IRSTI 31.25.17 https://doi.org/10.26577/IJBCh202619113

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THERMAL STABILITY OF BIO-BASED CALCIUM AND ALUMINUM CARBOXYLATES

Abstract: As bio-based metal carboxylates, calcium and aluminum carboxylates were synthesized using sunflower oil and soybean wax as renewable feedstocks, and their structures were characterized by Fourier-transform infrared spectroscopy (FT-IR). The FT-IR results confirmed the successful formation of the corresponding metal carboxylates. Thermogravimetric (TG) and differential thermal analysis (DTA) techniques were employed to evaluate the thermal stability of the synthesized compounds. According to the thermal analysis data, aluminum carboxylates exhibited faster thermal decomposition compared to calcium carboxylates, with the major decomposition step occurring predominantly in a single stage. The higher thermal stability of calcium carboxylates relative to aluminum carboxylates can be attributed to their low-er organic content and, additionally, to the fact that calcium forms more stable compounds due to its higher chemical reactivity, a trend that was clearly reflected in the TGA curves. Consequently, calcium carboxylates underwent multi-stage decomposition. This behavior was also evident in the DTA profiles, where the heat absorption and release events showed a fluctuating pattern. Given the significant industrial relevance of metal carboxylates as additives in polymer and lubricant formulations, understanding their physicochemical properties is essential.

Keywords: metal carboxylates, metal soaps, calcium carboxylates, aluminum carboxylates, thermal stability, addi-tives, bio-based additives, sunflower oil.

Introduction

Metal carboxylates – salts or coordination complexes formed between fatty acids and metal ions – constitute a structurally diverse class of organometallic compounds exhibiting highly tunable physico-chemical properties (Idiagheet al., 2014; Puspawiningtiyas et al., 2020). Their behavior strongly depends on the valence state and chemical nature of the metal ion, as well as the length, saturation, and branching of the carboxylate chain. Owing to this structural flexibility, metal carboxylates have found wide application across various industrial sectors (Folarin & Ayinde, 2016; Sukmawati & Lestari, 2020).

These compounds are widely employed as functional additives in lubricants, where they improve resistance to oxidation and thermal degradation, reduce friction and wear, and enhance surface protection. In the paints and coatings industry, they act as catalytic driers that accelerate oxidative curing. Within polymer systems, metal carboxylates serve as both processing aids and stabilizers, contributing to improved thermal, mechanical, and long-term performance. They are also used in catalytic systems, fuel and oil formulations, and the modification of composite materials due to their versatile functionalities (Balköse et al., 2010; Farone et al., 2015; Folarin et al., 2011; Folarin et al., 2012).

One of the most technologically important applications of metal carboxylates is their use as thermal stabilizers for polyvinyl chloride (PVC). During PVC processing, elevated temperatures trigger dehydro-chlorination, and the released hydrogen chloride accelerates discoloration, structural deterioration, and autocatalytic degradation of the polymer matrix (Altarawneh et al., 2022; Tüzüm-Demir et al., 2018; Wang et al., 2019; Xu et al., 2020; Yu et al., 2016). Metal carboxylates mitigate these processes by neutralizing HCl, replacing labile chlorine atoms in the polymer chain, and inhibiting the propagation of degradation pathways. Calcium and zinc carboxylates, as well as certain aluminum analogues, are among the most effective stabilizers for maintaining both the color stability and structural integrity of PVC during processing and service life (Morsy et al., 2024; Wang et al., 2014).

With the increasing regulatory restrictions on toxic lead- and cadmium-based stabilizers, the development of environmentally benign, bio-based metal carboxylates has gained major relevance (Bouchoul et al., 2017; Hosney et al., 2018; Jubsilp et al., 2022; Li et al., 2017). Renewable lipid feedstocks such as sunflower oil, soybean wax, palm-derived fatty acids, and other natural waxes provide sustainable and low-toxicity precursors for the synthesis of metal carboxylates. These bio-derived stabilizers offer enhanced compatibility with polymer matrices while supporting the transition to-ward greener additive technologies (Hasanov et al., 2025a; Ye et al., 2019).

Calcium and aluminum carboxylates synthesized from renewable feedstocks – particularly sunflower oil and soybean wax – are therefore of significant scientific and industrial interest. These natural materials contain long-chain fatty acids capable of forming stable metal–carboxylate structures. Their structural confirmation via FT-IR spectroscopy and the evaluation of their thermal behavior using TG–DTA methods are essential for assessing their suitability as PVC stabilizers. Moreover, a comparative investigation of the thermal degradation mechanisms of calcium and aluminum carboxylates provides valuable insight into the differences in their stability, decomposition pathways, and functional performance in polymer systems (Han et al., 2019; Özsin & Pütün, 2019).

Accordingly, this study focuses on the synthesis of bio-based calcium and aluminum carboxylates, the FT-IR verification of their structural features, and the comparative TG–DTA analysis of their thermal decomposition behavior, with the aim of determining their potential applicability as environmentally friendly thermal stabilizers for PVC.

Materials and methods

For the synthesis of metal carboxylates, refined sunflower oil of the "Final" brand and soy wax of the "Balmumcu" brand were used as the primary bio-based raw materials. Potassium hydroxide (KOH, analytical grade, "Lacherma," Czech Republic) was employed for the saponification of these oils, which constitutes the initial step in the preparation of metal carboxylates. For the subsequent formation of aluminum and calcium carboxylates, aluminum sulfate octadecahydrate ($Al_2(SO_4)_3 \cdot 18H_2O$, high purity, "Kimyalab") and calcium chloride ($CaCl_2$, analytical grade, "Vekton") were used.

The synthesis procedure consisted of two main stages. In the first stage, water-soluble soaps were produced via alkaline saponification of the oils. Ethyl alcohol (C_2H_5OH, 96%) was introduced as a co-solvent to enhance the interaction between the oil and the alkaline medium and was also used in several analytical determinations. To evaluate the saponification value of the selected oils and to neutralize unreacted alkali remaining after saponification, hydrochloric acid (HCl, 35%, AO "Base No. 1 Chemical Reagents") was used. Toluene was applied for determining the acid value of soybean wax, while Wijs reagent, glacial acetic acid, cyclohexane, potassium iodide, starch indicator, and sodium thiosulfate were used for determining the iodine value of the oils. In parallel tests, alcoholic solutions of phenolphthalein and methyl orange served as acid–base indicators.

The acid value of sunflower oil and soybean wax was determined in accordance with ISO 660:2020, the saponification value according to ISO 3657:2020, the iodine value according to ISO 3961:2018, and the moisture and volatile-matter content according to ISO 662:2016.

Metal carboxylates were synthesized from vegetable oils using a two-step approach. In the first step, water-soluble potassium soaps were produced by saponifying the oils with a 20% alkaline solution added in slightly excess stoichiometric quantity. Ethyl alcohol was added after the reaction progressed to a certain stage to improve miscibility. The resulting soap mass was subsequently diluted, and any remaining unreacted alkali – particularly in sunflower-oil-based soaps – was neutralized with standard hydrochloric acid. In the second step, termed "transsaponification," 20% aqueous solutions of the respective metal salts were added in excess of stoichiometric amounts to the diluted soap solution under continuous mixing to precipitate the corresponding calcium and aluminum carboxylates. The obtained metal carboxylates were separated using a funnel with filter paper, washed repeatedly with distilled water, and dried, following established procedures (Barman & Vasudevan, 2006; Hasanov et al., 2025b; Putrawanet al., 2022; Ronny et al., 2016; Ye et al., 2018). Synthesis process of metal carboxylates was described schematic on Figure 1.

The chemical structure of the synthesized metal carboxylates was characterized using Fourier-transform infrared (FT-IR) spectroscopy with a PerkinElmer Spectrum 100 (Germany). Moisture content and ash content after calcination at 1000°C in a muffle furnace were also measured. The elemental com-position of the ash residue was examined using a Spectro XEPOS (Germany) XRF spectrometer.

Figure 1
Synthesis scheme of bio-based aluminum and calcium carboxylates via saponification and transsaponification steps

Thermal stability was evaluated using a NETZSCH STA 449 F3 Jupiter (Germany) simultaneous TG-DTA analyzer. Measurements were carried out up to 900°C under a nitrogen atmosphere at a heating rate of 30 K·min^{-1}.

Results and discussion

Some of the key physicochemical properties of the sunflower oil and soybean wax used in the synthesis of metal carboxylates are presented in Table 1.

More than 90% of the sunflower oil and more than 80% of the soybean wax were converted through the two-stage saponification process. Calcium and aluminum carboxylates were precipitated from the water-soluble soaps by transsaponification.

The chemical composition of the synthesized metal carboxylates was examined using FT-IR spectroscopy, focusing on the formation of metal carboxylate structures and the possible presence of unreacted lipid residues, moisture, metal hydroxides, metal–oxygen bonds, and unsaturated C=C functionalities in the hydrocarbon chains.

Table 1
Physicochemical properties of the sunflower oil and soybean wax

Oil	Compositions of oils			Acid value, mg KOH/g	Iodine value, g I_2/100g	Saponification value, mg KOH/g
	Saturated fatty acids, %	Monounsaturated fatty acids, %	Others, %			
Sunflower oil	10.7	20.7	68.6	0.12	136	191
Soy wax	65	30	5	0.6	30	185

For aluminum carboxylate (AlSUN) synthesized from sunflower oil, the FT-IR spectrum exhibited characteristic absorption bands confirming successful carboxylate formation. Strong bands attributed to the asymmetric and symmetric stretching vibrations of carboxylate groups (COO^-) were observed at 1574.43 cm^{-1}, 1455.11 cm^{-1}, and 1377.31 cm^{-1}, indicating the coordination of fatty acid residues with aluminum ions.

Simultaneously, absorptions at 1713.50 cm^{-1} and 1180 cm^{-1} reflect the presence of residual triglycerides, demonstrating that saponification was not fully complete and that a small fraction of vegetable oil remained unreacted. Additional bands at lower wave-

numbers – 998.82, 880.46, and 667.44 cm^{-1} – correspond to out-of-plane deformation vibrations associated with C=C double bonds in the fatty acid chains, confirming the retention of unsaturation in the structure.

In the metal–oxygen vibrational region, a clear absorption at 516.83 cm^{-1} was assigned to Al–O stretching, supporting the formation of aluminum–carboxylate bonds. The absorption at 2922.84 cm^{-1} corresponds to CH_2 stretching vibrations, while the broad bands at higher wavenumbers are attributable to moisture and metal hydroxide species adsorbed onto the surface.

The FT-IR spectrum of AlSUN is presented in Figure 2.

The FT-IR spectrum of calcium carboxylate (CaSUN) synthesized from sunflower oil exhibited characteristic absorption bands in the wavenumber range of 1575.51–1541.53 cm^{-1}, confirming the formation of calcium carboxylate species. Additional carboxylate-related bands at 1464.03 and 1377.33 cm^{-1} further support the successful coordination of fatty acid anions with Ca^{2+} ions. The broadness of the absorption region suggests the coexistence of both mono- and di-substituted calcium carboxylate species, as well as the possible presence of chelated structures.

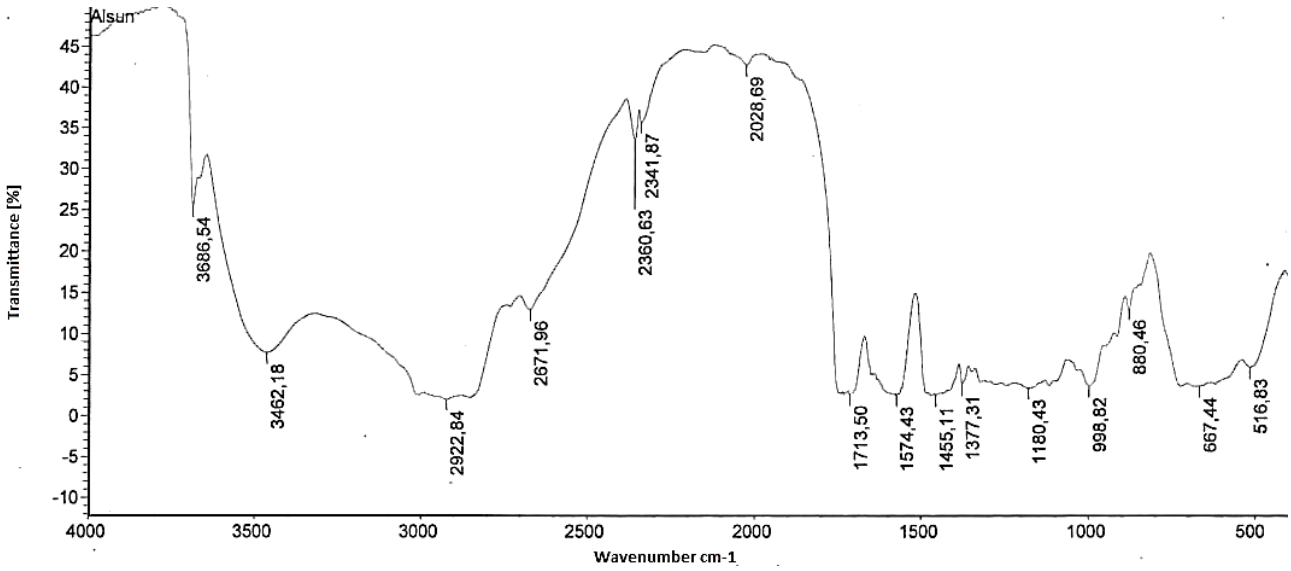
Importantly, no significant absorption was detected in the 1740–1710 cm^{-1} region, which corresponds to ester C=O stretching of unreacted triglycerides or ether groups. The absence of this band indicates that the vegetable oil was almost completely consumed during saponification.

Absorptions associated with unsaturated C=C moieties characteristic of sunflower oil were observed at 3008.44, 990.86, 924.55, 856.35, and 824.05 cm^{-1}, reflecting the retention of double bonds in the hydrocarbon chains. Bands appearing within the range of 678.04–578.32 cm^{-1} correspond to Ca–O stretching vibrations, confirming the formation of calcium dicarboxylate.

A broad absorption at 3396.14 cm^{-1} is attributed to moisture and adsorbed hydroxyl species, while strong absorptions at 2922.3 and 2852.8 cm^{-1} correspond to the aliphatic $–CH_2$ stretching vibrations of the fatty acid chains.

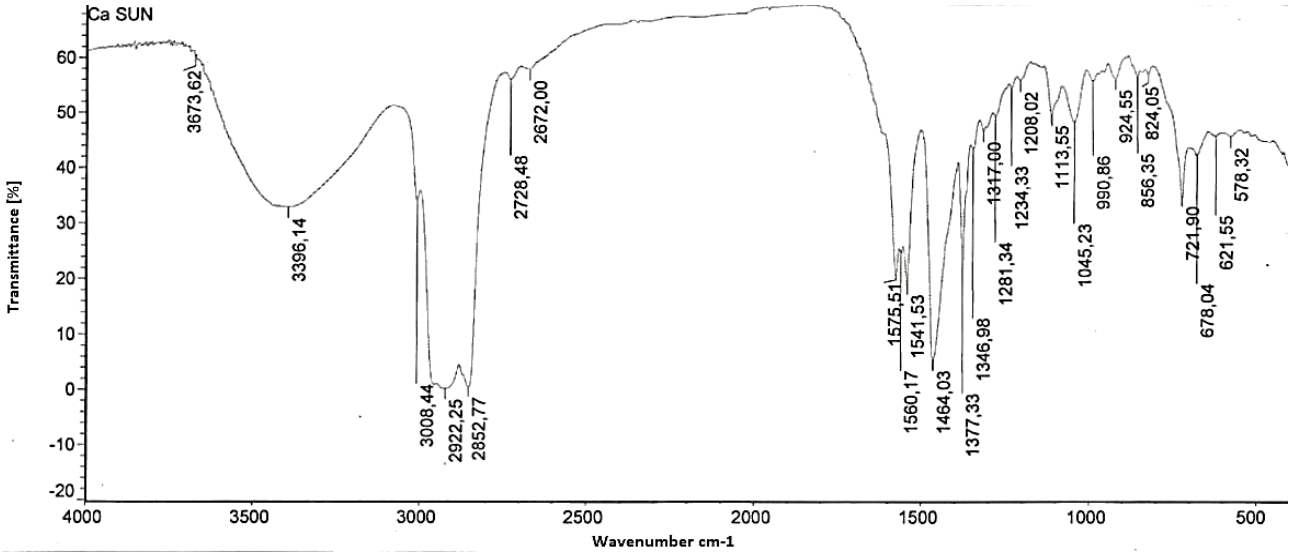
The FT-IR spectrum of CaSUN is shown in Figure 3.

Figure 2
FT-IR spectrum of AlSUN



Characteristic FT-IR peaks corresponding to metal carboxylate structures were also detected in the spectra of the aluminum (AlSO) and calcium (CaSO) carboxylates synthesized from soybean wax. Soybean wax, being a hydrogenation product of soybean oil, is more saturated than sunflower oil; however, the spectra still exhibited distinct carboxylate signatures for both AlSO and CaSO.

Figure 3
FT-IR spectrum of CaSUN



For AlSO, the FT-IR spectrum revealed a pronounced absorption band at 1585.27 cm^{-1}, corresponding to the asymmetric stretching vibration of the carboxylate group (COO^-), confirming successful formation of the metal carboxylate. Symmetric carboxylate stretching vibrations characteristic of coordinated carboxylate species were additionally observed at 1465.38 cm^{-1} and 1377.08 cm^{-1}.

Absorptions appearing in the range of 1712.65–1734.38 cm^{-1}, attributable to carbonyl (C=O) stretching, indicate the presence of ester groups and unreacted lipid components, demonstrating that the hydrogenated wax was not completely converted during saponification. Weak absorptions in the 987.92–889.90 cm^{-1} range correspond to deformation modes of unsaturated C=C bonds, confirming that a minor fraction of unsaturation remains in the soybean-wax-derived fatty acid chains despite hydrogenation.

Bands detected in the lower wavenumber region (617.64–496.68 cm^{-1}) are associated with metal–oxygen (M–O) stretching vibrations and are indicative of aluminum–oxygen coordination. Broad absorptions at higher wavenumbers (3852.82–3441.56 cm^{-1}) correspond to moisture and surface metal hydroxide groups. Intense absorptions in the aliphatic stretching region (2933.82–2852.80 cm^{-1}) originate from CH_2 asymmetric and symmetric stretching vibrations of the long aliphatic chains.

The FT-IR spectrum of AlSO is presented in Figure 4.

In the FT-IR spectrum of the calcium carboxylate synthesized from soybean wax (CaSO), characteristic carboxylate absorption bands were observed in the wavenumber range of 1576.27–1540.53 cm^{-1}, similar to those detected for CaSUN. Additional carboxylate-related bands appeared at 1465.50 cm^{-1} and 1377.28 cm^{-1}, further confirming the formation of coordinated calcium carboxylate species.

Due to the hygroscopic nature of the sample, an absorption band associated with bound water was detected at 1620.56 cm^{-1}. Although no distinct ester carbonyl bands were observed in the 1740–1710 cm^{-1} region – typically indicative of unreacted triglyceride residues – the presence of a peak at 1796.57 cm^{-1} may be related to residual carbonyl-containing species.

Weak absorption bands in the 974.45–810.04 cm^{-1} range correspond to vibrational modes of unsatu-rated C=C bonds, indicating a minor level of unsaturation in the fatty acid chains derived from soybean wax. Peaks occurring at lower wavenumbers (672.17–481.91 cm^{-1}) are attributed to Ca–O stretching vibrations and the formation of a calcium carboxylate network.

Strong absorptions between 2918.43 and 2850.09 cm^{-1} arise from CH_2 stretching vibrations of aliphatic hydrocarbon chains. The broad absorption at 3389.74 cm^{-1} is attributed to residual moisture in the sample.

The FT-IR spectrum of CaSO is presented in Figure 5.

Figure 4
FT-IR spectrum of AlSO

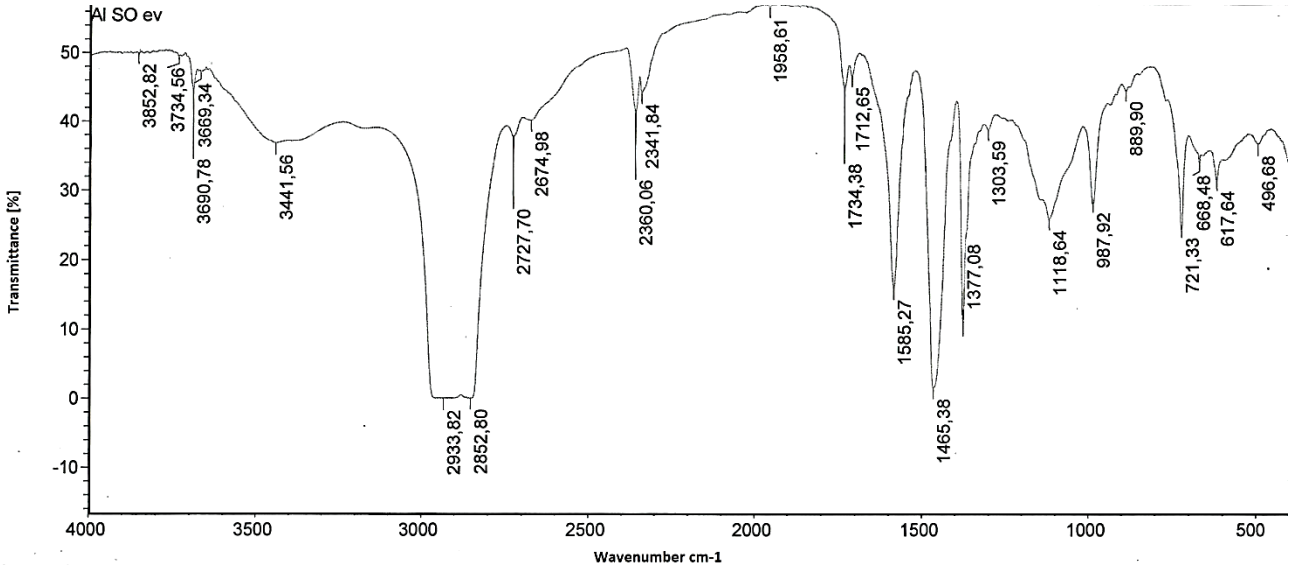


Figure 5
FT-IR spectrum of CaSO

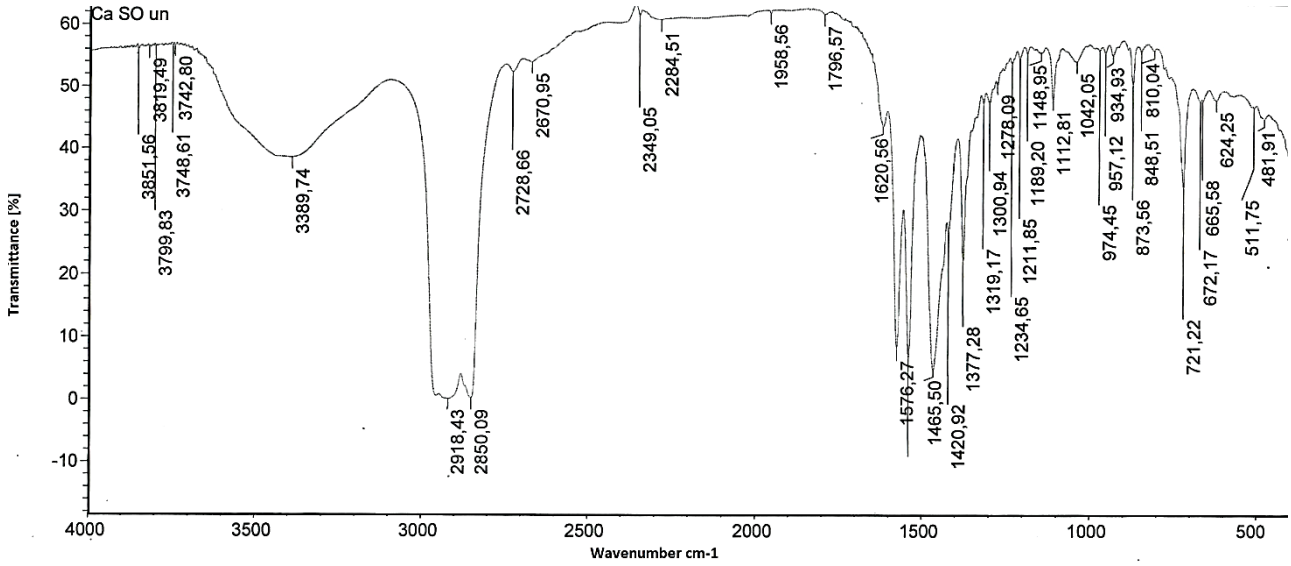


Table 2
Moisture and ash content of metal carboxylates

Metal carboxylate	Moisture, %	Ash content, %	Ash content (dry basis), %
AlSUN	0.20	4.47	4.47
CaSUN	5.87	5.50	5.84
AlSO	4.71	17.07	17.91
CaSO	2.64	6.82	7.01

The moisture and ash contents of the synthesized metal carboxylates were determined and are summarized in Table 2. The results confirm that AlSUN is highly hydrophobic and practically moisture-free. In contrast, AlSO, synthesized from soybean wax – which is more saturated than sunflower oil – exhibits lower hydrophobicity and therefore retains a slightly higher amount of moisture. Furthermore, the higher ash content of AlSO clearly reflects the presence of inorganic and organic impurities remaining from the synthesis process, indicating a direct correlation between the feedstock characteristics, hydrophobicity, and the residual impurity level of the corresponding metal carboxylates.

The ash composition of the metal carboxylates was examined using XRF analysis, and the results revealed that calcium carboxylates contain significantly fewer inorganic impurities compared to their aluminum analogues. This difference is attributed to the higher hydrophilicity of calcium carboxylates, which facilitates more effective removal of residual salts and by-products during the aqueous washing step. In contrast, the greater hydrophobicity of aluminum carboxylates limits their interaction with water, reducing washing efficiency and resulting in a higher level of retained impurities. The XRF results for the ash fractions are presented in Table 3.

TGA–DTA techniques were employed to evaluate the thermal stability of the synthesized metal carboxylates. According to the TGA data, all metal carboxylates exhibited decomposition temperatures higher than the thermal degradation temperature of PVC (Ma et al., 2022; Yang et al., 2023), supporting their potential applicability as PVC thermal stabilizers.

The thermal behavior of AlSUN indicates that its decomposition proceeds predominantly through a single major stage. The onset of intensive mass loss begins at approximately 230°C and continues up to 500°C. During the initial part of this interval, the mass loss increases gradually, with a 5% loss recorded at 259.8°C. This early loss corresponds to the release of a small amount of volatile species and the removal of approximately 0.2% residual moisture.

Beyond this point, the decomposition of the organic matrix and the breakdown of intermediate aluminum carbonate species occur simultaneously within one continuous stage. A 10% mass loss is observed at 289°C, followed by a 20% loss at 323.6°C. Fifty percent mass loss occurs at 388.2°C, while near-complete decomposition – corresponding to 90% mass reduction – is reached at 499.1°C.

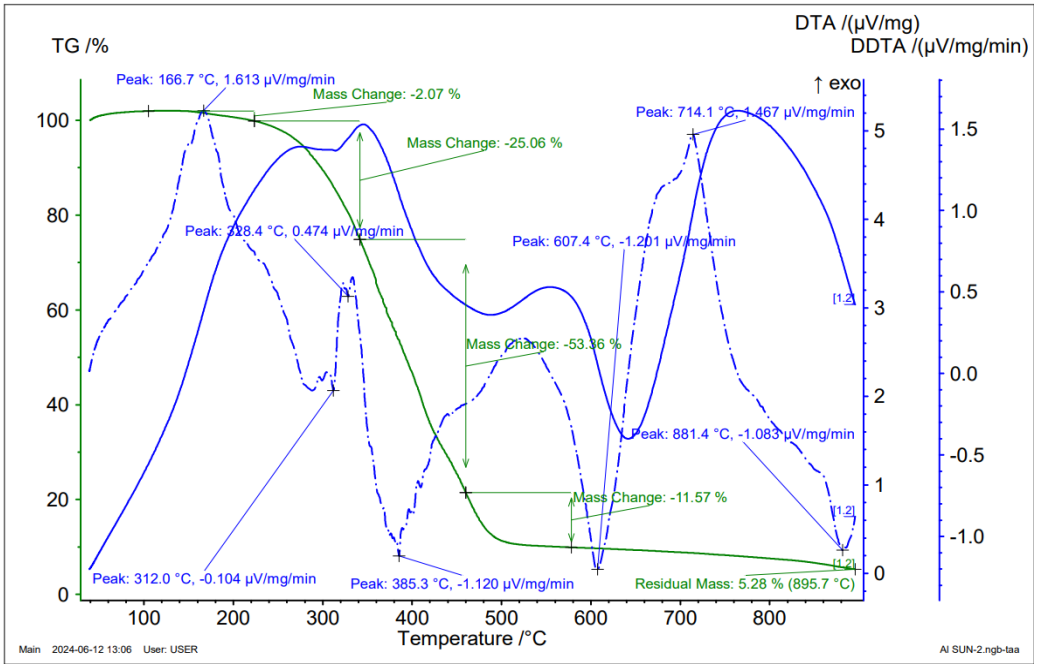
Past this temperature, degradation proceeds only slowly. At 895.7 °C, the final residue amounts to 5.28%, indicating deep and extensive decomposition of the sample. The TG–DTA–DDTA curves of AlSUN are presented in Figure 6. As seen in the DTA and DDTA profiles, the pronounced endothermic events align with the temperature intervals of mass loss, confirming that intensive decomposition reactions occur in these regions.

In contrast to AlSUN, the thermal decomposition of CaSUN proceeds through several distinct stages. This multistep mass loss can be attributed to the sequential release of initial moisture and volatile components, the removal of hydrate water, the decomposition of the organic matrix, and finally the breakdown of the calcium carbonates and other mineral species formed in the sample.

Table 3
XRF results of ash composition

Metal carboxylates ash composition, %							
AlSUN		CaSUN		AlSO		CaSO	
Al_2O_3	83.77	CaO	94.32	Al_2O_3	32.63	CaO	92.40
K_2O	12.23	K_2O	2.20	K_2O	36.84	K_2O	4.44
SO_3	2.62	Al_2O_3	1.14	SO_3	30.17	Al_2O_3	0.49
CaO	0.08	SiO_2	0.80	CaO	0.18	SiO_2	0.64
SiO_2	0.86	Cl	0.72	SiO_2	0.07	Cl	1.05
Trace	0.44	Trace	0.82	Trace	0.11	Trace	0.98

Figure 6
TG-DTA-DDTA curves of AlSUN



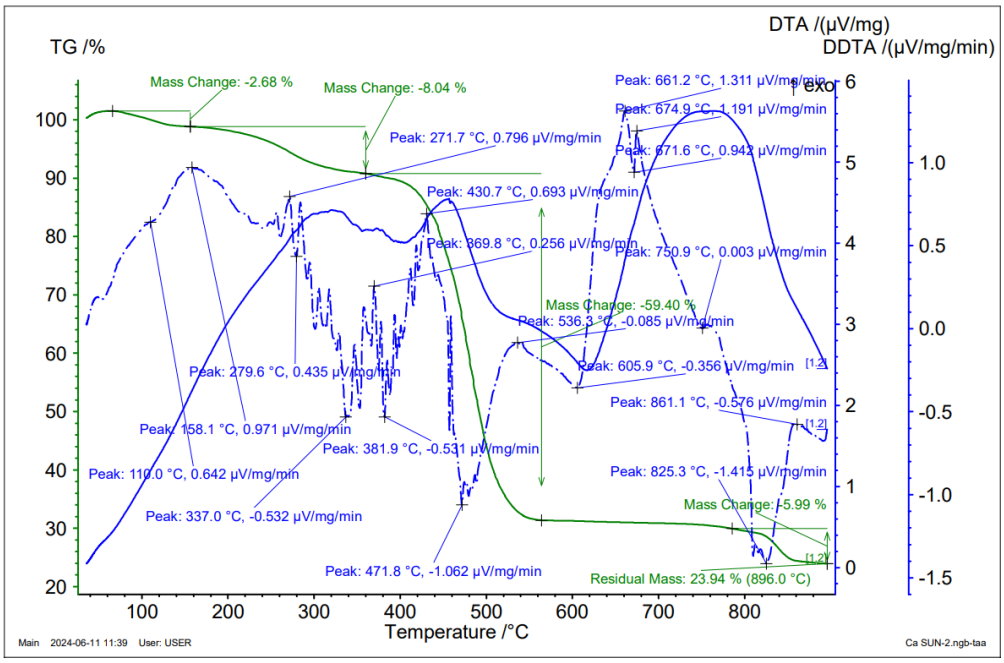
The first significant mass loss occurs early in the experiment, with a 5% reduction recorded at 242.5°C. Independent moisture analysis in a drying oven showed a moisture content of 5.87%, confirming that CaSUN is strongly hygroscopic. Furthermore, the TG–DTA–DDTA curves (Figure 7) exhibit multiple small mass-loss steps within this temperature region, indicating that the retained moisture and volatile components originate from different bonding environments or structural domains within the compound.

A 10% mass loss is observed at 332.8°C, and 20% at 443.3°C, demonstrating that CaSUN remains thermally stable throughout the typical high-temperature processing range of PVC (Shnawa, 2020). A 50% mass loss occurs at 491.2°C, and rapid decomposition continues up to approximately 520°C. Beyond this point, the mass remains nearly constant up to 800°C, after which further loss is associated with the calcination of carbonates within the residual material. At 896°C, the total mass loss reaches 23.94%, indicating partial carbonization of the sample.

The DDTA curve reveals that heat absorption within the main decomposition region occurs in a fluctuating manner. These fluctuations likely arise from the different melting and decomposition behaviors of carboxylate species derived from various higher carboxylic acids present in the material. As decomposition progresses, both the frequency and intensity of these thermal fluctuations increase, reflecting the trans-formation of different structural fractions. Similar fluctuations are consistently mirrored in the DTA pro-file.

General similarities and differences are observed in the thermal behavior of aluminum and calcium carboxylates synthesized from soybean wax compared with their counterparts derived from sunflower oil. As previously noted, AlSO differs from AlSUN in that it is a fine white powder with noticeably lower hydrophobicity. This distinction is also reflected in its moisture test results: AlSO exhibits a moisture content of 4.71%. Correspondingly, TGA analysis shows that 5% mass loss occurs at 144.6°C, demonstrating a clear correlation between the measured moisture level and the initial stage of thermal decomposition.

Figure 7
TG-DTA-DDTA curves of CaSUN



The overall TGA profile of AlSO indicates two primary mass-loss stages: (i) the release of moisture and volatiles, followed by (ii) the decomposition of the organic matrix. In this respect, AlSO shows a decomposition pattern qualitatively similar to that of AlSUN, though occurring at somewhat lower temperatures. Specifically, AlSO shows 10% mass loss at 249.4°C and 20% at 295.8°C. A 50% mass reduction is observed at 389.1°C, while the final mass residue at 896.5°C is 23.09%. Considering the ash content, these results suggest that the organic fraction undergoes deep and extensive decomposition, consistent with the behavior of aluminum carboxylates synthesized from other feedstocks.

The TG–DTA–DDTA curves of AlSO are presented in Figure 8. The DDTA profile shows fluctuations in heat absorption and release throughout the heating process, with pronounced thermal activity up to ap-proximately 313°C, followed by a strong endothermic event. These fluctuations likely arise from successive phase transformations of different carboxylate species and, ultimately, the formation and thermal decomposition of a more homogeneous phase at later stages.

The TGA results of CaSO indicate that its thermal decomposition proceeds through several distinct stages, closely resembling the multistep behavior observed for CaSUN. The initial mass loss corresponds to the release of moisture, followed by an early decomposition stage, and then a more intensive breakdown in the third stage. CaSO exhibits 5% mass loss at 278.8°C, 10% at 316.2°C, and 20% at 383.23°C. A 50% mass reduction is recorded at 474.5°C, while the final residue at 895.8°C is 19.69%.

As with CaSUN, carbonization occurs during the decomposition of CaSO. The DDTA curve of CaSO (Figure 9) also displays regular fluctuations in heat absorption and release, reflecting complex overlapping thermal events. These fluctuations likely arise from the decomposition of different carboxylate species and their associated phase transitions. The final decomposition stage again corresponds to the calcination of metal carbonates formed during earlier stages, mirroring the thermal behavior of CaSUN.

Figure 8
TG-DTA-DDTA curves of AlSO

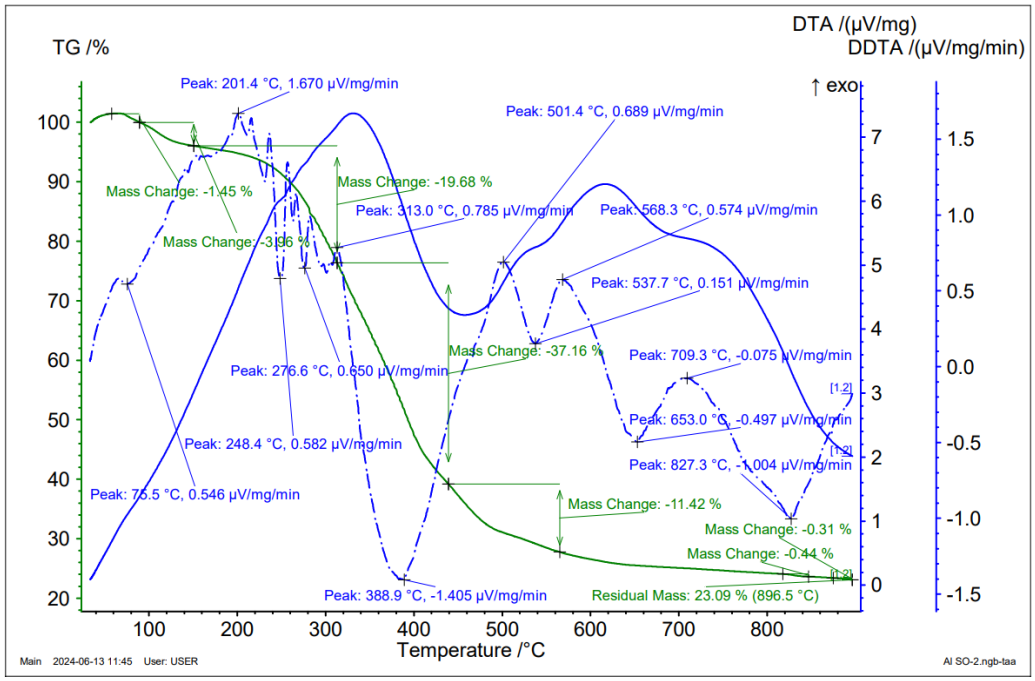
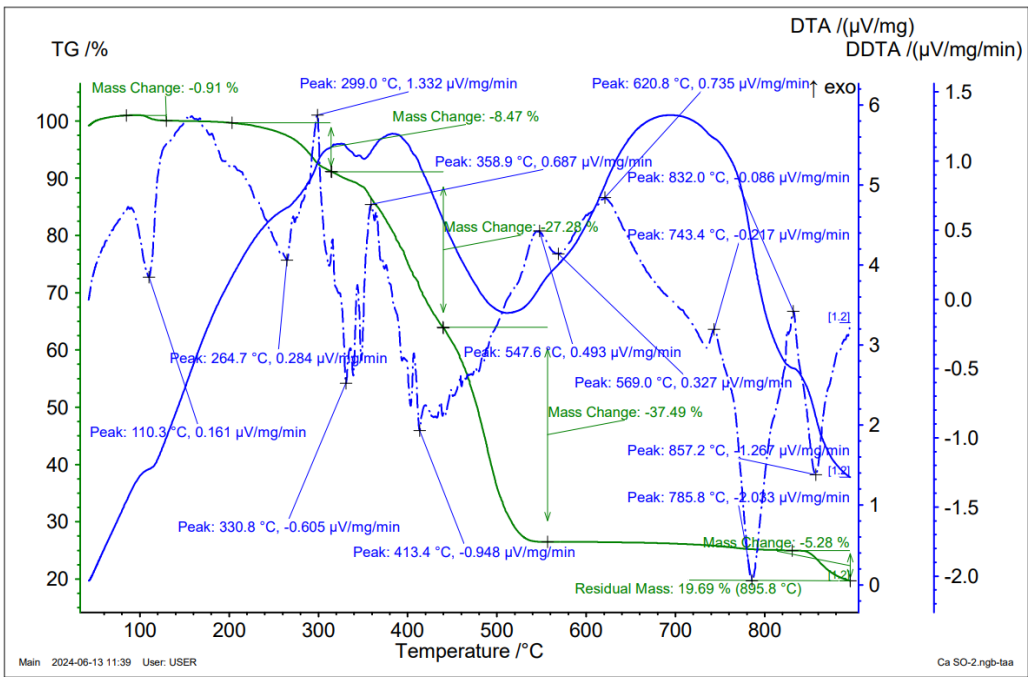


Figure 9
TG-DTA-DDTA curves of CaSO



Overall, the thermal decomposition of both calcium and aluminum carboxylates synthesized from sunflower oil and soybean wax occurs at temperatures substantially higher than the processing temperature of PVC – and even exceeds the intensive decomposition stage of PVC. This high thermal resilience represents a key advantage and supports the suitability of these bio-based metal carboxylates as potential thermostabilizers for PVC processing applications.

The comparative TG–DTA–DDTA analyses clearly demonstrate that both aluminum- and calcium-based bio-derived carboxylates possess sufficient thermal resilience for polymer-processing applications, particularly PVC stabilization. Aluminum carboxylates (AlSUN and AlSO) exhibited predominantly single- or two-step thermal degradation pathways, reflecting their relatively lower moisture content, higher hydrophobicity, and more uniform structural decomposition. In contrast, calcium carboxylates (CaSUN and CaSO) decomposed through multiple well-defined stages, associated with their higher hydrophilicity, greater moisture retention, and the sequential removal of bound water, volatiles, and intermediate carbonate species.

Across all samples, the temperatures corresponding to 10%, 20%, and 50% mass losses significantly exceeded the processing range of PVC, confirming that these bio-based carboxylates maintain structural integrity under relevant industrial conditions. Calcium carboxylates consistently displayed higher decom-position temperatures, indicating deeper carbonization and greater thermal robustness compared to their aluminum analogues.

Overall, the results demonstrate that calcium and aluminum carboxylates synthesized from sunflower oil and soybean wax exhibit favorable thermal characteristics, with calcium-based compounds showing particular promise as environmentally benign, bio-derived thermal stabilizers for PVC applications.

Conclusion

In this study, bio-based calcium and aluminum carboxylates were successfully synthesized from sun-flower oil and soybean wax and comprehensively characterized to evaluate their potential as environmentally benign thermal stabilizers. FT-IR analysis confirmed the formation of metal–carboxylate structures in all samples, while moisture and ash measurements demonstrated clear differences in hydrophobicity and impurity levels depending on both the metal ion and the renewable feedstock. XRF analysis further revealed that calcium carboxylates contained fewer residual inorganic impurities than their aluminum analogues, reflecting the greater washing efficiency associated with their higher hydrophilicity.

Thermal analysis showed that all synthesized metal carboxylates exhibit decomposition temperatures substantially above the typical processing range of PVC, indicating their suitability for high-temperature industrial applications. Aluminum carboxylates tended to decompose in one or two major steps, whereas calcium carboxylates underwent multistage decomposition involving moisture release, organic-matrix degradation and carbonate calcination. Among all samples, calcium carboxylates displayed the highest thermal stability and deepest organic mass decomposition.

The results demonstrate that bio-derived calcium and aluminum carboxylates synthesized from renewable lipid feedstocks possess promising thermal characteristics and can serve as viable, sustainable alternatives to conventional PVC thermostabilizers, supporting the transition toward greener polymer-additive technologies.

Author contributions

R.M. Hasanov: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Visualization, Writing – original draft.R.E. Mammadova: Conceptualization, Methodology, Validation, Writing – review & editing.

Acknowledgments

Authors thank Azerbaijan State Oil and Industry University.

Conflict of interest

The authors declare that they have no conflicts of interest.

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Received 20 December 2025;
received in revised form 26 May 2026;
accepted 15 June 2026