Wd} \text{ x 100 \%}$$

Contact Angle Measurements

The surface wettability of the prepared polyamide plates was evaluated using a drop shape analysis system (DSA 10 Mk2, Oldenburg Co., Ltd.). Water droplets were dropped onto the sample surfaces via a micro-syringe, and the static contact angles were measured and recorded.

Biodegradability Analysis

The biodegradation behavior of the samples was evaluated with reference to the CNS 14432 standard under natural composting conditions. The degree of plastic disintegration and weight loss were monitored and recorded at 30-day intervals over a total period of 60 days. Environmental parameters, including moisture content, temperature, and soil pH, were systematically documented throughout the test.

Results and Discussion

FTIR Spectral Analysis of Polyamide Copolymers

Fourier transform infrared (FTIR) spectroscopy was employed to identify the characteristic functional groups and confirm the chemical structures of the synthesized polyamide copolymers. Figures 2 (a-c) present the FTIR spectra of the polyamides with varying monosodium glutamate (MSG) contents, aliphatic carbon chain lengths, and acid-to-amine molar ratios, respectively. Across all spectra, typical characteristic absorption bands of polyamides are clearly observable: the N–H stretching vibration appears at approximately 3303 cm^{-1}, the asymmetric and symmetric C–H stretching vibrations of methylene groups are detected at around 2925 cm^{-1} and 2855 cm^{-1}, respectively, the characteristic amide I band (C=O stretching vibration) is located at 1632 cm^{-1}, and the amide II band (combining N–H in-plane bending and C–N stretching vibrations) appears at 1536 cm^{-1} [6]. In addition, the absorption bands around 1465 cm^{-1} and 1262 cm^{-1} correspond to the scissoring and twisting vibrations of $-CH_2-$ groups, respectively [7,8].

As shown in Figure 2 (a), with the progressive incorporation of MSG, a broad absorption band emerges in the region of 3350 to 3650 cm^{-1}, which becomes increasingly pronounced at higher MSG concentrations. This broad band is primarily attributed to the hydrogen-bonded N–H and OH stretching vibrations associated with the amino acid structure of MSG. Notably, no extraneous or new prominent peaks are generated upon MSG addition, indicating that the characteristic absorption peaks of MSG structurally overlap with those of the polyamide matrix without disrupting the fundamental polymer backbone [9].

Similarly, Figure 2 (b) illustrates the influence of varying dicarboxylic acid chain lengths (C6, C10, and C36) on the FTIR spectra. Sample HAG10 exhibits a significantly broadened

band in the 3350 to 3650 cm^{-1} regions compared to HA, which is attributed to the presence of MSG and enhanced hydrogen-bonding interactions within the adipic acid-based matrix. Furthermore, Figure 2 (c) displays the spectra of copolymers prepared with different acid-to-amine molar ratios containing 10 wt % MSG. Sample HhSG10 exhibits a more distinct and broadened band in the 3350 to 3650^{-1} region. This can be ascribed to the higher amine content (an asymmetric 1.1:1 ratio), which introduces excess amine groups and enhances interactions with the MSG modifier, thereby intensifying the hydroxyl and amino-related stretching absorption.

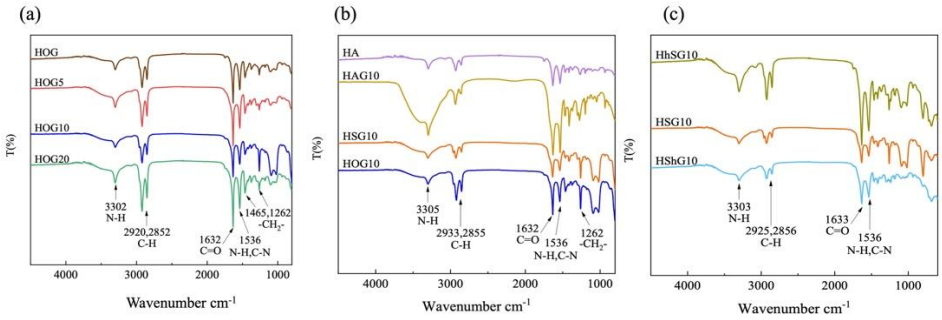


Figure 2. (a). FTIR spectra of polyamide copolymers with varying monosodium glutamate (MSG) contents. (b). FTIR spectra of polyamide copolymers with different dicarboxylic acid carbon chain lengths. (c). FTIR spectra of polyamide copolymers with various acid-to-amine molar ratios.

Thermal Properties Analysis

Differential scanning calorimetry (DSC) was employed to evaluate the thermal transitions and crystallization behavior of the synthesized polyamide copolymers. Figures 3 (a-c) illustrate the DSC heating curves of the polyamides with varying MSG contents, dicarboxylic acid carbon chain lengths, and acid-to-amine molar ratios, respectively.

As shown in Figure 3(a), the incorporation of MSG and the variation in chain length significantly affect the melting behavior. Specifically, looking at the structural comparison in Figure 3(b), the melting temperature (T_m) decreases substantially with increasing aliphatic chain length from adipic acid (C6) to sebacic acid (S) and C36 dimer acid (O). This trend may be associated with the longer methylene sequences and lower amide-group density, together with the structural heterogeneity and flexibility of the C36 dimer-acid-derived segments, which can hinder ordered chain packing [10,11]. Notably, sample HOG10 exhibits a drastically reduced melting enthalpy (ΔHm) compared to HA and HSG10, primarily because the irregular, branched structure and unsaturation of the C36 dimer acid hinder chain folding and lower overall crystallinity [10].

Figure 3(c) displays the DSC thermograms of copolymers prepared with different acid-to-amine molar ratios (HhSG10, HSG10, and HShG10). The stoichiometric sample with an equimolar ratio (HSG10) exhibits a well-defined melting peak with a higher melting enthalpy, indicating a more regular crystal lattice and optimized structural packing compared to off-stoichiometric compositions.

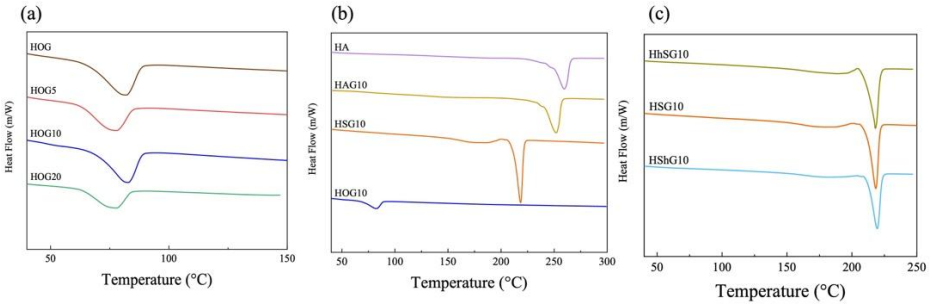


Figure 3. (a). DSC heating curves of polyamide copolymers with varying monosodium glutamate (MSG) contents. (b). DSC heating curves of polyamide copolymers with different dicarboxylic acid carbon chain lengths. (c). DSC heating curves of polyamide copolymers with various acid-to-amine molar ratios.

Thermal Properties and Melting Behavior of Polyamide Copolymers

The melting temperature (Tm) and melting enthalpy (ΔHm) of the synthesized polyamide copolymers, extracted from DSC thermograms, are summarized in Table 2. Figures 4 (a-c) illustrate the influence of monosodium glutamate (MSG) content, dicarboxylic acid carbon chain length, and acid-to-amine molar ratio on these thermal parameters, respectively.

As shown in Figure 4 (a) and Table 2, the addition of MSG causes slight fluctuations in Tm (ranging from 77.77℃ to 82.85℃ for the C36 dimer acid series), while ΔHm reaches a maximum at 10 wt % MSG (HOG10, 18.77 J/g), indicating an optimized balance of intermolecular interactions and crystallinity at this composition.

Figure 4 (b) demonstrates the profound effect of the dicarboxylic acid carbon chain length on the thermal behavior. Both Tm and ΔHm decrease drastically as the carbon number increases from adipic acid (C6, sample HA at 259.57℃) to sebacic acid (C10, sample HSG10 at 218.39℃) and C36 dimer acid (C36, sample HOG10 at 82.85℃). This downward trend is attributed to the increased flexibility of longer methylene sequences and the bulky, irregular structure of the C36 dimer acid, which significantly hinders regular chain folding and packing, thereby reducing crystallinity [12].

Furthermore, Figure 4 (c) presents the effect of varying the acid-to-amine molar ratio ($COOH/NH_2$) from 0.9 (HhSG10) to 1.1 (HShG10). The melting enthalpy reaches its highest value (69.20 J/g) at the stoichiometric equimolar ratio ($COOH/NH_2$ = 1.0, sample HSG10), signifying a well-balanced molecular weight and a more ordered crystal lattice structure [13]. Off-stoichiometric ratios lead to chain-end imbalances that restrict crystal growth, lowering the overall melting enthalpy.

Table 2. Melting temperature (Tm) and melting enthalpy (ΔHm) data of the synthesized polyamide copolymers.

Sample	Tm(°C)	Melting enthalpy ΔH(J/g)
HOG	82.00	14.42
HOG5	78.81	10.66
HOG10	82.85	18.77
HOG20	77.77	8.203
HA	259.57	79.08
HAG10	252.02	66.44
HSG10	218.39	69.20
HOG10	82.85	18.77
HhSG10	218.05	65.64
HSG10	218.39	69.20
HShG10	219.50	52.56

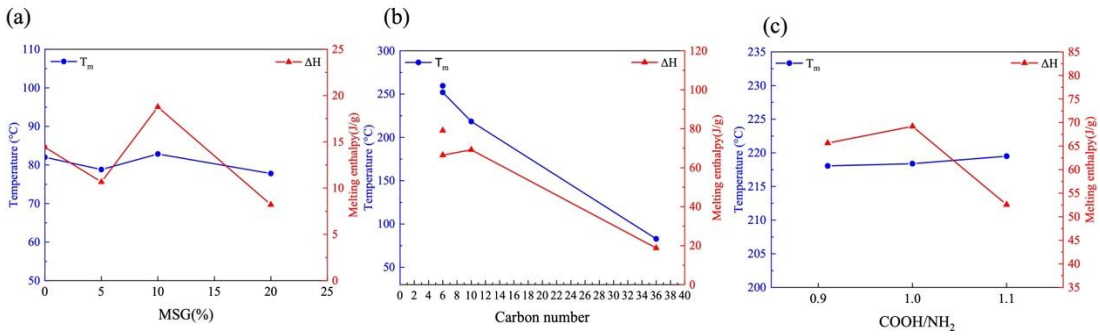


Figure 4. (a). Trends in melting temperature and melting enthalpy of polyamide copolymers with varying monosodium glutamate (MSG) contents. (b). Trends in melting temperature and melting enthalpy of polyamide copolymers with different dicarboxylic acid carbon chain lengths. (c). Trends in melting temperature and melting enthalpy of polyamide copolymers with various acid-to-amine molar ratios ($COOH/NH_2$).

Thermal Stability and Thermogravimetric Analysis (TGA)

The thermal stability and degradation behavior of the synthesized polyamide copolymers were evaluated using thermogravimetric analysis (TGA). Table 3 summarizes the characteristic decomposition temperatures at 5 wt % and 50 wt % weight loss (Td,5 and Td,50, respectively), while Figure 5 presents the overall TGA thermograms. Furthermore, Figures 6 (a-c) illustrate the effects of monosodium glutamate (MSG) content, dicarboxylic acid chain length, and acid-to-amine molar ratio on the thermal degradation trends.

As shown in Figure 6 (a) and Table 3, the incorporation of MSG leads to a moderate decrease in the initial decomposition temperature (Td,5). This reduction is primarily attributed to the lower thermal stability of the amino acid-derived segments and the release of bound moisture or early-stage thermal transitions associated with the MSG modifier relative to the neat polyamide backbone [14]. However, the bulk thermal stability (Td,50) remains relatively stable across varying MSG concentrations, indicating that the primary polymer network is successfully formed and preserved.

Figure 6 (b) demonstrates the influence of the dicarboxylic acid carbon chain length. Sample HAG10 exhibits lower decomposition temperatures compared to HSG10 and HOG10. This behavior is attributed to the rigid, highly crystalline structure of the adipic acid-based segment combined with MSG modification, which creates specific packing defects or localized

thermal sensitivities, whereas longer methylene sequences or branched structures modulate the degradation profile differently.

Additionally, Figure 6 (c) displays the effect of the acid-to-amine molar ratio ($COOH/NH_2$). The stoichiometric equimolar ratio ($COOH/NH_2$ = 1.0, sample HSG10) and slightly amine-rich compositions exhibit favorable thermal resistance, as stoichiometric balance ensures optimal molecular weight and structural integrity, minimizing vulnerable chain ends that typically initiate premature thermal degradation [15].

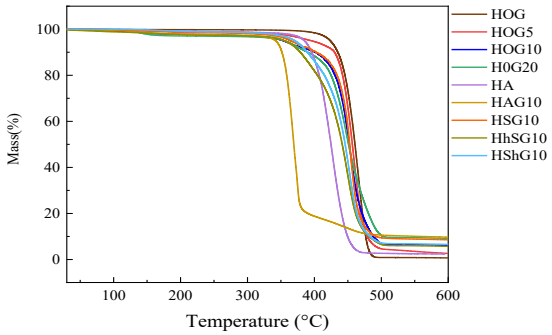


Figure 5. TGA thermograms of the synthesized polyamide copolymers.

Table 3. Thermal degradation temperatures (Td,5 and Td,50) of the synthesized polyamide copolymers.

Sample	Td5(°C)	Td50(°C)
HOG	423.78	460.59
HOG5	395.45	456.74
HOG10	353.47	452.28
HOG20	355.26	450.93
HA	384.93	424.77
HAG10	341.95	369.25
HSG10	364.39	452.75
HOG10	353.47	452.28
HhSG10	355.11	441.61
HSG10	364.39	452.75
HShG10	370.85	446.02

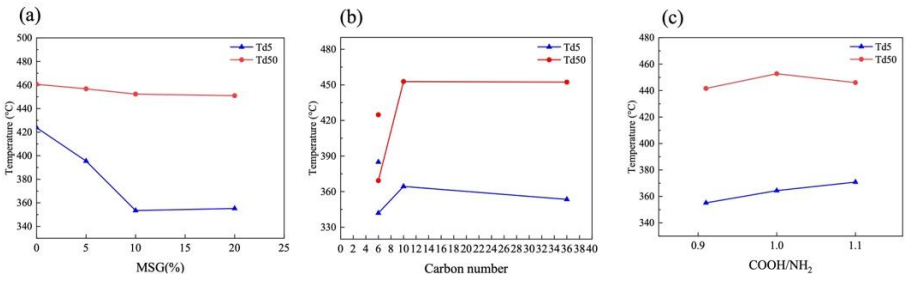


Figure 6. (a). Trends in Td,5 and Td,50 of polyamide copolymers with varying monosodium glutamate (MSG) contents. (b). Trends in Td,5 and Td,50 of polyamide copolymers with different dicarboxylic acid carbon chain lengths. (c). Trends in Td,5 and Td,50 of polyamide copolymers with various acid-to-amine molar ratios ($COOH/NH_2$).

Surface Properties and Water Absorption Behavior

The surface wettability and water absorption characteristics of the synthesized polyamide copolymers were evaluated via contact angle measurements and water absorption tests at 24 and 48 hours. Table 4 summarizes the numerical data, while Figures 7 (A-C) show the contact angle profile images, and Figures 8 (a-c) display the trends against MSG content, dicarboxylic acid carbon chain length, and acid-to-amine molar ratio, respectively.

As shown in Figure 8 (a-c) and Table 4, the water absorption of the C36 dimer acid-based polyamides remains relatively low (<2%) and changes only slightly with increasing monosodium glutamate (MSG) content. This is primarily attributed to the long, hydrophobic aliphatic chains of the C36 dimer acid, which restrict water penetration. However, the contact angle first increases from 97.1° (HOG) to 101.0° (HOG5) and 100.7° (HOG10), then decreases to 93.8° for HOG20. This initial increase is likely due to morphological reorganization, whereas the decrease at higher MSG loadings (HOG20) stems from the surface segregation of excess hydrophilic MSG components that fail to uniformly integrate into the polymer matrix [16].

Figure 8 (b) demonstrates the profound effect of dicarboxylic acid carbon chain length (comparing HA, HAG10, HSG10, and HOG10). Water absorption decreases drastically as the carbon number increases from C6 (adipic acid, sample HAG10 at 9.34% at 48h) to C10 (sebacic acid, HSG10) and C36 (dimer acid, HOG10). Concurrently, the water contact angle increases significantly from 44.2° (HAG10) to 76.1° (HSG10) and 100.7° (HOG10). This trend confirms that shorter methylene sequences reduce steric hindrance and increase the concentration of polar amide/carboxyl groups accessible to water molecules, thereby enhancing hydrophilicity.

Furthermore, Figure 8 (c) illustrates the impact of the acid-to-amine molar ratio ($COOH/NH_2$). The water absorption decreases as the ratio increases from 0.9 (HhSG10) to 1.1 (HShG10). This occurs because an excess of dicarboxylic acid introduces a higher fraction of hydrophobic aliphatic segments, reducing overall polarity. The contact angle reaches a local minimum at the stoichiometric balance ($COOH/NH_2 = 1.0$, sample HSG10 at 76.1°), indicating optimal and uniform dispersion of polar groups within the structured matrix, whereas off-stoichiometric imbalances (HhSG10 and HShG10) alter surface energy and increase contact angles.

Table 4. Water absorption (24 h and 48 h) and contact angle data of the synthesized polyamide copolymers.

Sample	Water Absorption (%)		Contact angle (°)
	24 h	48 h	
HOG	1.91	1.94	97.1
HOG5	1.80	1.91	101.0
HOG10	1.42	1.63	100.7
HOG20	1.23	1.56	93.8
HA	2.94	3.37	75.4
HAG10	8.90	9.34	44.2
HSG10	2.96	4.06	76.1
HOG10	1.42	1.63	100.7
HhSG10	7.10	8.50	86.1
HSG10	2.96	4.06	76.1
HShG10	1.11	1.14	82.8

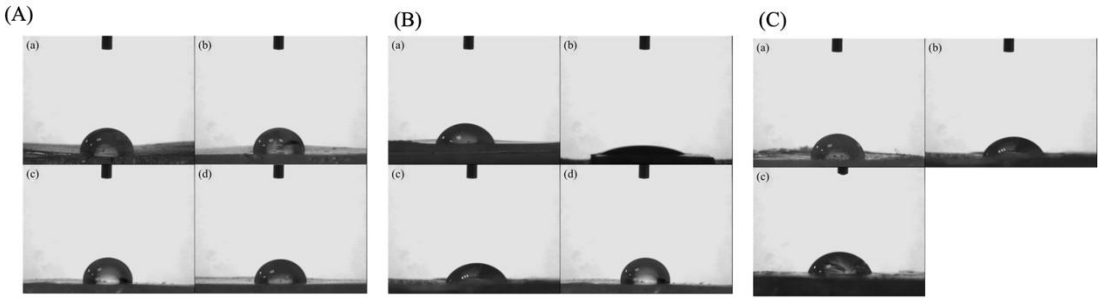


Figure 7. (A). Water contact angle images of polyamide copolymers with varying MSG contents: (a) HOG, (b) HOG5, (c) HOG10, and (d) HOG20. (B). Water contact angle images of polyamide copolymers with different dicarboxylic acid carbon chain lengths: (a) HA, (b) HAG10, (c) HSG10, and (d) HOG10. (C). Water contact angle images of polyamide copolymers with various acid-to-amine molar ratios: (a) HhSG10, (b) HSG10, and (c) HShG10.

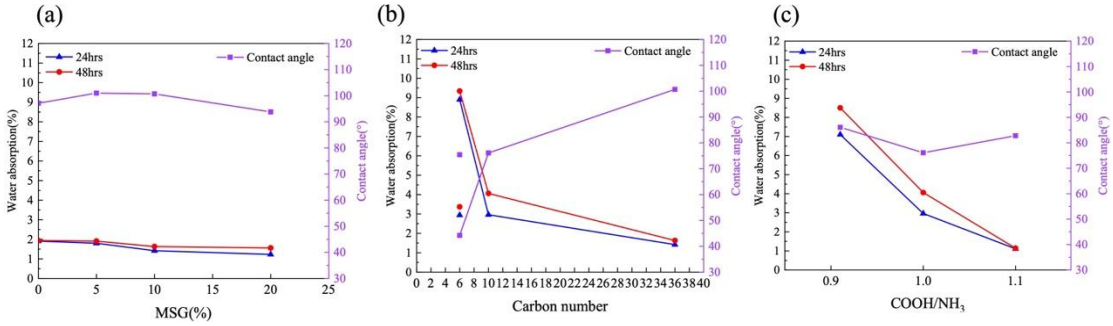


Figure 8. (a). Trends in water absorption and contact angle of polyamide copolymers with varying MSG contents. (b). Trends in water absorption and contact angle of polyamide copolymers with different dicarboxylic acid carbon chain lengths. (c). Trends in water absorption and contact angle of polyamide copolymers with various acid-to-amine molar ratios ($COOH/NH_2$).

Biodegradability Analysis

The biodegradability of the synthesized polyamide copolymers was evaluated by monitoring the residual weight percentage over a 60-day period. As shown in Figure 9 (a), the weight loss increases with higher monosodium glutamate (MSG) content, as the incorporation of bio-based and hydrophilic MSG segments enhances moisture accessibility and susceptibility to microbial attack [17]. Similarly, Figure 9 (b) demonstrates that samples with longer dicarboxylic acid carbon chain lengths (such as C36 dimer acid in HOG10) exhibit higher biodegradability than adipic acid-based samples (HA). This is attributed to the lower crystallinity and increased chain flexibility of longer aliphatic sequences, which facilitate hydrolytic and enzymatic cleavage [18].

Furthermore, Figure 9 (c) illustrates the effect of the acid-to-amine molar ratio ($COOH/NH_2$), where sample HhSG10 displays a slightly greater weight loss due to an increased fraction of terminal groups that promote early hydrolytic degradation. Overall, the incorporation of MSG and tailored aliphatic chain lengths successfully improves the environmental degradability of the polyamide copolymers.

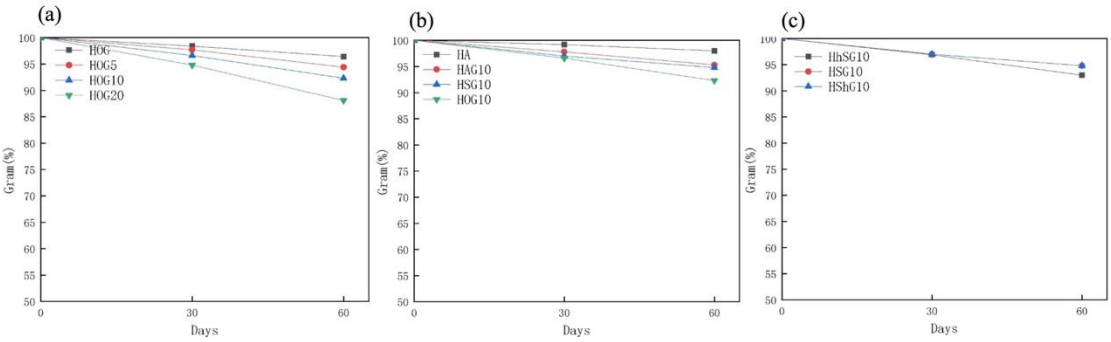


Figure 9. (a). Biodegradation weight loss trends of polyamide copolymers with varying monosodium glutamate (MSG) contents. (b). Biodegradation weight loss trends of polyamide copolymers with different dicarboxylic acid carbon chain lengths. (c). Biodegradation weight loss trends of polyamide copolymers with various acid-to-amine molar ratios ($COOH/NH_2$).

Conclusions

This study successfully synthesized bio-based polyamide copolymers containing monosodium glutamate (MSG) and various dicarboxylic acids [19]. FTIR spectroscopy confirmed the successful polymerization of the polyamide structure. Thermal analyses revealed that while the incorporation of MSG and variations in the acid-to-amine molar ratio slightly reduced initial thermal stability and melting temperatures due to disruptions in regular chain packing, the optimized compositions—specifically HOG10 and HSG10—demonstrated excellent thermal properties with maximized melting enthalpies.

Furthermore, physical property evaluations indicated that MSG incorporation and shorter dicarboxylic acid carbon chain lengths enhance water absorption and surface hydrophilicity. Crucially, the biodegradability tests demonstrated that the introduction of bio-based MSG segments and increased aliphatic chain lengths effectively improve the environmental degradability of the polyamide matrix by reducing crystallinity and increasing moisture accessibility [19,20].

Acknowledgments

The authors gratefully acknowledge the financial and technical support provided by Chinese Culture University, Taipei, Taiwan, for the facilities and resources used in this study.

The authors also thank the staff of the Department of Textile Engineering and the Department of Chemical and Materials Engineering at Chinese Culture University for their assistance with materials preparation and characterization.

Author Contributions

Y.-T.H. and C.-C.L. conceived and designed the study. Y.-T.H., C.-C.L., and K.-Y.C. performed the polymer synthesis and characterization experiments. Y.-T.H. wrote the original draft of the manuscript. Y.-T.H., C.-C.L., and M.-C.K. contributed to data interpretation and critically reviewed and edited the manuscript. C.-C.L. secured institutional support and supervised the overall project. All authors have read and approved the final version of the manuscript.

Funding statement

This research was funded by Department of Textile engineering of Chinese Culture University provided the financial and technical support for this study.

Conflict of Interest

The authors declare that there are no known financial or personal relationships that could have appeared to influence the work reported in this paper. The authors declare no conflict of interest.

Reference

1. Liao, G., Li, Z., Luan, C., Wang, Z., Yao, X., & Fu, J. (2022). Additive manufacturing of polyamide 66: Effect of process parameters on crystallinity and mechanical properties. *Journal of Materials Engineering and Performance, 31*, 191–200. https://doi.org/10.1007/s11665-021-06149-6[link.springer]
2. Wang, W. Y., He, P., Peng, T., Zhang, S., Li, G. Z., Nie, M., & Han, R. (2025). Tailoring polyamide66 mechanical performance: A strategy for condensed phase structure optimization through hydrogen bond reorganization. *Molecules, 30*(4), 862. https://doi.org/10.3390/molecules30040862[pubmed.ncbi.nlm.nih]
3. Lu, W., Wang, C., Yi, Y., Liao, M., Li, J., & Wang, W. (2025). Synthesis and non-isothermal crystallization kinetics of polyamide 66 copolymers containing alicyclic structures. *RSC Advances, 15*(4), 2900–2911. https://doi.org/10.1039/D4RA08482A[pubs.rsc]
4. Paraskar, P. M., Major, I., Ladole, M. R., Doke, R. B., Patil, N. R., & Kulkarni, R. D. (2023). Dimer fatty acid – A renewable building block for high-performance polymeric materials. *Industrial Crops and Products, 200*, 116817. https://doi.org/10.1016/j.indcrop.2023.116817[research.tus][ouci.dntb.gov]
5. Balogun-Agbaje, O. A., Odeniyi, O. A., & Odeniyi, M. A. (2021). Drug delivery applications of poly-γ-glutamic acid. *Future Journal of Pharmaceutical Sciences, 7*, 125. https://doi.org/10.1186/s43094-021-00280-w[link.springer]
6. Tummino, M. L., Chrimatopoulos, C., Bertolla, M., Tonetti, C., & Sakkas, V. (2023). Configuration of a simple method for different polyamides 6.9 recognition by ATR-FTIR analysis coupled with chemometrics. *Polymers, 15*(15), 3166. https://doi.org/10.3390/polym15153166[scholar.google]
7. Gül, A., & Tiyek, İ. (2023). Production and characterization of polyamide-6 (PA6) and cellulose acetate (CA) based nanofiber membranes by electrospinning method. *International Journal of Chemistry and Technology, 7*(1), 91–101. https://doi.org/10.32571/ijct.1207544[search.trdizin.gov][dergipark.org]
8. Gardeniers, M., Leone, N., Kneepkens, R., van Diepen, A., Droste, J., Hansen, M. R., Rastogi, S., & Harings, J. A. W. (2025). Breaking the hydrogen bond barrier reversibly: Toward ultradrawable polyamides. *ACS Applied Polymer Materials, 7*(11), 6825–6836. https://doi.org/10.1021/acsapm.5c00426[pmc.ncbi.nlm.nih]
9. Beier, C. J. A., Schiebahn, A., & Reisgen, U. (2024). Influence of the water content in polyamide 6 on atmospheric pressure plasma jet pre-treatment and adhesion for adhesive bonding. *Discover Mechanical Engineering, 3*, 36. https://doi.org/10.1007/s44245-024-00072-5[link.springer]
10. Frihart, C. R. (2023). Chemistry of dimer acid production from fatty acids and the structure–property relationships of polyamides made from these dimer acids. *Polymers, 15*(16), 3345. https://doi.org/10.3390/polym15163345[pubmed.ncbi.nlm.nih]

11. Al-Shawabkeh, A. F. (2023). Thermodynamic characteristics of the aliphatic polyamide crystal structures: Enhancement of nylon 66α, 610α and 77γ polymers. *Heliyon, 9*(10), e21042. https://doi.org/10.1016/j.heliyon.2023.e21042[pmc.ncbi.nlm.nih]
12. Liang, S., Zhao, H., Li, X., Feng, Y., & Zhao, J. (2024). Efficient strategy to enhance the properties of fully biobased linear dimeric acid polyamides. *ACS Applied Polymer Materials, 6*(16), 9615–9626. https://doi.org/10.1021/acsapm.4c01460[pubs.acs]
13. Meaurio, E. (2024). Generalization of the Carothers equation for linear step growth polymers. *Scientific Reports, 14*, 27281. https://doi.org/10.1038/s41598-024-78476-2[pubmed.ncbi.nlm.nih]
14. Kurima, A., Kinashi, K., Sakai, W., & Tsutsumi, N. (2022). Spin-trapping analysis of the thermal degradation reaction of polyamide 66. *Polymers, 14*(21), 4748. https://doi.org/10.3390/polym14214748[pmc.ncbi.nlm.nih]
15. Meyer, P. M., Forrester, M., & Cochran, E. W. (2024). Synthesis of laboratory nylon: A scale-up method for high molecular weight polyamides. *Industrial & Engineering Chemistry Research, 63*(45), 19506–19514. https://doi.org/10.1021/acs.iecr.4c03175[pubs.acs][polycy.cbe.iastate]
16. Wang, J., Wu, Y., Cao, Y., Li, G., & Liao, Y. (2020). Influence of surface roughness on contact angle hysteresis and spreading work. *Colloid and Polymer Science, 298*(8), 1107–1112. https://doi.org/10.1007/s00396-020-04680-x[link.springer]
17. Nakayama, Y., Watanabe, K., Tanaka, R., Shiono, T., Kawasaki, N., Yamano, N., & Nakayama, A. (2020). Synthesis, properties, and biodegradation of sequential poly(ester amide)s containing γ-aminobutyric acid. *International Journal of Molecular Sciences, 21*(10), 3674. https://doi.org/10.3390/ijms21103674[pubmed.ncbi.nlm.nih][mdpi]
18. Zheng, L., Wang, M., Li, Y., Xiong, Y., & Wu, C. (2024). Recycling and degradation of polyamides. *Molecules, 29*(8), 1742. https://doi.org/10.3390/molecules29081742[mdpi]
19. Lee, J. A., Kim, J. Y., Ahn, J. H., Ahn, Y. J., & Lee, S. Y. (2023). Current advancements in the bio-based production of polyamides. *Trends in Chemistry, 5*(12), 873–891. https://doi.org/10.1016/j.trechm.2023.10.001[pure.kaist.ac]
20. Jha, S., Akula, B., Enyioma, H., Novak, M., Amin, V., & Liang, H. (2024). Biodegradable biobased polymers: A review of the state of the art, challenges, and future directions. *Polymers, 16*(16), 2262. https://doi.org/10.3390/polym16162262[pubmed.ncbi.nlm.nih]