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Utilization of Tasar Pupae (*Antheraea mylitta*) for Biodiesel Production: An Alternative and Green Approach

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Abstract

The biofuels as a rule are usually centered around the reality that they are obtained from agricultural products. In the event that the effective innovation is developed for the extraction of biofuels from waste byproducts, many industries including mining, aviation and transportation sectors would then furnish the most consequential changes in waste management, waste to value-added products and decreased transportation costs. The present study focuses on the utilization of silkworm pupae waste from Antheraea mylitta as useful energy in the tanks of diesel vehicles. The physiochemical properties such as saponification value, iodine number and viscosity of obtained biodiesel after transesterification were seen to be 186 mg/g, Iodine values were 112 mg/g and 35.8 mm^2/s respectively. Formation of FAME's was confirmed by GC-MS analysis. The pupae biodiesel chemical composition exhibited ten types of FAME's that were identified by retention time data and verified by the mass fragmentation pattern. The sample consists of predominantly Pentane,2,2,4-trimethyl, cyclobutanol, glycerine, diglycolic acid, silane, diethoxyldimethyl, glycolic acid, succinic acid, 1,4-cyclohexane. The percentage yield of biodiesel obtained was found to be fairly high as 78%. This elevated percentage conversion of pupae oil to biodiesel concludes that silkworm pupae waste has the potency to be used as an alternative feed stalk to create supplement fuels for CI engines. This integration holds the promise of not only addressing environmental concerns but also providing a cost-effective and locally sourced energy solution for mining and other fuel requiring operations.

Keywords: *Antheraea mylitta*, Biodiesel, FAME, GCMS Analysis, Pupae Waste

1.0 Introduction

In recent times, the upheaval caused by the incessant burning of fossil fuels has affected the earth ghastly. It is an established fact that these resources are scarce in quantity. Furthermore, the cost of fossil fuels has increased exponentially due to their excessive consumption. The scientific community has been compelled by this to consider ways to reduce our reliance on fossil fuels and increase the usage of renewable and environmentally benign fuels derived from viable biomass. There is a plethora of measures to downscale the ill-effects of global-warming in which encouraging the use of clean energy forms such as wind energy, solar energy and energy from organic waste seems to be evidently promising and rewarding in the longer run. The rationale being, the earth is endowed with

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unending supply of renewable energy resources which, if used with proper technical know-how can bring about a revolutionary change in lowering the greenhouse effect.

As far as renewable fuels are concerned, biodiesels are the answer to these challenges and has garnered a lot of attention worldwide. Many vegetable oils extracted from wide plant sources like peanut, soybean, non-edible oils such as jatropha, rapeseed, rice bran, and canola have been used in diesel engine as a biofuel[1]. However, the high cost of these sources has limited the industrial applications in most of the countries excepting a few. Hence, an approach towards selecting a cost effective, suitable and non-edible biodiesel sources are being explored in a wide array.

Microalgae, plants and their products have been already explored for lipid extraction and bio fuel analysis. But the research and efforts taken to study the extraction of biofuels from animal source is limited. Hence, one of the major sources that are found is the silk making industries. Production of silk is an age-old practice found in different parts of India which utilizes silkworm as the sole source. The sericulture industry is responsible for generating enormous quantities of dry waste from dead pupae after production of silk from the cocoon. The dead pupae being produced as a waste product are rich in oil (30-35%) along with other nutrients[2]. On the other hand, the pupae are a substantial chunk and these obligatory residues thrown out into the environment, after picking the commercial byproduct as raw silk.

The adoption of this silkworm-derived pupae waste biodiesel in the varied industrial sectors like aviation, textile, transportation and mining industry presents a comprehensive solution to various challenges prevalent in traditional fuel usage. In mining operations, where environmental impact, logistical complexities in remote areas, and fluctuating fuel costs are significant concerns, the incorporation of this alternative biodiesel addresses these issues effectively. By offering a locally sourced, sustainable fuel option, it not only mitigates the carbon footprint associated with conventional fuels but also reduces operational costs linked to transportation in remote locations. Additionally, the conversion of silkworm pupae waste into biodiesel addresses waste management challenges, contributing to a circular economy and promoting responsible resource utilization. The only nation in the world to produce all four commercially important varieties of silk, namely Tasar, Mulberry, Eri, and Muga, is India. Scientific reports revealed much of the work done on Mulberry, Eri and Muga silk worms as a source for biodiesel production but there is a dearth of information on exploring Tasar silkworm as an alternative eco-friendly fuel for the engines.

A. mylitta Drury is the scientific name for the wild and commercial insect known as the tasar silkworm. The 43 eco-races that make up the species are widely dispersed from West Bengal in the east to Karnataka in the south. According to reports, among all the insects that produce silk in the world, tasar cocoons are the biggest. Although being extremely high in amino acids, oil, carbs, and minerals, the pupae that are salvaged after reeling of silk worm's cocoons are typically disposed off. With the aim to evaluate its potential as a biodiesel, the current effort was created to convert the bio oil from used tasar silk pupae to methyl ester.

2.0 Material and Methods

2.1 Sample Collection and Processing

Pupae used for the study were obtained from sericulture unit located at Byraveshwara silk industry located in Hoskote of rural Bangalore. About 2 kg of dead pupae were collected, weighed and used for the experiments. The physical properties of dead pupae were taken before the processing (Table 1). Later they were grinded to coarse powder using pestle and mortar and were preserved in an air tight container for further study.

2.1.1 Oil Extraction from Silkworm Pupae by Soxhlet Extraction Method

The soxhlet apparatus was utilised for extraction of pupae oil using n-Hexane as a solvent. Temperature was kept in the range 35-40°C and the process was continued for 5hrs. Extractions were carried out for 3 cycles. The solvent was separated using rotary vacuum evaporator at 40°C to take out the crude oil. The extracted oil was quantified by its dry weight basis and was measured as-

Table 1. Properties of wild dead tasar pupa

Appearance	Oval Shape Non-Sticky
Colour	Dark brown
Smell	Unpleasant
Weight	0.9-1.4 g
Diameter	2-2.8 mm
Length	3.8 mm

%yield = Amount of oil extracted/Amount of biomass taken X 100

2.2 Evaluation of Physicochemical Properties of Pupae Oil by Standard Traditional AOCS Method:

The extracted pupae oil was characterized to evaluate its potential as a source of biodiesel. The properties like viscosity, iodine value, saponification value of extracted tasar pupae oil was analyzed by using standard procedures (AOCS methods).

2.2.1 Conversion of Tasar Pupae Bio Oil to Biodiesel by Transesterification of Reaction Using Suitable Catalyst

An alkali (NaOH) and acid (H_2SO_4) catalyzed reaction for trans esterification of pupae oil was carried out using oil: Methanol in 6:1 ratio. The liquid mixture was kept undisturbed overnight to form 2 layers for separation of glycerol from methyl ester. The recovered ester was washed with three volumes of deionized water. The process was repeated twice to remove any impurities. After washing, 0.1 gm of anhydrous sodium sulphate was mixed with the by product to drain off the water content, if any. Finally, the obtained methyl ester was filtered to extract any other residual impurities.

2.2.2 Quantitative Analysis of Total Fatty Acids Methyl Esters (FAME) in Extracted Silkworm Pupae Biodiesel by Gas Chromatography Mass Spectroscopy

Under typical circumstances, the methyl esters found in the sample biodiesel were examined using GCMS. The standard curve that relates the concentration of several esters, such as hexanoic acid, di-methyl ethyl ester, diazene, and cyclo pentanol, to their respective peaks in the GC chromatogram was used to quantify the conversion of biodiesel into refined silkworm pupae oil.

3.0 Results and Discussion

The following Table I, II, and III lists the characteristics of wild dead tasar pupae as well as the oil's physicochemical parameters collected from waste pupae and those of the methyl ester produced post trans esterification. The saponification value, iodine number, and viscosity of *A. mylitta* were found to be 226.35 mg/g, 116.8 mg/g of sample, and 34.3 mm^2/s, respectively (Table 2). The results found were at par with the studies conducted in other varieties of silkworm pupae as the values obtained are compatible with high degree of unsaturation and carbon chain length.

Also, it was discovered that the FAME's iodine value and viscosity fell within the acceptable limit. Another factor to consider when choosing a biodiesel is the range or degree of unsaturation, which is measured by the iodine value (Table 3). The presence of a little unsaturated fatty acid component in methyl ester is desirable since it partly restricts the FAME from solidification.

Pupae biodiesel was synthesized by the acid-base catalyzed trans esterification reaction with methanol and it met ASTM standards. Formation of FAME's was confirmed by GC-MS analysis. The pupae biodiesel chemical composition showed ten varieties of FAME's that were identified by the retention time data and further verified by mass fragmentation pattern. The excellent conversion percentage of pupae oil into biodiesel indicates toward the fact that pupae oil is a great raw material for commercially producing biodiesel.

Table 2. Physicochemical properties of wild tasar pupae oil

Properties	Tasar Pupae Oil
Avg. oil content	%
pH	6.3
Sp. gravity (35°C)	0.966
Moisture content (mg/g)	
Viscosity (25°C) mm^2/s	34.3
Saponification value (mg/g)	226.35
Iodine value (mg/g)	116.8

Table 3. Physiochemical properties of biodiesel obtained after transesterification

Properties	Tasar Pupae Oil
Biodiesel yield	78%
pH	7.1
Sp. gravity (35°C)	0.850
Moisture content (mg/g)	0.21
Viscosity (25°C) mm^2/s	35.8
Saponification value (mg/g)	186
Iodine value (mg/g)	112

The GC-MS chromatogram revealed chemical composition of the synthesized pupae biodiesel. The sample mainly consists of a mixture of two unsaturated and two saturated predominant compounds of FAME. The study demonstrates that, the FAME derived from the oil is soap-free and that the majority of the triglycerides are transformed to mono glycerides. The methyl ester fatty acid exhibited the presence of pentane,2,2,4-trimethyl, cyclobutanol, glycerine, diglycolic acid, silane, diethoxyldimethyl, glycolic acid, succinic acid, 1,4-cyclohexane (Table 4 and Figure 1).

The main saturated fatty acids found in the biodiesel were palmitic and stearic acids. Alkanes like

Table 4. Unique compounds present in pupae oil during GCMS analysis

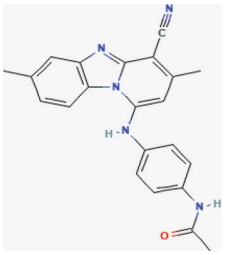
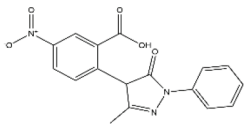
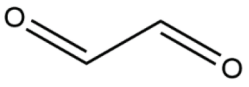
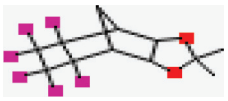
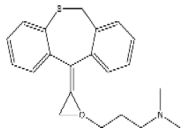
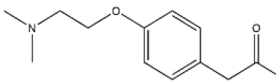
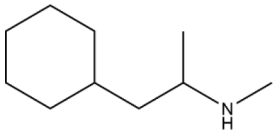
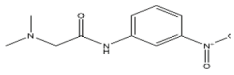
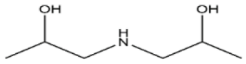
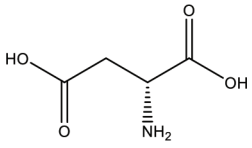
Sl.No	Name of the Compound	RT	MW	Molecular Formula	Structure	Reference
1	1-(4-Acetamidoanilino)-3,7-dimethylbenzo [4,5] imidazo[1,2-a] pyridine-4-carbonitrile	4.023	$C_{22}H_{19}N_5O$	369.0		8
2	2-(4,5-Dihydro-3-methyl-5-oxo-1-phenyl-4-pyrazolyl)-5-nitrobenzoic acid	4.023	367.3	$C_{17}H_{13}N_5O_5$		9
3	Ethanedial,dioxime	4.023	88.07	$C_2H_4N_2O_2$		10
4	8,9,9,10,10,11-Hexafluoro-4,4-dimethyl-3,5-dioxatetracyclo [5.4.1.0(2,6).0(8,11)] dodecane	4.023	302.21	$C_{12}H_{12}F_6O_2$		11
5	1-propanamine-3, dibenzo [B, E] thiepin-11(6H)-ylidine-N, N-dimethyl-S-oxirane	6.886	295.442	$C_{19}H_{21}NS$		12
6	Acetone,1- [4-(Dimethylamino Ethoxy)phenyl]-	6.886	221.29	$C_{13}H_{19}NO_2$		13
7	Benzedrex	6.886	155.28	$C_{10}H_{21}N$		14
8	2-(Dimethylamino-N-(3-nitrophenyl) acetamide	6.886	223.23	$C_{10}H_{13}N_3O_3$		15
9	Diisopropanolamine	7.094	133.19	$C_6H_{15}NO_2$		16
10	D-Aspartic Acid	7.094	133.1	$C_4H_7NO_4$		17

Table 4. Continued...

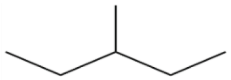
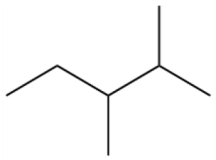
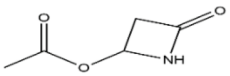
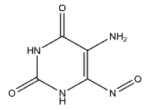
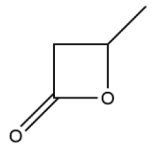
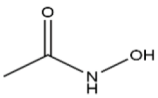
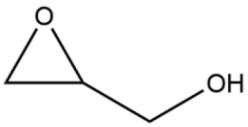
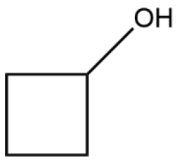
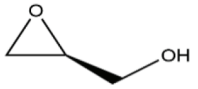
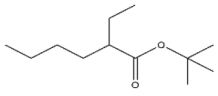
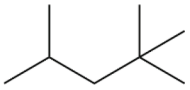
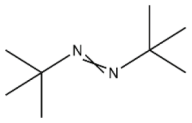
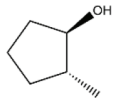
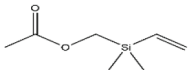
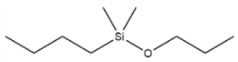
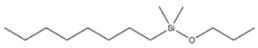
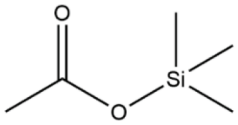
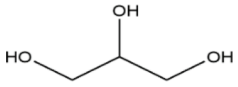
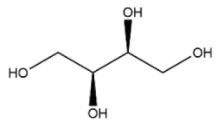
Sl.No	Name of the Compound	RT	MW	Molecular Formula	Structure	Reference
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12	Pentane, -3methyl-	7.878	86.2	$CH_3CH_2CH(CH_3)CH_2CH_3$		19
13	Pentane,2,3-Dimethyl	7.878	100.2	C_7H_{16}		20
14	4-Acetoxy-2-Azetidinone	11.769	129.11	$C_5H_7NO_3$		21
15	Pyrimidine-2,4(1H,3H)-Dione,5-Amino-6-Nitoso-	11.769	156.1	$C_4H_4N_4O_3$		22
16	2-oxetanone,4-methyl-	11.769	86.0892	$C_4H_6O_2$		23
17	Acetohydroxamic Acid	11.769	75.07	$C_2H_5NO_2$		24
18	Glycidol	11.849	74.08	$C_3H_6O_2$		25
19	Cyclobutanol	11.849	72.10	C_4H_8O		26
20	Oxiranemethanol, (S)-	11.849	74.08	$C_3H_6O_2$		27
21	Hexanoic acid,2-ethyl-,1,1-dimethylethyl Ester	12.868	216.32	$C_{12}H_{24}O_3$		28
22	Pentane,2,2,4-Trimethyl-	12.868	114.2285	C_8H_{18}		29
23	Diazene,Bis(1,1-Dimethylethyl)-	12.868	$C_8H_{18}N_2$	142.2419		30

Table 4. Continued...

Sl.No	Name of the Compound	RT	MW	Molecular Formula	Structure	Reference
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25	Cyclopentanol,2-methyl-, Trans-	12.929	$C_6H_{12}O$	100.1589		32
26	Vinyldimethyl(Acetoxymethyl) Silane	16.959	158.27	$C_7H_{14}O_2Si$		33
27	1-Butyl(dimethyl)Silyloxpropane	16.959	206.35	$C_9H_{22}O_3Si$		34
28	1-Dimethyl(octyl) Silyloxpropane	16.959	230	$C_{13}H_3OOS$		35
29	Trimethylsilyl acetate	16.959	132.23	$C_5H_{12}O_2Si$		36
30	Glycerin	18.184	92.0938	$C_3H_8O_3$		37
31	1,2,3,4-Butanetetrol, [S- (R*, R*)	18.184	122.1198	$C_4H_{10}O_4$		38

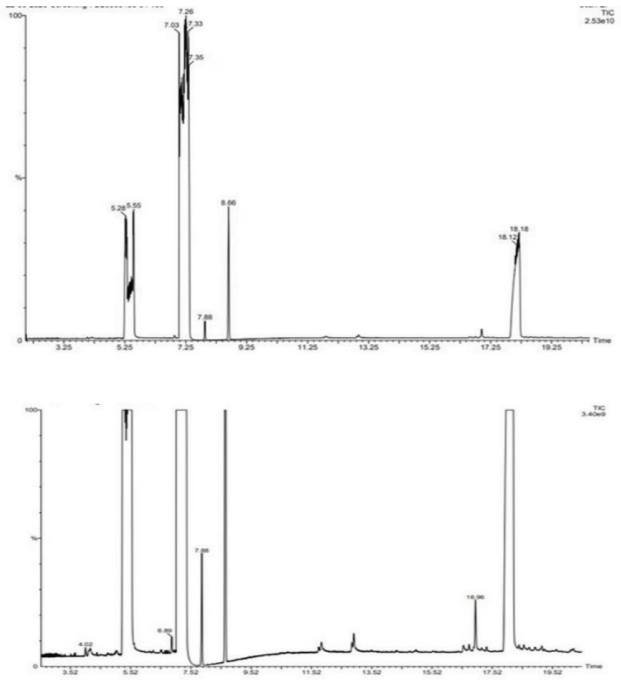


Figure 1. Detailed chromatogram of pupae oil by GCMS analysis.

hexane, pentane and other components like glycerine, propanolamine were also matched with the GCMS spectral library. On a dry weight basis, the average oil production from tasar pupae waste was 20.5%, while the percentage yield of biodiesel was seen to be quite high (78%). The above results are in congruence with the work done by M. Sharma *et al.*, 2016 in muga silkworm pupae where the waste silkworm pupae contained a high percentage of oil (30-40%), which was further converted into biodiesel. In contrast to our results, the study conducted in the de-silked *Bombyx mori* L., for the production of methyl ester by two step trans esterification reaction showed the highest conversion of pupae oil to the fatty acid methyl ester as 98.9 wt% at the favourable conditions of 65 degree celsius. The conversion and methyl ester properties were confirmed by H-NMR[4,5,7]. Similar findings were seen in Eri silkworm pupae where trans-esterification process resulted in 90% of the methyl ester yield[2].

In recent studies, animal fat has become very popular and can be used as an alternative fuel for CI engines[7].

Many of such research are confined to *B. mori*, Eri and Muga varieties of silkworms. The study conducted by author[4], showed use of de-silked *B. mori* L., as a raw material, for producing methyl ester by utilising two step reaction technique. Its comparison with tasar variety used in this study revealed a significant result with a yield of 78%. Also, the de-silked silkworm pupae oil's high concentrations of free fatty acids have garnered a lot of interest. The viability of producing biodiesel from de-silked silkworm pupae was examined, and the experimental parameters (such as the catalyst concentration, molar ratio of methanol oil, reaction time, and temperature) were researched by the author[2]. Similar findings were seen by the author[7], in *B. mori* pupae biodiesel which was then synthesized by the base catalyzed trans esterification along with methanol and it met the ASTM standards.

4.0 Conclusion

The exploration of unconventional feedstock for biofuel production has gained attraction in various industries across various sectors, with a notable example being the conversion of silkworm pupae waste into biodiesel. This innovative approach not only addresses waste management challenges but also holds the potential to revolutionize fuel sources. One such economy fetching sectors is the mining industries where energy demands are substantial and transportation costs can be a significant operational concern. The adoption of biofuels derived from waste byproducts offers a dual benefit. The integration of silkworm pupae waste-derived biodiesel in the mining sector render a multifaceted approach to address environmental, economic, and social aspects, aligning with the industry's evolving landscape and sustainability goals.

Through this study, we infer that the waste Tasar generated from silkworm cocoons can be reckoned as a fitting and future-ready resource for the extraction of biofuels for diesel-powered vehicles. This is augmented by the fact that the successful conversion rate of bio oil to biodiesel stands at an above average value of 78%. Tasar is a wild variety of silkworm, so the yield thus obtained is certainly of interest. Results reveal that FAME obtained by the trans-esterification process, matches the prerequisite for a preferable biodiesel. The yield of the biodiesel may further be enhanced by altering its reaction condition or catalyst concentration. Lastly, this work concludes that all kinds of silkworm pupae have a latent potential of providing alternative feed stalk for generating CI engine biofuels, in the days to come.

5.0 Future Work

The study as a whole, aims at exploring and utilising silkworms and its potential beyond the silk industry. The concern about conversion of bio oil to biodiesel from the tasar silkworm pupae waste can pave a new way to meet the demand of fuel consumption as well as utilize the pupae waste effectively. Since the production will surely be ecofriendly, this novel approach will mitigate the ever-increasing demand of fossil fuels and efficiently use the waste silkworm pupae to a useful commercial product. The adoption of this biodiesel aligns with regulatory standards, enhances energy security by diversifying fuel sources, and improves community relations by showcasing a commitment to eco-friendly practices.

Moreover, the discarded pupae pack in a good amount of lipids, converting them into biodiesel is remarkably the best solution in a sustainable way.

6.0 References

1 Rodriguez RP, Melo EA, Perez LG, Verhelst S. Conversion of by-products from the vegetable oil industry into biodiesel and its use in internal combustion engines: A review. Braz J Chem Eng. 2014; 31(2):287-301. https://doi.org/10.1590/0104-6632.20140312s00002763

2. Sharma M, Ganguly M. *Attacus ricinii* (Eri) pupae oil as an alternative feedstock for the production of biofuel. Environmental Science, Agricultural and Food Sciences. 2011; 2(2).

3. Sarma M, Ganguly M. Production of high-quality biodiesel from desilked muga pupae (*Antheraea assamensis*). *Res J Chem Environ Sci*. 2016; 4(4):40-5.

4. Nadanakumar V, Arivalagar AA, Lagumurthi NA. Studies on production and optimization of silkworm biodiesel. J Chem Pharm Res. 2016; 9(4):3063-9.

5. Gu SS, Wang J, Pang N, Wang FQ, Li C, Wu F. Biodiesel production from silkworm pupae oil using solid base catalyst. Adv Mater Res. 2013; 634-638:711-5. https://doi.org/10.4028/www.scientific.net/amr.634-38.711

6. Leong SY, Kutty SRM, Malakahmad A, Tan CK. Feasibility study of biodiesel production using lipids of *Hermetia*

illucens larva fed with organic waste. Waste Manag. 2016; 47:84-90. https://doi.org/10.1016/j.wasman.2015.03.030
7. Pradeep NR, Kumarappa S, Kulkarni BM. Characterization and evaluation of fuel properties of pupae biodiesel-diesel blends. International Journal of Latest Technology in Engineering, Management and Applied Science (IJLTEMAS). 2017; 6(8):23-36.
8. Jessica A, Rao MRK, Anthony J, Prabhu K, Johnson WMS, Balasubramanian BS, Dinakar S. The GC-MS study of one *ayurvedic* preparation *Katakakhadiradi kashayam*. Int J Pharm Sci Rev Res. 2016; 39(2):216-24.
9. Mathkoor MM, Alkhfaji EN, Oda NAU. Using GC-MS technology to identify the compounds resulting from mixing of alcoholic extracts of some medicinal plants. 2023; 6(3): 486-99. https://doi.org/10.26655/JMCHEMSCI.2023.3.5
10. Wilson WC. Evaluation of ethanedial dioxime (pik-off) as an abscission agent on Florida oranges used for processing1. J Am Soc Hortic Sci. 1981; 106(2):184-6. https://doi.org/10.21273/jashs.106.2.184
11. Ureche D, Rija A, Bulhac I, Coropceanu E, Bourosh P. Synthesis and structural study of 2D coordination polymers of Zn (II), Cd (II) and Mn (II) based on diaminobenzoylglyoxime. Russ J Inorg Chem. 2020; 65(12):1838-47. https://doi.org/10.1134/s0036023620120189
12. Sumathi BM, Uthayakumari F. GC MS analysis of leaves of *Jatropha maheswarii* Subram and Nayar. Sci Res Rep. 2014; 4(1):24-30.
13. Trimm HH. An efficient preparation, spectroscopic properties, and crystal structure of 1, 1-Bis (4-[2-(dimethylamino) ethoxy] phenyl)-2-(3-guaiazulenyl) ethylene. Org Chem. 2011. https://doi.org/10.1201/b12874-8
14. Kollensperger F. Treatment of rhinitis with benzedrex inhalation. Wien Med Wochenschr. 1946; 103(44):834.
15. Ferguson G. Acta crystallographica section C-crystal structure communications. Acta Cryst. 2008; A64:C167-168.
16. Lewis RA, Hawley's Condensed Chemical Dictionary. 16th ed. Hoboken (NJ): Wiley; 2016. p. 1568.
17. Melville GW, Siegler JC, Marshall PW. Three and six grams supplementation of d-aspartic acid in resistance trained men. J Int Soc Sports Nutr. 2015; 12(1):1-6. https://doi.org/10.1186/s12970-015-0078-7
18. Eskenazi B, Maizlish NA. Effects of occupational exposure to chemicals on neurobehavioral functioning. In: Tarter RE, Butters N, Beers SR, editors. Medical Neuropsychology. Boston (MA): Springer; 1988. p. 223-64. Available from: https://doi.org/10.1007/978-1-4757-1165-3_9
19. Clough SR. Hexane. Encyclopedia of Toxicology. Science Direct. 2014; 3:900-4.
20. Polyakov P, Luettmer-Strathmann J, Wiegand S. Study of the thermal diffusion behavior of alkane or benzene mixtures by thermal diffusion forced rayleigh scattering experiments and lattice model calculations. J Phys Chem. 2006; 110(51):26215-24. https://doi.org/10.1021/jp065825v
21. Zhou GB, Guan YQ, Tang H, Zhao YB, Yang LR. Practical synthetic approach to 4-acetoxy-2-azetidinone for the preparation of carbapenem and penem antibiotics. Res Chem Intermed. 2012; 38(1):251-9. https://doi.org/10.1007/s11164-011-0344-5
22. Yavolovskii AA, Timofeev OS, Ivanov EI. Novel polycyclic pyrimidines. Heterocycl Chem. 1998; 34(8):976-8. https://doi.org/10.1007/bf02311336
23. Kohsaka Y. Conjugate substitution reaction of α- (substituted methyl) acrylates in polymer chemistry. Polym J. 2020; 52(10):1175-83. https://doi.org/10.1038/s41428-020-0376-z
24. Sun Y, Liu F, Wang X, Wang H, Liu Z. Effect of acetohydroxamic acid on the extraction of plutonium by dilute tri-n-butyl phosphate/n-dodecane in the presence of a high concentration of $AI(NO_3)_3$. J Radioanal Nucl Chem. 2021; 327(3):1121-9. https://doi.org/10.1007/s10967-021-07602-5
25. Appel KE, Abraham K, Berger-Preiss E, Hansen T, Apel E, Schuchardt S, Lampen A. Relative oral bioavailability of glycidol from glycidyl fatty acid esters in rats. Arch Toxicol. 2013; 87(9):1649-59. https://doi.org/10.1007/s00204-013-1061-1
26. Cunningham J, Srijaranai S. Metal oxides sensitized photooxidations in heterogeneous and homogeneous systems. I. initial photodehydrogenations of isopropanol and cyclobutanol. Photocatalysis and Environment. Springer. 1988: pp. 688-9. https://doi.org/10.1007/978-94-009-3015-5_31
27. Bredikhin AA, Pashagin AV, Strunskaya EI, Gubaydullin AT, Litvinov IA, Bredikhina ZA. New reaction of glycidols with oxalyl chloride and phosgene-an approach to cyclic esters. Russ Chem Bull. 1999; 48(11):2086-90. https://doi.org/10.1007/bf02494853
28. Seferis JC, Nicolais L. The role of the polymeric matrix in the processing and structural properties of composite materials. Springer. 2012. https://doi.org/10.1007/978-1-4615-9293-8
29. Elsayed Y, Dallas A, Beatty P. Experimental and predicted adsorption isotherms of 2, 2, 4-trimethylpentane and toluene on activated carbon for industrial applications. Res Chem Intermed. 2015; 41(3):1267-82. https://doi.org/10.1007/s11164-013-1271-4
30. Ghijsen RT, Nooitgedacht F, Poppe H. The preparation of immobilized polysiloxane coated on packings materials for high-pressure gas chromatography. Chromatographia. 1986; 22(1):201-8. https://doi.org/10.1007/bf02257329
31. Azarbad MH, Jelen H. Determination of hexanal-an indicator of lipid oxidation by static headspace gas chromatography (SHS-GC) in fat-rich food matrices. Food Anal Methods. 2015; 8(7):1727-33. https://doi.org/10.1007/s12161-014-0043-0

32. Yan W, Liao T, Tuguldur O, Zhong C, Petersen JL, Shi X. Mitsunobu reaction of 1,2,3-NH-Triazoles: A region - and stereoselective approach to functionalized triazole derivatives. Chem Asian J. 2011; 6(10):2720-4. https://doi.org/10.1002/asia.201100357
33. Mabaso NH. Exploring Iso-mukaadial acetates and other small compounds as inhibitors of recombinant plasmodium falciparum lactate dehydrogenase. 2021.
34. Schneider C. Synthesis of 1,2-difunctionalized fine chemicals through catalytic, enantioselective ring-opening reactions of epoxides. Synth. 2006; 23:3919-44. https://doi.org/10.1055/s-2006-950348
35. Elmore JS, Mottram DS, Enser M, Wood JD. Novel thiazoles and 3-thiazolines in cooked beef aroma. J Agric Food Chem. 1997; 45(9):3603-7. https://doi.org/10.1021/jf970066m
36. Voronkov MG, Roman VK, Senatorskaya VN. Reaction of tris (trimethylsilyl) phosphate with salts of inorganic and organic acids. Chem Informationsdienst. 1978; 9(26):192-3. https://doi.org/10.1002/chin.197826237
37. Mota CJ, Pinto BP, Lima AL. Glycerol utilization. In: Paganini MC, editor. Glycerol. Cham: Springer; 2017. p. 11-19. Available from: https://doi.org/10.1007/978-3-319-59375-3_2
38. Jesus AJL, Tome LIN, Eusebio ME, Redinha JS. Enthalpy of sublimation in the study of the solid state of organic compounds: application to erythritol and threitol. J Phys Chem B. 2005; 109(38):18055-60.