Original Article (Special Issue)

Preparation and Characterization and Thermal Study of New Copolymers of Semicarbazide and Fatty Acids Derivatives with Malic Anhydride and Assess their Biological Activity

Iman Aywob Yass*

Department of Chemistry, College of Education for Women, University of Tikrit, Tikrit, Iraq

ARTICLE INFO

ABSTRACT

In this study, new semicarbazide derivatives [E_1-E_5] were prepared by the reaction of semicarbazide with different fatty acids (olic, linolic, linolinic, recenolic and cinnamic acid) in DMF, then this compounds will polymerization with malic anhydride in H_2O_2 as initiator to get [EP_1-EP_5]. The prepared compounds were characterized by physical properties, UV-Vis, FT-IR, ^{1}H-NMR, ^{13}C-NMR and TGA analysis.TLC checked the purity for these compounds.The antibacterial activity were studied against different kinds of bacteria, namly*Stophylococcuceaures,Stophylococcuce Saprophytic* and *Protes.*

GRAPHICAL ABSTRACT
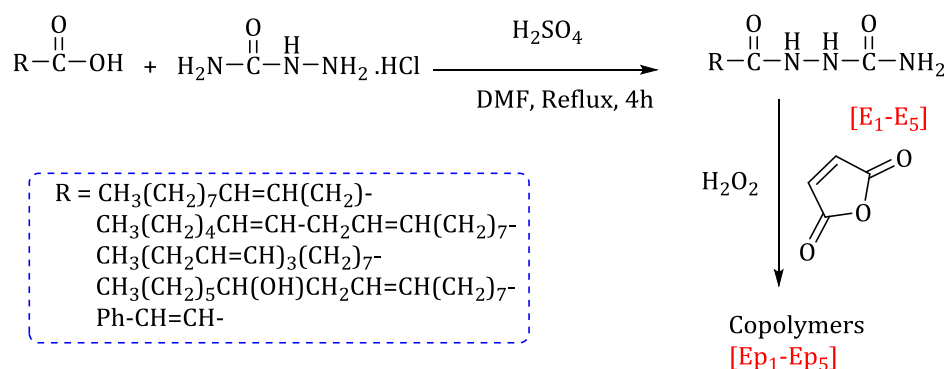
Introduction

Plant oils offer many advantages apart from their renewability. Their world -wide availability and relatively low prices make them industrially attractive and feasible. as daily demonstrated with industrial oleo chemistry. Furthermore diverse chemistry can be applied on them. Leading to a large variety of monomers and polymers [1]. Most importantly, the synthetic potential of nature is very high with this renewable feedstock and consequently. Only a few minor modification reactions (if any at all) have to be performed in order to obtain suitable monomers for many different applications [2]. The double bonds present in fatty acids [FA] make them ideal starting materials for such transformations .Moreover olefin metathesis can not only be used for monomer synthesis but also as polymerization technique [3]. The possibility of polymerization of FA is feasible since in their structure many double bonds are found and available. Therefore, there is favored radical polymerization reaction through the hydrogen in the allyl position, duo to the higher reactivity of this hydrogen creating a distinct monomer [4]. A large number of polymers applications results from their early properties and the way they are processed. In order to increase these applications and also to improve some properties, it is common in polymer industry to under go by synthesis modification [4]. In a recent studies fatty acids demonstrated biological activity [5-18] and some physical properties [19-28] and its polymers [29-41].

Materials and Methods

All chemicals had been used as supplied by (Alfa Assar and Aldrich).

Devices instrument

The melting points were determined by Electro thermal Melting Apparatus 9300 in open capillary tubes that were uncorrected. Thin layer chromatography (TLC) was used for monitory the reaction and check purity.The FT-IR spectra were recorded using FT-IR 8400s shimadzu spectro photometer scale (400-4000 cm^{-1}). The UV-Vis spectra was measured in ethanol using shimadzu 800UV in rang (200-400) nm. ^{1}H-NMR and ^{13}C-NMR spectrum was recorded on Varianoperaing at 400 MHz instrument using DMSO-d^6 and CDCl$_3$ as a solvent.Thermal analysis *Tg* was recorded on instrument SDT Q600 V20.9 Build 20 under Nitrogen.

Synthesis methods.

Synthesis of semicarbazide derivatives [E$_1$-E$_5$]

Semicarbazide (0.0l mol, 0.75 g) was dissolved in (50 mL) of DMF. After complete dissolving, 0.0l mol of one of different fatty acid was add. After adding (3 drops) of diluted H$_2$SO$_4$ (1:1), the mixture was then refluxed for 4-5 hours and cooled to room temperature. Filtered, dried and recrystallized physical properties are given in Table 1 [42].

Table 1: Physical properties of prepared compounds [E$_1$-E$_5$]

$$R-\overset{\overset{O}{\|}}{C}-\overset{H}{N}-\overset{H}{N}-\overset{\overset{O}{\|}}{C}-NH_2$$

| Comp. No.	R	Molecular formula M.Wt. (g/mole)	Color	M.P (°C)	Time (h)	Yield (%)	Rf. EtOH (cm)
E$_1$	CH$_3$(CH$_2$)CH=CH(CH)$_7$C=O	C$_{19}$H$_{37}$N$_3$O$_2$ 340.53	White	261 dce.	4	82	3
E$_2$	CH$_3$(CH$_2$)$_4$CH=CHCH$_2$=CH(CH$_2$)$_7$C=O	C$_{19}$H$_{35}$N$_3$O$_2$ 338.52	White	265	4	60	2.6
E$_3$	CH$_3$CH$_2$(CH=CHCH$_2$)$_3$CH(CH)$_7$C=O	C$_{19}$H$_{33}$N$_3$O$_2$ 332.50	Yellow	268-270	4	75	5
E$_4$	CH$_3$(CH$_2$)$_5$CH(OH)CH$_2$CH=CH(CH$_2$)$_7$C=O	C$_{19}$H$_{37}$N$_3$O$_3$ 356.52	White	212-214	5	23	1
E$_5$	Ph-CH=CH-C=O	C$_{10}$H$_{11}$N$_3$O$_2$ 221.23	White	160	6	50	5

Synthesis of polymer [EP₁-EP₅]

In dry polymerization bottle (0.0l mol) of semicarbzide derivatives [E₁-E₅] and equivalent moles of malic anhydride was dissolved in (10 mL) of DMF then (0.1 L of H_2O_2 was add and bottle was flushed with nitrogen and fimly stoppered.The mixture was maintained at 80 °C for 3 h. then the resulted solution was poured into 25 mL of ethanol and precipitated polymer was filtered washed with ethanol and dried physical properties of polymer [EP₁-EP₅] are listed in Table 2 [43].

Table 2: Physical properties of prepared polymer [EP₁-EP₅]

Comp. No.	R	Color	S.P. (°C)	Yield (%)	R.f. EtOH (cm)
Ep₁	$CH_3(CH_2)_7CH=CH(CH)_7C=O$	Dark Brown	>300	85	1
Ep₂	$CH_3(CH_2)_4CH=CHCH_2ch=CH(CH_2)_7C=O$	Dark Brown	198 dec.	75	1.5
Ep₃	$CH_3(CH_2)_4CH=CHCH_2CH=CH$ $CH_2CH=CH(CH_2)_7C=O$	Dark Brown	142 dec.	70	1.6
Ep₄	$CH_3(CH_2)_5CH(OH)CH_2CH=CH(CH_2)_7C=O$	Brown	130-137	85	1.2
Ep₅	$Ph-CH=CH-C=O$	Yellow	194 dec.	80	1.8
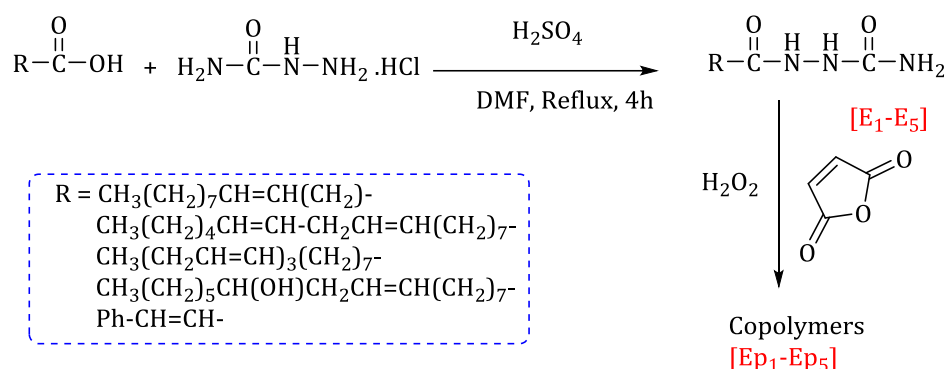
Scheme 1: Synthesis of polymer [EP₁-EP₅]

Results and Discussion

Characterization of seiecarbazide derivatives [E₁-E₅]

The semicarbazide derivatives [E₁-E₅] were prepared by the reaction semicarbazide with (1mol) of fatty acids (olic, lenolic, lenolinic, recenolic and cinnamic acid) in DMF.

The UV spectra gave absorption band at different wave lengthe for the resulted semicarbazide derivatives (in %99 EtOH) due to $\pi \rightarrow \pi^*$ and $n \rightarrow \pi^*$ transition and all these transition are listed in Table 3.

The FT-IR spectrum for semicarbazide derivatives showed to appear two band due to primary amid group (3595-3392), (3394-3300) cm⁻¹, beside secondary amid group which appear (3433-3249) cm⁻¹, ν(=CH) alken appear (3086-3010) cm⁻¹, (ν C-H) aliphatic appear to band (2962-2926), (2860-2818) cm⁻¹, also (C=O) amid group appear (1695-1646) cm⁻¹ and (1600-1608) cm⁻¹ due to (ν C=C) alken, (CH₂ and CH₃) group appear (1492-1402) cm⁻¹, and (769-750), (754-715) cm⁻¹ attributed to ν (C-C)asy., sym. In addition, a band at (3222) cm⁻¹ attributed to (ν OH) alcohol in [E₄] also appearance of bands (3190) cm⁻¹ due toν (C-H)arom., and (1616, 1525) cm⁻¹ due to ν (C=C)arom. in [E₅],These results are in agreement with recent literature[14]. As shown in Figure S1 E₁. UV and FT-IR spectrum are given in Table 3.

Moreover the ¹H-NMR spectra of [E₁] Figure S2 shows a clear singlet signal at δ=10.66ppm attributed to –CO-NH and δ =10.37 ppm attributed to NH- C=O, triplet signal at δ = 7.23, 7.10,6.97 attributed to NH₂, triplet signal at δ =5.03, 5.02, 4.93, 4.74 ppm attributed to -CH=CH-, triplet

signal at δ =4.74, 4.34, 4.33 ppm attributed to CH₂-C=O, multiple signal at arrange δ =4.33-2.01 ppm for CH₂ and singlet signal at δ = 2.01 to CH₃. As well as signal of DMS0-*d₆* appear at δ = 2.50, 2.51, 2.52 ppm.

The ¹³C-NMR spectrum of [E₁] Figure S3 shows a clear singlet signal at δ =178.89 ppm attributed to -C=O-NH, singlet signal at δ =152.12 ppm attributed to -C=O-NH₂, doublet signal at δ =131.94, 119.34 ppm attributed to -CH=CH-, multiple signal at rang δ=25.50-18.02 ppm due to CH₂ and singlet signal at δ =15.87 ppm attributed to CH₃.

The ¹H-NMR spectra of [E₂] Figure S4 shows singlet signal at δ =10.66 ppm attributed to C=O-NH, singlet signal at δ =10.37 ppm attributed to HNC=O, triplet signal at δ =7.23, 7.10, 6.97 ppm attributed to NH₂, multiple signal an the rang 5.03-4.74 ppm attributed to-CH=CH, triplet signal at δ =4.34, 4.33, 3.98 ppm attributed to -CH=CH-CH₂*-CH=CH-, also multiple signal at δ =3.58-2.01 ppm attributed ta CH₂ group and singlet signal at δ =2.01 ppm attributed to CH₃ as well as signal of DMSO-*d₆* appear at δ =2.52, 2.51, 2.50 ppm.

The ¹³C-NMR spectrum of [E₂] shows singlet signal at δ =167.37 ppm attributed to C=O-NH and singlet signal at δ =155.21ppm attributed to C=ONH₂, Doublet signal at δ =132.17, 129.12 ppm attributed to -CH=CH-, singlet signal at δ =61.78 ppm due to CH₂, multiple signal an the rang δ =17.90-16.62 ppm attributed CH₂, singlet signal at δ =14.35ppm due to CH₃.

The ¹H-NMR spectra of [E₃] Figure S5 shows a clear singlet signal at δ =11.12 ppm attributed to amin group in CH₂-CO-NH and singlet single at 10.58 ppm attributed to -CO-NH troubled signal appear at δ =7.26, 7.14, 7.01 ppm attributed to NH₂, triplet signal at δ =6.25, 5.83, 4.53 ppm attributed to CH=CH, triplet signal at δ =2.51, 2.44, 2.28 ppm attributed to CH₂ and singlet signal at δ =1.24 ppm attributed to CH₃. DMSO-*d₆* signal appear at δ =2.51 ppm.

The ¹³C-NMR spectra of [E₃] Figure S6 shows doublet signal at δ =169.76, 163.40 ppm attributed to -CO-NH, and triplet signal at δ =150.45, 147.28, 145.34 ppm attributed to -CO-NH₂ singlet signal at δ =130.11ppm due to HC=CH, triplet signal at δ=79.77,79.44, 79.11 ppm attributed to CH=CHCH₂*CH=CH, multiple signals at rang δ=31.15 -16.66ppm due to CH₂ and singlet signal at δ =16.41 attributed to CH₃ group.

The ¹H-NMR spectra of [E₄] Figure S7 shows doublet signal to NH group at δ =9.90, 9.71 ppm and doublet signal for NH₂ group at δ=8.70, 8.58 ppm multiple signal at ring δ =7.90-7.01ppm attributed to -HC=CH-doublet signal at δ =3.39, 3.37 ppm duo to OH alcohol. Singlet signal at δ =2.29 ppm attributed to CH. multiple signal at rang δ =2.10-1.39 ppm duo to CH₂ and singlet signal at δ=0.85 ppm attributed to CH₃ as well as signal of DMSO-*d₆* appear at δ =2.51 ppm.

The ¹³C-NMR spectrum of [E₄] shows singlet signal at δ =163.02 ppm attributed to C=O-NH and singlet signal at δ =154.17ppm attributed to C=ONH₂, Doublet signal at δ =1143.46, 135.41 ppm attributed to -CH=CH-, singlet signal at δ =60.92 ppm due to C-OH, singlet signal at δ =53.21ppm due to CH₂, multiple signal an the rang δ =25.08-16.62 ppm attributed CH₂, and singlet signal at δ =16.41ppm due to CH₃.

The ¹H-NMR spectra of [E₅] shows doublet signal at δ =10.91, 10.73 ppm attributed to C=O-NH, δ =10.37 ppm attributed to C=ONH, multiple signal at δ =7.75 -7.61 ppm attributed to CH aromatic, doublet signal at δ =7.68, 7.67 ppm due to NH₂ and multiple signal at 6.67 -7.63ppm attributed to -CH=CH- aleph. As well as signal of DMSO-d₆ appear at δ =2.57, 2.50 ppm.

The ¹³C-NMR spectrum of [E₅] shows singlet signal at δ =169.15 ppm attributed to C=O-NH and singlet signal at δ =159.08ppm attributed to C=ONH₂, multiple signal at δ =133.28-128.80ppm attributed to CH aromatic, doublet signal at δ =127.63, 125.60 ppm due to -CH=CH-.

Characterization of polymers [Ep₁-Ep₅]

Semicarbazid derivatives copolymers [Ep₁-Ep₅] were prepared from the reaction semicarbazide derivatives [E₁-E₅] and malice hydride in DMF with H₂O₂ as initiator. The FT-IR spectrum showed to appear two band due to primary amid group (3450-3393), (3496-3340) cm⁻¹, beside secondary amid group which appear (3327-3192) cm⁻¹.

Beside new bands appear at 1728-1701 cm^{-1} attributed to the (C=O) of malice anhydride as well as the appearance of the bond at 1116-1105 cm^{-1} due to (C-O) malic anhydride. The rest of the packages kept their positions as shown in Figure S8 and S9, Ep$_1$, Ep$_5$ and FT-IR spectrum are given in Table 3.

Table 3: FT-IR & UV-Vis data of prepared compounds and Copolymers

Comp. No.	IR (KBr) cm^{-1}									λmax EtOH
	ν (NH$_2$) Asy. Sym.	ν (NH)	ν (=CH) Alkene	ν (CH$_2$)(CH$_3$) Alep. Asy. Sym.	ν (C=O) Amid	N (C=C) Alkene	δ(CH$_2$)(CH$_3$) Asy. Sym.	ν (C-C)	other	
E$_1$	3488 3394	3288	3041	2962 2918	1646	1600	1479 1355	769 754	-	246 260
E$_2$	3450 3390	3249	3016	2948 2858	1695	1608	1456 1367	763 727	-	254 250 260
E$_3$	3495 3450	3433	3086	2926 2860	1674	1600	1452 1367	750 715	-	250 260 280
E$_4$	4360 3420	3250	3018	2927 2850	1697	1608	1464 1370	763 721	ν O-H Alcohol 3222	251 265
E$_5$	3392 3300	3288	3010	2928 2854	1690	1600	1492 1381	769 719	ν C-H Ar. 3190 ν C=CAr. 1616 1525	278

CoPoly No.	IR (KBr) cm^{-1}						
	ν (NH$_2$) Asy. Sym.	ν (NH)	ν (CH$_2$)(CH$_3$) Alep. Asy. Sym.	ν (C=O) Acid	δ (CH$_2$)(CH$_3$) Asy. Sym.	N (C-O)	other
Ep$_1$	3414 3373	3327	2912 2850	1722	1460 1373	1114	-
Ep$_2$	3433 3340	3271	2995 2880	1718	1450 1396	1105	-
Ep$_3$	3450 3496	3271	2926 2850	1701	1421 1380	1105	-
Ep$_4$	3417 3394	3265	2924 2840	1730	1450 1370	1116	OH alcohol 3433
Ep$_5$	3394 3350	3192	2930 2835	1728	1460 1367	1114	C=C Aromatic. 1631,1595,1458

Thermal characterization of copolymers [Ep$_2$-Ep$_5$]

The thermal behavior data of copolymers [Ep$_2$-Ep$_5$] is summarized in Table 5. Thermogram of [Ep$_3$] show a broad single stage weight loss because of linkages in its structure. Is higher than other copolymers that may emanate from higher cross linking in copolymer backbond (Figure S11).

Thermogram of [Ep4] show a double stage weight loss because of double bond and OH alcohol in its structure that come from cross linking in copolymer bacbbond (Figure S12). Thermograms of [Ep2] and [Ep3] have three and four stage decomposition straight in the rate of 97.33%, 89.57%. Char yield of Ep2 is higher than other copolymers (Figure S10 and S13).

Also the prepared copolymers showed good thermal stability through their thermal analysis, softening points and this due to the presence of semicarbazide and fatty acids and malic anhydride in their repeating units since insertion of these components in copolymeric chains exhibit the copolymer good thermal and chemical stability.

Table 4: ^{1}H&^{13}C data of prepared compounds *[E$_1$-E$_5$]*

Comp. No.		
E$_1$	^{1}H	*^{1}H-NMR Spectrum, δppm, 300H$_Z$, δ40 (DMSO-d$_6$)*, 10.66 (1H, NH), 10.37 (1H, NH), 7.23, 7.10, 6.97 (2H, NH$_2$), 5.03-4.74 (4H, CH=CH), 4.74, 4.33 (3H, CH$_2$C=O), 3.96, 3.58 (28H, CH$_2$), 1.01 (3H, CH$_3$).
	^{13}C	*^{13}C-NMR Spectrum, δppm, 300H$_Z$, δ40 (DMSO),* 178.89 (O=C-NH), 152.12 (O=C-NH$_2$) 131.94, 119.34 (C=C), 25.50-18.02 (CH$_2$), 15.87 (CH$_3$).
E$_2$	^{1}H	*^{1}H-NMR Spectrum, δppm, 300H$_Z$, δ40 (DMSO-d$_6$)*, 10.66 (1H,NH-C=O), 10.37 (1H,NH-C=O), 7.23, 7.10, 6.97 (2H, NH$_2$), 5.03-4.74 (CH=CH), 4.34, 4.33, 3.98 (2H, CH$_2$), 3.58, 2.01 (22H, CH$_2$), 2.01 (3H, CH$_3$), (28H, CH$_2$), 1.01 (3H, CH$_3$).
	^{13}C	*^{13}C-NMR Spectrum, δppm, 300H$_Z$, δ40 (DMSO),* 167.37 (O=C-NH), 155.21 (O=C-NH$_2$), 132.17, 129.12 (C=C), 61.78 (CH$_2$), 17.90-16.62 (CH$_2$), 14.35 (CH$_3$).
E$_3$	^{1}H	*^{1}H-NMR Spectrum, δppm, 300H$_Z$, δ40 (DMSO-d6)*, 11.12(1H, NH), 10.58 (1H, NH-C=O), 7.26, 7.14, 7.01 (2H, NH$_2$), 6.25, 5.83, 4.53 (22H, CH$_2$-CH=CH), 2.51, 2.44, 2.28 (2H, CH$_2$), 1.24 (3H, CH$_3$).
	^{13}C	*^{13}C-NMR Spectrum, δppm, 300H$_Z$, δ40 (DMSO),* 169.76, 163.40 (O=C-NH), 150.45, 147.28, 145.34 (O=C-NH$_2$), 130.11 (C=C), 79.77, 79.44, 79.11 (CH=CH-CH$_2$*-CH=CH), 31.15-16.66 (CH$_2$), 16.41 (CH$_3$).
E$_4$	^{1}H	*^{1}H-NMR Spectrum, δppm, 300H$_Z$, δ40 (DMSO-d$_6$)*, 9.90,(1H, NH), 9.71 (1H, NH), 8.7, 8.58, (2H, NH$_2$), 7.90, 7.01 (2H, CH=CH), 3.39, 3.37 (1H, OH), 2.92 (1H, CH), 2.10-1.39 (15H, CH$_2$), 0.85 (3H, CH$_3$).
	^{13}C	*^{13}C-NMR Spectrum, δppm, 300H$_Z$, δ40 (DMSO),* 163.02, (O=C-NH), 154.17, (O=C-NH$_2$), 143.46, 135.41 (C=C), 60.92 (C-OH), 53.21 (CH$_2$), 25.08-16.62 (CH$_2$), 16.41 (CH$_3$).
E$_5$	^{1}H	*^{1}H-NMR Spectrum, δppm, 300H$_Z$, δ40 (DMSO-d$_6$)*, 10.91, (1H, NH), 10.73 (1H, NH), 7.75-7.71 (5H, CH-Ar), 7.68, 7.67, 7.65-6.97 (2H, CH=CH).
	^{13}C	*^{13}C-NMR Spectrum, δppm, 300H$_Z$, δ40 (DMSO),* 169.15 (O=C-NH), 159.08, (O=C-NH$_2$), 133.28-128.80 (C-H$_{Arom.}$), 127.63, 125.60 (C=C).

Table 5: Thermal properties of copolymers [Ep$_2$-Ep$_5$]

CoPoly.	Step	TG%		
		T$_i$ C^o	T$_f$ C^o	Wt loss %
Ep$_2$	1	25	230	6.165
	2	230	350	34.66
	3	350	600	56.51
Ep$_3$	1	25	600	80.58
Ep$_4$	1	250	290	33.07
	2	290	600	12.87
Ep$_5$	1	25	150	3.655
	2	150	225	10.37
	3	225	350	70.53
	4	350	600	5.027

Antibacterial activity

The effect of the prepared compounds [Ep$_1$-Ep$_5$] on the growth of bacterla, namely *Staphylococcus auras*, *Staphylococcus staprophyticus* gram (+ve)*, Proteus* gram (-ve). Antibacterial activity of the prepared compounds were studied and the results showed that some of the prepared compounds possess good antibacterial activity. The results of in hibition zone diameter (IZD) in millimeter are shown in Table 5 [16].

Table 6: Growth inhibition zone diameter (mm) of seven heterocyclic compounds against two pathogenic bacteria species

Comp. No.	Conc. (mg/mmol)	*Staphylococcus auras*	*Staphylococcus saprophytic*	*Protes*
P1	0.01	17	20	11
	0.001	14	14	13
	0.0001	19	13	16
P2	0.01	20	15	12
	0.001	23	25	14
	0.0001	20	20	11
P3	0.01	25	10	31
	0.001	22	14	28
	0.0001	25	10	29
P4	0.01	21	14	21
	0.001	23	19	20
	0.0001	27	14	24
P5	0.01	21	14	19
	0.001	22	17	21
	0.0001	21	10	16
Ep$_1$	0.01	20	21	16
	0.001	24	20	18
	0.0001	21	25	15
Ep$_2$	0.01	21	15	10
	0.001	21	21	11
	0.0001	20	25	10
Ep$_3$	0.01	23	24	21
	0.001	18	25	19
	0.0001	22	25	23
Ep$_4$	0.01	26	16	21
	0.001	23	10	19
	0.0001	16	15	20
Ep$_5$	0.01	11	14	27
	0.001	26	15	26
	0.0001	15	21	30
Amoxicillin	0.01	12	11	15
	0.001	13	14	10
	0.0001	14	13	11
Ampicillin	0.01	22	22	23
	0.001	23	21	33
	0.0001	44	24	40
Ciprofluxacin	0.01	20	21	23
	0.001	36	26	41
	0.0001	34	30	43
Blank dish	0.01	0	0	0
	0.001	0	0	0
	0.0001	0	0	0

Conclusion

The aim of the research was to preparation of some new compounds and polymers for some

fatty acids and study of their thermal stability, which showed high stability. The antibacterial activity of all of the synthesized compounds [E1-EP5] was tested in vitro. It showed good activity against selected gram-negative and gram-positive bacteria.

Funding

Authors' contributions

All authors contributed toward data analysis, drafting and revising the paper and agreed to responsible for all the aspects of this work.

Conflict of Interest

Authors have declared that they have no known competing financial interests or non-financial

ORCID:

Iman Aywob Yass

https://orcid.org/0000-0002-9796-3983

References

[1]. Nayak P.L., Natural oil-based polymers: opportunities and challenges. *Journal of Macromolecular Science, Part C: Polymer Reviews*, 2000, **40**:1 [Crossref], [Google Scholar], [Publisher]

[2]. de Espinosa L.M., Meier M.A., Plant oils: The perfect renewable resource for polymer science?!. *European Polymer Journal*, 2011, **47**:837 [Crossref], [Google Scholar], [Publisher]

[3]. Warwel S., Brüse F., Demes C., Kunz M., gen Klaas M.R., Polymers and surfactants on the basis of renewable resources. *Chemosphere*, 2001, **43**:39 [Crossref], [Google Scholar], [Publisher]

[4]. Lattmann B.H., Lunelli C.E., Scremin D.M., Padilha B., Trindade E.M., Zawadzki S.F., Synthesis and Characterization of Modified Polystyrene with Oleic Acid and an Allyl Ester Derivative. *Materials Research*, 2019, **22** [Crossref], [Google Scholar], [Publisher]

[5]. Darwees M.F., Molecular Characterization of ESBL Gene in Citrobacter Spp and Antibacterial Activity of Omega-3 Against Resistant Isolates. *Acta Environmentalica Universitatis Comenianae*, 2016 **24**:5 [Crossref], [Google Scholar], [Publisher]

[6]. Hady A.A., Darweesh M.F., Motar A.A., The antibacterial of essential fatty acid semicarbazide extracted from flaxseed oil against some nosocomial infection bacteria in Iraq. *International Journal of Current Pharmaceutical Research,* 2017, **8**:31 [Google Scholar], [PDF]

[7]. Darweesh M.F., Molecular characterization of ESBL gene in Citrobacter spp. and antibacterial activity of omega-3 against resistant isolates. Current Issues in Pharmacy and Medical Sciences, 2017, **30**:156 [Crossref], [Google Scholar], [Publisher]

[8]. Chen L., Deng H., Cui H., Fang J., Zuo Z., Deng J., Li, Y., Wang X., Zhao L., Inflammatory responses and inflammation-associated diseases in organs. *Oncotarget*, 2018, **9**:.7204 [Crossref], [Google Scholar], [Publisher]

[9]. Goyal A., Sharma V., Upadhyay N., Gill S., Sihag M., Flax and flaxseed oil: an ancient medicine & modern functional food. *Journal of food science and technology*, 2014, **51**:1633 [Crossref], [Google Scholar], [Publisher]

[10]. Fritsche K.L., Anderson M., Feng C., Consumption of eicosapentaenoic acid and docosahexaenoic acid impair murine interleukin-12 and interferon-γ production in vivo. *The Journal of infectious diseases*, 2000, **182**:S54 [Crossref], [Google Scholar], [Publisher]

[11]. Elagbar Z.A., Naik R.R., Shakya A.K., Bardaweel S.K., Fatty acids analysis, antioxidant and biological activity of fixed oil of Annona muricata L. seeds. *Journal of Chemistry*, 2016, **2016** [Crossref], [Google Scholar], [Publisher]

[12]. Ahmed N., Barrow C.J., Suphioglu C., Exploring the effects of omega-3 and omega-6 fatty acids on allergy using a HEK-blue cell line. *International Journal of Molecular Sciences*, 2016, **17**:220 [Crossref], [Google Scholar], [Publisher]

[13]. Lu Y., Chen Y., Wu Y., Hao H., Liang W., Liu J., Huang R., Marine unsaturated fatty acids: structures, bioactivities, biosynthesis and benefits. *RSC Advances*, 2019, **9**:35312 [Crossref], [Google Scholar], [Publisher]

[14]. Nuerxiati R., Wubulikasimu A., Mukhamedov N., Mirzaakhmedov S., Gao Y., Aisa H., Yili A., Biological Activity of Fatty Acids from Lipids of Orchis chusua. *Chemistry of Natural Compounds*, 2021, **57**:230 [Crossref], [Google Scholar], [Publisher]

[15]. Kaseke T., Opara U.L., Fawole O.A., Fatty acid composition, bioactive phytochemicals, antioxidant properties and oxidative stability of edible fruit seed oil: Effect of preharvest and processing factors. *Heliyon*, 2020, **6**:e04962 [Crossref], [Google Scholar], [Publisher]

[16]. Kumar N.G., Contaifer D., Madurantakam P., Carbone S., Price E.T., Van Tassell B., Brophy D.F., Wijesinghe D.S., Dietary bioactive fatty acids as modulators of immune function: implications on human health. *Nutrients*, 2019, **11**:2974 [Crossref], [Google Scholar], [Publisher]

[17]. Koch E., Hopmann C., Fröhlich L.F., Schebb N.H., Fatty acid and oxylipin concentration differ markedly between different fetal bovine serums: A cautionary note. *Lipids*, 2021, **56**:613 [Crossref], [Google Scholar], [Publisher]

[18]. Borhade S., Studies of Omega-3 Fatty Acid Semicarbazide Derivative of Natural Seed Oil. *International Journal of Development Research*, 2014, **4**:1428 [PDF]

[19]. Xia Y., Quirino R.L., Larock R.C., Bio-based thermosetting polymers from vegetable oils. *Journal of Renewable Materials*, 2013, **1**:3 [Google Scholar], [Publisher]

[20]. Wijayapala R., Mishra S., Elmore B., Freeman C., Kundu S., Synthesis and characterization of crosslinked polymers from cottonseed oil. *Journal of Applied Polymer Science*, 2019, **136**:47655 [Crossref], [Google Scholar], [Publisher]

[21]. Koivu K.A., Sadeghifar H., Nousiainen P.A., Argyropoulos D.S., Sipilä J., Effect of fatty acid esterification on the thermal properties of softwood kraft lignin. *ACS Sustainable Chemistry & Engineering*, 2016, **4**:5238 [Crossref], [Google Scholar], [Publisher]

[22]. Gan H., Hutchinson S.A., Hurren C., Liu Q., Wang X., Long R.L., Effect of oleic purity on the chemical structure, thermal and rheological properties of bio-based polymers derived from high oleic cottonseed oil via RAFT polymerization. *Industrial Crops and Products*, 2021, **171**:113882 [Crossref], [Google Scholar], [Publisher]

[23]. Lomège J., LapinteV., Negrell C., Robin J.J., Caillol S., Fatty acid-based radically polymerizable monomers: From novel poly (meth) acrylates to cutting-edgeproperties. *Biomacromolecules*, 2018, **20**:4 [Crossref], [Google Scholar], [Publisher]

[24]. Al-Ahmed A., Sarı A., Mazumder M.A.J., Salhi B., Hekimoğlu G., Al-Sulaiman F.A., Thermal energy storage and thermal conductivity properties of fatty acid/fatty acid-grafted-CNTs and fatty acid/CNTs as novel composite phase change materials. *Scientific Reports*, 2020, **10**:1 [Crossref], [Google Scholar], [Publisher]

[25]. Yang L., Zhang N., Yuan Y., Cao X., Xiang B., Thermal performance of stearic acid/carbon nanotube composite phase change materials for energy storage prepared by ball milling. *International Journal of Energy Research*, 2019, **43**:6327 [Crossref], [Google Scholar], [Publisher]

[26]. Wang J., Xie H., Xin Z., Li Y., Increasing the thermal conductivity of palmitic acid by the addition of carbon nanotubes. *Carbon*, 2010, **48**:3979 [Crossref], [Google Scholar], [Publisher]

[27]. Yang L., Cao X., Zhang N., Xiang B., Zhang Z., Qian B., Thermal reliability of typical fatty acids as phase change materials based on 10,000 accelerated thermal cycles. *Sustainable Cities and Society*, 2019, **46**:101380 [Crossref], [Google Scholar], [Publisher]

[28]. Zarski A., Bajer K., Zarska S., Kapusniak, J., From high oleic vegetable oils to hydrophobic starch derivatives: I. Development and structural studies. *Carbohydrate polymers*, 2019, **214**:124 [Crossref], [Google Scholar], [Publisher]

[29]. Steiner J., Alaneed R., Kressler J., MäderK., Fatty acid-modified poly (glycerol adipate) microparticles for controlled drug delivery. *Journal of Drug Delivery Science and Technology*, 2021, **61**:102206 [Crossref], [Google Scholar], [Publisher]

[30]. Sharif I., Farooq J., Chohan S.M., Saleem S., Kainth R.A., Mahmood A., Sarwar G., Strategies to enhance cottonseed oil contents and reshape fatty acid profile employing different breeding and genetic engineering approaches. *Journal of Integrative Agriculture*, 2019, **18**:2205 [Crossref], [Google Scholar], [Publisher]

[31]. Lacerda T.M., Gandini A., The cationic polymerization of tung oil and its fatty-acid methyl ester. *Industrial Crops and Products*, 2020, **157**:112886 [Crossref], [Google Scholar], [Publisher]

[32]. Biermann U., Bornscheuer U.T., Feussner I., Meier M.A., Metzger J.O., Fatty acids and their derivatives as renewable platform molecules for the chemical industry. *Angewandte Chemie International Edition*, 2021, **60**:20144 [Crossref], [Google Scholar], [Publisher]

[33]. Piccini M., Leak D. J., Chuck C. J., Buchard A. Polymers from sugars and unsaturated fatty acids: ADMET polymerisation of monomers derived from D-xylose, D-mannose and castor oil. *Polymer Chemistry, 2020*, **11**:2681 [Crossref], [Google Scholar], [Publisher]

[34]. Brandolese A., Della Monica F., Pericàs M.À., Kleij A.W., Catalytic Ring-Opening Copolymerization of Fatty Acid Epoxides: Access to Functional Biopolyesters. *Macromolecules*, 2022, **55**:2566 [Crossref], [Google Scholar], [Publisher]

[35]. Cabral T.O., Sarrouh B., Naves F.L., Lofrano R.C.Z., Insights on the preparation and characterization of the poly (glycerol-co-malic acid) from renewable sources. *Clean Technologies and Environmental Policy*, 2020, **22**:735 [Crossref], [Google Scholar], [Publisher]

[36]. Loutelier-Bourhis C., Zovi O., Lecamp L., Bunel C., Hubert-Roux M., Lange C.M., Mechanistic study of maleic anhydride grafting onto fatty double bonds using mass spectrometry. *Rapid Communications in Mass Spectrometry*, 2012, **26**:1265 [Crossref], [Google Scholar], [Publisher]

[37]. Boboqulova F., Maksumova O., Technology of products of interaction of oleic acid and maleic anhydride. *EPRA International Journal of Research & Development (IJRD)*, 2021, **6**:1 Google Scholar], [PDF]

[38]. Al-Sabagh A.M., El-Hamouly S.H., Khidr T.T., El-Ghazawy R.A., Higazy S.A., Preparation the esters of oleic acid-maleic anhydride copolymer and their evaluation as flow improvers for waxy crude oil. *Journal of dispersion science and technology*, 2013, **34**:1585 [Crossref], [Google Scholar], [Publisher]

[39]. Molina P., Arques A., Cartagena I., Noguera, J.A., Valcarcel M.V., Reaction of 3-hetero-substituted 2-phenyl-4-thioxo-3, 4-dihydro-quinazolines with acyl chlorides and phenacyl bromides. *Journal of Heterocyclic Chemistry*, 1983, **20**:983 [Crossref], [Google Scholar], [Publisher]

[40]. Pyriadi T.M., Hamad A.S., Preparation of new copolymers of vinyl acetate and N-substituted maleimides. *Polymer*, 1996, **37**:5283 [Crossref], [Google Scholar], [Publisher]

[41]. Yass I.A., Ayed N.J., Synthesis and Characterization of New Compounds of Amic Acid and Imides Derived from Oleic Acid and Evaluation of Their Biological Activity. *Journal of Education and Scientific Studies*, 2020, **5** [Google Scholar], [Publisher]

[42]. Al-Azzawi A.M., Yaseen H.K., Synthesis, characterization and polymerization of new maleimides. *Journal of Chemical and Pharmaceutical Research,* 2016, **8**:241 [Google Scholar]

[43]. Ivanišová E., Frančáková H., Ritschlová P., Dráb Š., Solgajová M., Tokár M., Biological activity of apple juice enriched by herbal extracts. *Journal of Microbiology, Biotechnology and Food Sciences*, 2021, **2021**:69 [Crossref], [Google Scholar], [Publisher]