






Studies on Thermal Stability of Barium Carboxylates from Coconut Oil

Peace Olajide^{1,*}, Babatunde Adetuyi¹, Peter Oni², Oluwaseun Adebisi³,
Oyetola Oyebanjo⁴, Abel Oyebamiji⁵

^{1.} Department of Natural Sciences, Precious Cornerstone University, Ibadan, Nigeria; olajidepeace2019@gmail.com (P.A.O.); badetuyi@gmail.com (B.O.A.);

^{2.} Department of Chemistry and Biochemistry, Worcester Polytechnic Institute, USA; pgoni@wpi.edu (P.O.);

^{3.} Department of Biochemistry, Osun State University, Osogbo, Nigeria; adebiseun15@gmail.com (O.A.);

^{4.} Department of Physiology, Babcock University, Ilishan-Remo, Ogun State; tolaoyebanjo@gmail.com (O.O.);

^{5.} Department of Chemistry, Bowen University, Iwo, Osun State; abeloyebamiji@gmail.com (A.O.);

* Correspondence: olajidepeace2019@gmail.com (P.O.);

Scopus Author ID 57205304514

Received: 15.05.2023; Accepted: 11.08.2023; Published: 19.02.2024

Abstract: Petrochemical substitution with oleochemical feedstocks in various domestic and industrial uses has caused a high demand for bio-based products. Coconut oil is a significant source of industrial, and pharmaceutical raw materials, etc. The evolution of sustainable development has necessitated the exploration and exploitation of raw materials from various renewable sources for industries. Seed oil is useful in replacing petroleum feedstock in producing paints, inks, cosmetics, and pharmaceuticals. When synthesized from seed oil, metal carboxylate is employed as a cleaning agent, but the thermal stability must be understood. This paper investigates the thermal stability of barium carboxylate of coconut seed oil to ascertain its quality. Metal carboxylate of the coconut oil (Ba-CSO) was made by precipitation through ethanol metathesis. The use of FTIR spectrophotometer confirmed the formation of carboxylate. The kinetics study of carboxylate decomposition indicated that the process is endothermic and a first-order kinetics reaction. The activation energy for the decomposition process of Ba-CSO was 47.42kJ/mol, which aligned with figures earlier reported for some metal carboxylates, thus indicating possible applications in the industry. It is, therefore, likely to generate polyvinyl chloride (PVC) thermal stabilizers from this oil.

Keywords: petrochemicals; thermal stability; kinetic reaction; coconut oil.

© 2024 by the authors. This article is an open-access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Seed oil is a type of vegetable oil obtained from the seeds or endosperm of some plants instead of the pericarp (or fruit). Most vegetable oils are seed oils; examples include but are not limited to sunflower oil, canola oil, and sesame oil. Some important vegetable oils that are not seed oils include olive and peanut oil. Seed oil is the mainstay of research as they have been the source of several industrial materials and valuable products such as metal carboxylates, also known as metal soaps. Regarding performance and cost, some of these materials obtained from seed oils possess competitive values relative to petroleum-based products [1].

They are employed in producing inks, paints, pharmaceuticals, and chemical intermediates, including metal carboxylates and cosmetics. Seed oil comprises triglycerides with appropriate functional groups, for example, alcohol, ester, double and triple bonds, either

non-conjugated or conjugated, and any suitable functional group capable of undergoing various chemical alterations [2]. This property ensured their capability to supplant petroleum feedstocks in numerous uses. Varieties of commonly grown herbs, flora, and plants in Nigeria have been shown to be one of the most widespread floras in Africa; their seeds contain large quantities of oils that are acceptable in preference to petroleum resources for several use [3]. For thousands of years, soaps with potassium or sodium salts of fatty were produced by heating animal oil or fat with wood ashes, which have sodium and potassium carbonate, making it an alkaline solution.

The current profitable process of producing soap includes boiling oils or fats in an aqueous potassium or sodium hydroxide and adding sodium or potassium chloride for precipitation. The product, which is soap, is then desiccated and pressed into different shapes. Perfumes are sometimes included for scents, dyes for color, sand for scouring, and air to make it float. They have a polar carboxylate ion and a non-polar hydrocarbon responsible for their micelle formation, a spherical cluster that cannot be dissolved in an aqueous solution. The non-polar ends are attached to dirt and oils that dissolve it and are removed. Furthermore, soaps can lower water surface tension, making them slippery and allowing the soap to infiltrate fabric fibers, hence its cleaning ability [4]. Interest in the chemistry of metal carboxylates has continued to grow.

Many workers have continued investigating their fundamental properties, such as crystal structures, thermal properties, and carboxylate bonding modes. Most studies were done using metallic soaps produced from pure fatty acids with minute attention to triglycerides used as the starting materials for soap preparation [5,6]. Also, some studies observed that some metallic soap obtained from some vegetable oils are fairly stable thermally and could be an appropriate polyvinyl chloride (PVC) stabilizer [7]. Thermal decomposition of lipids and long-chain fatty acids is known to involve radical production to activate the processes. The preliminary step may be hydroperoxide decomposition through catalytic reactions or heat [8].

Adequate radicals can initiate chain reactions by removing hydrogen from complex molecules. Thermal decomposition of the acetates of sodium, calcium, copper (II), and silver (I) using thermogravimetry (TG) and differential thermal analysis (DTA), together with analysis of the gaseous products formed during the decomposition process was investigated, thus suggesting that the major organic product formed is either acetone or acetic acid depending on whether the final solid product is the metal oxide or pure metal [9]. Researchers evaluated the thermal stability of metal carboxylates of *Ximenia americana* (XSO) and *Balanites aegyptiaca* seed oil (BSO) and discovered that BSO metal soaps are more thermally stable than the equivalent XSO soaps [10].

The thermal stability of some metal soaps from *Hura crepitans* Seed Oil (HSO) was also studied; the study shows that metal soaps of the seed oil are fairly stable, with Ba-HSO being the most stable, followed by Ca-HSO and Cu-HSO while Zn-HSO is the least stable [10]. Many other researchers have carried out similar studies using other seed oils, but works on *Cocos nucifera* seed oil are metal soap and are very scanty. In this study, the authors particularly focus on investigating the thermal stability of a metal soap of coconut oil to ascertain its quality.

2. Materials and Methods

2.1. Collection of samples.

Coconut fruits were obtained from the Okitipupa market, Ondo State, Nigeria. The fruits were dried for five days, deshelled, pulverized, and n-hexane extraction was done with the soxhlet extraction method according to the method described by AOCS [11].

2.2. Extraction of coconut seed oil.

Oil extraction was done using a soxhlet extractor and n-hexane as the solvent while heating was between (70-80°C). The crushed sample was loaded in thimble and placed in the extractor, and about 400mL of n-hexane was poured into the round bottom flask, and anti-bumping granules were added. The setup was clamped with the condenser and heated with a Stuart 500mL heating mantle [12, 13]. Each extraction batch was performed for approximately 3 hours to ensure total oil removal. After extraction, distillation was carried out to recover the solvent and to concentrate the oil with the help of a condenser. The weight of the oil left was determined after allowing it to cool off [11].

$$\% \text{ oil content} = \frac{\text{Loss in weight after extraction}}{\text{Weight of original sample}} \times 100 \quad (1)$$

2.3. Metal carboxylate preparation.

The seed oil of *C. nucifera* metal soaps was prepared via metathesis in an aqueous alcohol solution. Approximately 50mL of hot ethanol was used to dissolve 9.2g of the oil and then treated with 20% (w/v) NaOH solution (20mL). Dilute HNO₃ (a few drops) was added to remove excess NaOH, and a 30 percent (w/v) solution of suitable metal salt (100mL) was added gently with constant mixing. The precipitated metal carboxylate was removed with warm water, air-dried, and afterward oven-dried at 60°C to constant weight [3]. The salt used to produce Barium Carboxylate of *Cocos nucifera* Seed Oil (Ba-CSO) soap was analytical grade of BaCl₂·2H₂O [12, 13].

After the preparation of metal carboxylate of the oil (Ba-CSO), it was characterized using FTIR spectrophotometer to confirm the synthesized product. Subsequently, a kinetics study of the decomposition of the carboxylate was also explored.

2.4. Thermal stability study.

The thermal stability study was performed in the temperature range 160°C, 180°C, and 200°C as a function of time as described by [14]. Metal soap (Ba-CSO) of 3g was weighed accurately into a container and heated in an oven at the temperature of 160°C, 180°C, and 200°C, respectively, for a certain period of time (30, 60, 90, and 120 min). After heating, the samples were removed from the oven; weight loss was recorded and evaluated with the expression-

$$\text{Weight loss (\%)} = \frac{w_0 - w_1}{w_0}$$

Where-

w₀ = initial weight of the metal soap

w₁ = residual weight of the metal soap after heating.

2.5. Statistical analysis.

For statistical analysis, statistical significance was evaluated using one-way analysis of variance (ANOVA), followed by Dunnett's Data points corresponding to the mean of independent experiments and error bars (S.E.M); the level of significance was set at $p < 0.05$

3. Results and Discussion

The thermal decomposition rate of metal carboxylates is usually attributed to first-order kinetics [5,7]. The kinetics is expressed mathematically thus:

$$\frac{dw}{dt} = K(W_0 - W_1) \quad (1)$$

Where, w_0 = Initial weight of metal soaps,

w_1 = residual weight of metal soaps after heating,

k = rate constant.

By re-arranging and integrating equation (1), it gives (2)

$$\text{Log } (W_0 - W_1) = \text{Log } W_0 - \frac{kt}{2.303} \quad (2)$$

The bands of FTIR for *C. nucifera* seed oil and its metal carboxylate are shown in Figure 1. The metal carboxylate was characterized by two bands, 1468, 1384, and 1635, 1511 cm^{-1} as shown in Table 1.

The former and latter are ascribed to the carboxylate group's symmetric and asymmetric stretching vibration, respectively. The seed oils spectrum is characterized by a solid band (1735cm^{-1}) that can be ascribed to the $\nu(\text{C}=\text{O})$ of a free acid or ester existing in the oil. Band range of $1300\text{-}1100\text{cm}^{-1}$ is ascribed to $\nu(\text{C}-\text{O})$ of the triglyceride oil. The CH_2 symmetric and asymmetric stretching vibrations happen with strong intensity at 2850 and 2918cm^{-1} , respectively. The weak band (3443cm^{-1}) is allocated to $\nu(\text{O}-\text{H})$ of the -free acid oil (figure 1). All other bands faded in the equivalent metal carboxylate spectra except for the oil spectrum at 2918 and 2848cm^{-1} band. The total disappearance of the carbonyl band close to 1700cm^{-1} in the carboxylate spectra revealed a thorough resonance between the two $\text{C}=\text{O}$ bonds of the carboxylate [12, 15].

Salts of carboxylate do not indicate a carbonyl band; however, a strong band owing to the symmetric and asymmetric stretching vibrations of the carboxylic acid group are detected at $1420\text{-}1300$ and $1650\text{-}1550\text{cm}^{-1}$. Metal carboxylate spectra revealed two typical symmetric and two asymmetric carboxylate vibrations, demonstrating a bridging bidentate binding mode. For BaCSO, two symmetric vibrations were detected at 1468 and 1384cm^{-1} , whereas two asymmetric vibrations were detected at 1635 and 1511cm^{-1} . This correlates with the reports on some carboxylates [3,13, 16], thus establishing metal carboxylate formation. The change in symmetric and asymmetric carboxylic acid stretching vibrations ($\Delta\nu = \nu_{\text{asym}} - \nu_{\text{sym}}$) is their coordination mode empirical marker. The change ($\Delta\nu$) of $>200\text{ cm}^{-1}$ shows a mono-dentate coordination mode. For Ba-CSO, $\Delta\nu$ value was 114cm^{-1} . The carboxylate is characterized by the broadband at 3448.29cm^{-1} and can be ascribed to the hydrogen-bonded hydroxyl (OH) groups, probably from water [17, 18].

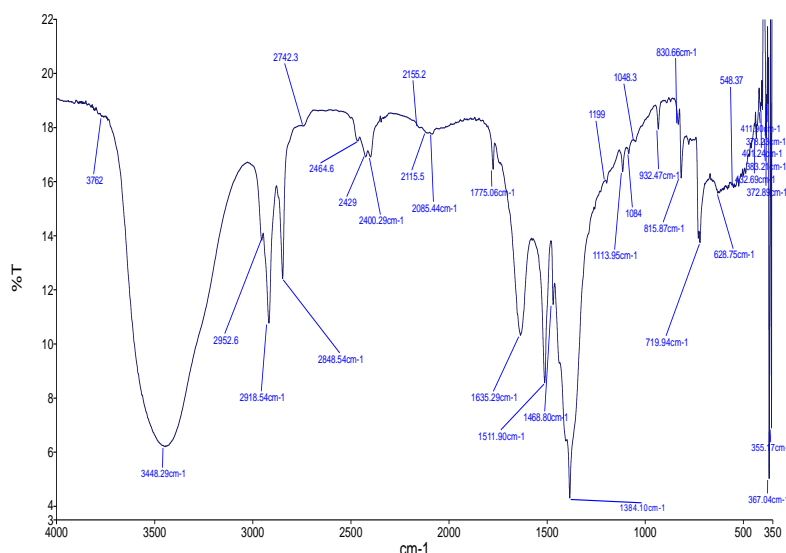


Figure 1. Fourier-Transform infrared spectrum of metal carboxylate of cocos nucifera seed oil (Ba-Cso).

Table 1. Frequencies (cm⁻¹) of absorption of *cocos nucifera* seed oil and its metal carboxylate (Ba-CSO).

Assignment	Ba-CSO
OH stretch	3448 vs
CH ₂ , CH asymmetric elasticity	2918 vs
CH ₂ , C-H asymmetric elasticity	2848 vs
C=O stretch	1556w, 1512vs
COO ⁻ asymmetric stretch	1635s, 1511vs
COO ⁻ symmetric stretch	1468s, 1384vs
C-O elasticity + O-H in plane deform	-
C-O stretch	-
O-H out of plane deform	932 w
CH ₂ rocking	719 w

vs-very strong; s- Strong; w- Weak.

The thermal stability of the carboxylate was examined gravimetrically via heating at 160°C, 180°C, and 200°C in a muffle furnace within a steady time (30-120 min) interval, as shown in Table 2. The rate constant (k) is assigned to the energy barrier that a reaction needs to overcome [19], and there is the occurrence of an inverse relationship between the two parameters [20, 21]. The larger the rate constant, the smaller the barrier. The calculated rate constants are temperature dependent of 10⁻³ min⁻¹ order with an increase of 50 and 20% detected within the BaCSO temperature range [22, 23].

With the rate constant temperature dependence, the value of the activation energy (E_A) for metal carboxylate decomposition was calculated with the relationship as in Equation. 3:

$$\text{Log} \frac{K_2}{K_1} = \frac{E_a}{2.303R} \left(\frac{T_2 - T_1}{T_2 T_1} \right) \quad (3)$$

Table 2. Percentage weight loss and logarithmic weight loss at 160°C, 180°C and 200°C.

Temperature	Heating time (mins)	Ba-CSO (%wl)	Ba-CSO (log %wl)
160°C	30	0.923	0.260
	60	2.727	0.436
	90	3.636	0.561
	120	5.455	0.737
180°C	30	0.952	0.021
	60	4.762	0.678
	90	8.824	0.946
	120	10.231	1.646
200°C	30	1.905	0.280
	60	6.796	0.832
	90	10.377	1.016
	120	12.621	1.101

Through the plots of the log of percentage weight loss against time, k values for Ba-CSO decomposition obtained are presented in Table 3.

Table 3. The rate constant for the decomposition of metal carboxylate of *Cocos nucifera* seed oil (CSO)

Temperature (°C)	Rate Constant ($k \times 10^{-3} \text{ mins}^{-1}$)	Average Rate Constant ($k \times 10^{-3} \text{ mins}^{-1}$)
160	5.0	2.67
180	2.0	
200	1.0	

BaCSO decomposition process activation energy was 47.42kJ/mol, as shown in table 4. The value was in accordance with figures reported earlier for some metal carboxylates [24, 25,26]. The decomposition process enthalpy activation, ΔH^\ddagger was calculated using $\Delta H^\ddagger = E_A - RT$, and the results are shown in Table 4. From the ΔH^\ddagger values, the reaction was shown to be endothermic [15].

Table 4. Thermodynamic parameters for metal carboxylate decomposition of CSO.

Metal soap	E_A (kJ mol ⁻¹)	ΔH^\ddagger (kJ mol ⁻¹)
Barium soap	47.42	43.19

4. Conclusions

Taking the suitability of *Cocos nucifera* seed oil, a polysaturated oil, together, it was examined for producing metal carboxylate. The oil metal carboxylate (Ba-CSO) was produced by precipitation through ethanol metathesis. The FTIR spectrophotometer was used to establish carboxylate formation. Kinetics study of the carboxylate decomposition done within the 160-200°C range indicates that the decomposition followed first-order kinetics and was endothermic. The activation energy for metal carboxylate decomposition shows possible applications in the industry. Due to the fairly thermal stability, it is likely to form a PVC thermal stabilizer from this oil.

Funding

This research received no external funding.

Acknowledgments

I acknowledge the administrative support of Mrs. Tomi Adetuyi for the time spent proofreading this manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Grover, J.; Kaur, S.; Pandey, O.P. Thermal, structural, optical, and photon shielding studies of cerium-doped barium tellurite glasses. *Luminescence* **2023**, *38*, 308-317, <http://doi.org/10.1002/bio.4450>.
2. Wypych-Puszkarcz, A.; Cetinkaya, O.; Yan, J.; Udovyt'ska, R.; Jung, J.; Jenczyk, J.; Nowaczyk, G.; Jurga, S.; Ulański, J.; Matyjaszewski, K.; Pietrasik, J.; Kozanecki, M. Molecular Dynamics and Structure of Poly(Methyl Methacrylate) Chains Grafted from Barium Titanate Nanoparticles. *Molecules* **2022**, *27*, 6372, <http://doi.org/10.3390/molecules27196372>.
3. Kim, D.H.; Lee, S.J.; Theerthagiri, J.; Choi, M.; Jung, J.; Yu, Y.; Im, K.S.; Jung, H.J.; Nam, S.Y.; Choi, M.Y. In-situ thermal phase transition and structural investigation of ferroelectric tetragonal barium titanate

- nanopowders with pseudo-cubic phase. *Chemosphere* **2021**, *283*, 131218, <http://doi.org/10.1016/j.chemosphere.2021.131218>.
4. Al-Ghamdi, H.; Almuqrin, A.H.; Kassim, H. Effect of Gamma Irradiation on the Structural, Optical, Electrical, and Ferroelectric Characterizations of Bismuth-Modified Barium Titanate Ceramics. *Materials* **2022**, *15*, 4337, <http://doi.org/10.3390/ma15124337>.
 5. Wang, L.; Wei, Y.; Deng, H.; Lyu, R.; Zhu, J.; Yang, Y. Synergistic Flame Retardant Effect of Barium Phytate and Intumescent Flame Retardant for Epoxy Resin. *Polymers* **2021**, *13*, 2900, <http://doi.org/10.3390/polym13172900>.
 6. Kang, S.; Kwon, S. Preparation and Performance Evaluation of Platinum Barium Hexaaluminate Catalyst for Green Propellant Hydroxylamine Nitrate Thrusters. *Materials* **2021**, *14*, 2828, <http://doi.org/10.3390/ma14112828>.
 7. Wang, M.; Li, Y.; Cui, M.; Li, M.; Xu, W.; Li, L.; Sun, Y.; Chen, B.; Chen, K.; Zhang, Y. Barium alginate as a skeleton coating graphene oxide and bentonite-derived composites: Excellent adsorbent based on predictive design for the enhanced adsorption of methylene blue. *J. Colloid Interface Sci.* **2022**, *611*, 629-643, <http://doi.org/10.1016/j.jcis.2021.12.115>.
 8. Adetuyi, B.O.; Adebisi, O.A.; Adetuyi, O.A.; Ogunlana, O.O.; Toloyai, P.-E.; Egbuna, C.; Uche, C.Z.; Khan, J.; Adumanya, O.C.U.; Patrick-Iwuanyanwu, K.C. *Ficus exasperata* Attenuates Acetaminophen-Induced Hepatic Damage via NF- κ B Signaling Mechanism in Experimental Rat Model. *BioMed Res. Int.* **2022**, *2022*, 6032511, <http://doi.org/10.1155/2022/6032511>.
 9. Mustaffa, M.A.; Arith, F.; Noorasid, N.S.; Zin, M.S.I.M.; Leong, K.S.; Ali, F.A.; Mustafa, A.N.M.; Ismail, M.M. Towards a Highly Efficient ZnO Based Nanogenerator. *Micromachines* **2022**, *13*, 2200, <http://doi.org/10.3390/mi13122200>.
 10. Owolabi, J.B.; Alabi, K.A.; Lajide, L. Synthesis and characterization of copper metal soaps from *Thevetia peruviana* and *Hura crepitans* seed oils. *Sci. Res. Essays.* **2015**, *10*, 649-654, <http://doi.org/10.5897/SRE2015.6216>.
 11. Oderinde, R.A.; Ajayi, I.A.; Adewuyi, A. Characterization of seed and seed oil of *Hura crepitans* and the kinetics of degradation of the oil during heating. *Electron. J. Environ. Agric. Food Chem.* **2009**, *8*, 201-208.
 12. Folarin, O.M.; Olumayede, E.G.; Nwachukwu, P.C.; Fakoya, S. Antimicrobial activity of Cu, Ni Carboxylates of Castor (*Ricinus communis*) Seed Oil and Their Calcinated Derivatives. *J. Appl. Sci. Environ. Manage.* **2013**, *17*, 483-490.
 13. Mady, M.F.; Rehman, A.; Kelland, M.A. Synthesis and Antiscalcing Evaluation of Novel Hydroxybisphosphonates for Oilfield Applications. *ACS Omega.* **2021**, *6*, 6488-6497, <http://doi.org/10.1021/acsomega.1c00379>.
 14. Cichocki, W.; Kmiecik, D.; Baranowska, H.M.; Staroszczyk, H.; Sommer, A.; Kowalczewski, P.L. Chemical Characteristics and Thermal Oxidative Stability of Novel Cold-Pressed Oil Blends: GC, LF NMR, and DSC Studies. *Foods.* **2023**, *14*, 2660. doi: 10.3390/foods12142660.
 15. Egbuchunam, T.O.; Balköse, D.; Okieimen, F.E. Effect of zinc soaps of rubber seed oil (RSO) and/or epoxidised rubber seed oil (ERSO) on the thermal stability of PVC plastigels. *Polym. Degrad. Stab.* **2007**, *92*, 1572-1582, <https://doi.org/10.1016/j.polymdegradstab.2007.05.002>.
 16. Adetuyi, B.O.; Olajide, P.A.; Awoyelu, E.H.; Adetuyi, O.A.; Adebisi, O.A.; Oloke, J.K. Epidemiology and Treatment Options for COVID-19: A review. *Afr. J. Reprod. Health* **2020**, *24*, 142-153.
 17. Bakare, I.O.; Pavithran, C.; Okieimen, F.E.; Pillai, C.K.S. Polyesters from renewable resources: Preparation and characterization. *J. Appl. Polym. Sci.* **2006**, *100*, 3748-3755, <https://doi.org/10.1002/app.23386>.
 18. Awoyelu, E.H.; Oladipo, E.K.; Adetuyi B.O.; Senbadejo, T.Y.; Oyawoye, O.M.; Oloke, J.K. Phyloevolutionary analysis of SARS-CoV-2 in Nigeria. *New Microbes New Infect.* **2020**, *36*, 100717, <https://doi.org/10.1016/j.nmni.2020.100717>.
 19. Folarin, O.M.; Eromosele, I.C.; Eromosele, C.O. Relative thermal stability of metal soaps of *Ximenia americana* and *Balanites aegyptiaca* seed oils. *Sci. Res. Essays.* **2011**, *6*, 1922-1927, <https://doi.org/10.5897/SRE10.438>.
 20. Smida Nourhene, B.; Abdelhak, O.; Raoudha, A. The Study of Impedance and Conductivity of New Modified Polystyrene Used as an Effective Adsorbent of Ba(II) Ions. *Chem. Biodivers.* **2023**, *20*, e202201150, <http://doi.org/10.1002/cbdv.202201150>.
 21. Reddy, V.J.; Dixit, P.; Singh, J.; Chattopadhyay, S. Understanding the core-shell interactions in macrocapsules of organic phase change materials and polysaccharide shell. *Carbohydr. Polym.* **2022**, *294*, 119786, <http://doi.org/10.1016/j.carbpol.2022.119786>.
 22. Ogunlana, O.O.; Ogunlana, O.E.; Adekunbi, T.S.; Adetuyi, B.O.; Adegboye, B.E.; Iheagwam, F.N. Anti-inflammatory Mechanism of Ruzu Bitters on Diet-Induced Nonalcoholic Fatty Liver Disease in Male

- Wistar Rats. *Evid.-Based Complementary Altern. Med.* **2020**, *2020*, 5246725, <https://doi.org/10.1155/2020/5246725>.
23. Batiha, G.E.-S.; Alqarni, M.; Awad, D.A.B.; Algamma, A.M.; Nyamota, R.; Wahed, M.I.; Shah, M.A.; Amin, M.N.; Adetuyi, B.O.; Hetta, H.F.; Cruz-Martins, N.; Koirala, N.; Ghosh, A.; Echeverría, J.; Pagnossa, J.P.; Sabatier, J.-M. Dairy-Derived and Egg White Proteins in Enhancing Immune System against COVID-19. *Front. Nutr.* **2021**, *12*, 629440, <http://doi.org/10.3389/fnut.2021.629440>.
 24. Oluwafemi Adetuyi, B.; Olamide Okeowo, T.; Adefunke Adetuyi, O.; Abraham Adebisi, O.; Ogunlana, O.O.; Janet Oretade, O.; Marraiki, N.; Beshbishy, A.M.; N. Welson, N.; Batiha, G.E.-S. Ganoderma Lucidum from Red Mushroom Attenuates Formaldehyde-Induced Liver Damage in Experimental Male Rat Model. *Biology* **2020**, *9*, 313, <http://doi.org/10.3390/biology9100313>.
 25. Aashli; Reddy, S.G.; Siva Kumar, B.; Prashanthi, K.; Murthy, H.C.A. Fabricating transdermal film formulations of montelukast sodium with improved chemical stability and extended drug release. *Heliyon* **2023**, *9*, e14469, <http://doi.org/10.1016/j.heliyon.2023.e14469>.
 26. Wang, H.; Dong, H.; Liu, X.; Zhang, P. Preparation and Laboratory Testing of Polymeric Scale Inhibitor Colloidal Materials for Oilfield Mineral Scale Control. *Polymers* **2022**, *14*, 4240, <http://doi.org/10.3390/polym14194240>.