Synthesis and characterization of novel heterosubstituted pyrroles, thiophenes, and furans

Nevin Kaniskan[1], Dilek Elmali[1], and Pervin U. Civcir[2*]

[1]*Anadolu University, Faculty of Sciences, Department of Chemistry, Eskisehir, Turkey*
[2] *University of Ankara, Faculty of Health Sciences, Ankara, Turkey*
E-mail: civcir@health.ankara.edu.tr

Abstract

Sixteen new compounds, including novel five-membered heterocyclic systems (pyrrole, thiophene, or furan) linked to imidazole, thiazole, or quinoline rings are reported. The intermediate 1,4-diketones were synthesized *via* the Stetter reaction in the presence of thiazolium salt as a catalyst. Cyclization reactions of the 1,4-dicarbonyl compounds with polyphosphoric acid, ammonium acetate or Lawesson's reagent by the Paal-Knorr synthesis, afforded unknown 2,5-disubstituted furan, pyrrole, or thiophene compounds in moderate yields, respectively. The structures of the synthesized compounds were confirmed by IR, ^{1}H NMR, ^{13}C NMR, and elemental analysis.

Keywords: Stetter reaction, Paal-Knorr reaction, imidazole, thiazole, quinoline, pyrrole, thiophene, furan

Introduction

Furan, thiophene, pyrrole, imidazole, thiazole, and quinoline are well known examples of heteroaromatic organic compounds and found naturally in plants and in animal cell constituents. They are also found in artificial compounds,[1] such as agrochemicals,[2] pharmaceuticals,[3] dyes,[4] plastics, solvents, photographic chemicals, electronics, corrosion inhibitors,[5] preservatives, and polymers.[6] They can be used in synthetic organic chemistry as building blocks, due to their presence as key structural units in many natural products and in important pharmaceuticals. For example, the nature of the N- atoms in the imidazole molecule makes possible an extraordinary variety of reactions and this is the main reason for the great biological importance of the amino acid, histidine. Thiophenes are also used as synthetic intermediates, taking advantage of the susceptibility of the carbon atoms adjacent to sulfur toward electrophilic reactions.[7-11]

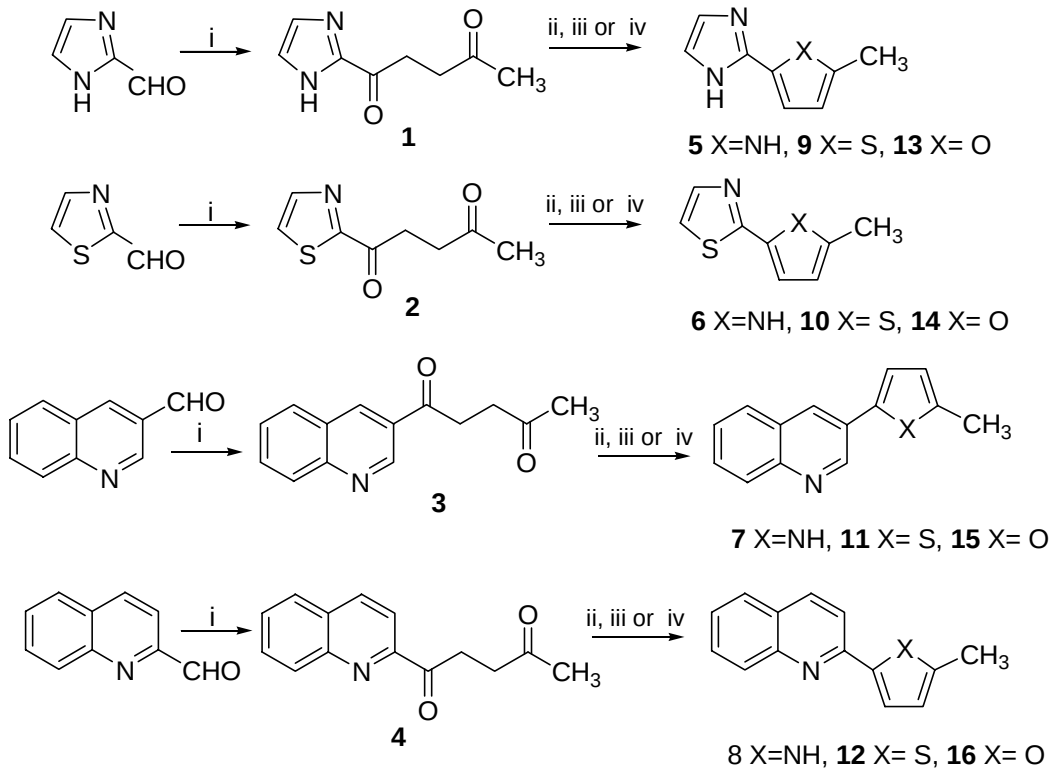
Polymers of these compounds, which have potential as semi-conducting material are of great importance, because of their good thermal and chemical stability and relative ease of

functionalization, which potentially permit the fine tuning of their physical and electronic properties.[12-18] Ando *et al.*[12] show that polythiophenes are the most important organic semi-conductors and are obtained from thiophene oligomers and their properties are tuned by introducing substitutuents in the π-conjugated systems, which leads to strong inter-molecular interactions. Among such thiophene oligomers, derivatives with thiazole units are important and enhanced stability to oxygen due to the electron-accepting property of the thiazolyl groups. Over the last few years, the application of such polymers to flexible, light and small electronic and optical devices have been actively carried out.[13-15] Despite a large number of studies,[19-38] which comprise polymeric heterocyclic systems such as imidazolyl-, thiazolyl-, or quinolylpyrroles, thiophenes or furans, there is no work about the synthesis and properties of these simple linked two ring systems in the literature.

Several methods are available for the synthesis of two ring systems, which contain the pyrrole, thiophene or furan ring linked to an imidazole, thiazole, or quinoline ring. One of these methods is the most versatile in terms of readily accessible starting compounds and involves the Paal-Knorr formation of the pyrrole, thiophene and furan rings from a 1,4-dicarbonyl systems of the imidazole, thiazole, or quinoline compounds by using ammonium acetate, Lawesson's reagent[39] or polyphosphoric acid, respectively.[20,21]

It is also well known that 1,4-dicarbonyl derivatives are valuable intermediates for the preparation of cyclopentenones[40,41] and five membered heterocyclic compounds such as pyrroles, furans and thiophenes.[20,21] The most versatile general 1,4-dicarbonyl synthesis is known as the Stetter reaction,[42,43] which is the catalyzed conjugate addition of an aldehyde to a Michael acceptor such as an enone. Thiazolium salt,[44] cyanide ion,[45,46] and tributylphosphine[47] are used as the catalyst in the presence of a base. The effectiveness of the procedure depends significantly upon the choice of the catalysts. Previously, our group obtained the pyridylthiophenes, furans and pyrroles from the pyridyldiketones, which were most effectively prepared by reaction of methyl vinyl ketone or divinylsulfone with the appropriate formylpyridine in the presence of a thiazolium ylide catalyst.[20,21] Our results showed that the pyridyldiketones were converted to the pyridylfuran, thiophene and pyrrole rings with polyphosphoric acid, Lawesson's reagent and ammonium acetate in good yields, respectively. It would be interesting to see how the results vary in the case of the imidazole, thiazole, and quinoline compounds.

In this work, we report the synthesis and characterization of simple, but unknown thiophene, furan, and pyrrole rings containing quinoline, imidazole, or thiazole rings (Scheme 1), which provide a general procedure for the synthesis and characterization of the alternating quinoline, imidazole, or thiazole: thiophene, furan, or pyrrole polymers. They may also be useful as bioactive compounds.



Scheme 1. Reagents and Conditions: **i**. But-3-en-2-one, thiazolium chloride, triethylamine, dioxane, 90^0C, 36 hours, **ii**. Ammonium acetate, 125^0C, 2 hours, **iii.** Lawesson's reagent, toluene, 110^0C, 50 hours, **iv**. Polyphosphoric acid, 130-140^0C, 4-6 hours.

Results and Discussion

The reaction between heteroaromatic aldehydes and 3-buten-2-one in the presence of thiazolium ylide catalyst and triethylamine as a base leads to the corresponding Stetter type products **1**–**4** in moderate yields (Scheme 1). There is no report on experiments for the investigated compounds in the literature; therefore, we cannot compare our experimental results with others. Instead, we compare our spectroscopic data for substituted rings relative to unsubstituted rings. ^{13}C and ^{1}H NMR spectroscopic data for the novel pyrrole, thiophene and furans and their dicarbonyl precursors, presented in detail in the Experimental Section and are summarized in Tables 1-3.

The structures of the 1,4-dicarbonyl compounds were deduced from their IR, ^{1}H NMR, ^{13}C NMR spectroscopic data and elemental analysis. They have satisfactory elemental analyses. Infrared spectrum of these compounds displayed a strong peak in the region 1620-1720 cm^{-1}, characteristic of the carbonyl groups, which confirms the formation of 1,4-dicarbonyl compounds. ^{13}C NMR spectrum of the 1,4-dicarbonyl compounds also exhibited characteristic peaks in the region 29.6-37.2 ppm (with a mean position of 33.4 ppm) assignable to the methylene groups and singlets over the range 190.0- 207.1 ppm (with a mean position of 198.6 ppm) characteristic of the carbonyl groups. These are supported by the signals for the

heteroaromatic ring protons (in the region *ca.* 7.2 and 9.6 ppm), methyl protons (at *ca*. 2.2 ppm) and methylene protons (in the region 2.7-3.5 ppm) in proton NMR, clearly indicating the aromatic and alkyl hydrogens. Table 1 shows the ^{13}C and ^{1}H NMR chemical shifts (ppm) for the diketones **(1-4)** and related compounds.

Table 1. ^{13}C and ^{1}H NMR chemical shifts (ppm) for the imidazole, thiazole, or quinoline rings of the diketones (**1-4**) and related compounds

Diketone comp	C2	C3	C4	C5	C6	C7	C8	C9	C10	C1' C=O	C2' CH_2	C3' CH_2	C4' C=O	CH_3
^{13}C NMR														
2-Imidazoyl, **1**	144.0	-	126.8	126.8	-	-	-	-	-	190.0	34.4	36.3	207.1	29.4
2-Thiazolyl, **2**	160.9	-	141.5	126.6	-	-	-	-	-	194.2	29.6	36.2	206.9	25.3
2-Pyridyl [a]	153.2	127.2	136.8	121.6	149.0	-	-	-	-	200.1	37.2	31.9	206.9	29.8
3-Quinolinyl, **3**	150.4	132.6	138.1	129.8	129.1	127.5	130.6	149.9	129.8	197.6	31.7	36.7	205.6	30.1
2-Quinolinyl, **4**	150.5	121.7	132.1	126.7	127.6	125.5	130.6	143.2	129.8	201.5	34.5	36.7	206.8	30.0
^{1}H NMR														
2-Imidazolyl, **1**	-	-	7.21	7.21	-	-	-	-	-	-	2.69	3.40	-	2.21
2-Thiazolyl, **2**	-	-	8.06	7.79	-	-	-	-	-	-	2.74	3.33	-	2.22
2-Pyridyl [a]	-	7.80	7.45	7.80	8.07	-	-	-	-	-	2.87	3.50	-	2.25
3-Quinolinyl, **3**	9.61	-	8.24	8.01	7.71	7.96	8.89	-	-	-	2.74	3.36	-	2.26
2-Quinolinyl, **4**	-	7.37	8.07	7.78	7.53	7.63	8.07	-	-	-	2.94	3.35	-	2.25

[a] From Reference 20.

The dicarbonyl compounds **1-4** were converted in moderate yield into the corresponding pyrroles **5-8,** thiophenes **9-12,** and furans **13-16** using standard Paal-Knorr procedures (Scheme 1). Elemental analysis results for the ring systems are acceptable. Examination of the spectroscopic data for the simple pyrroles, thiophenes, and furans indicated that ^{13}C NMR spectroscopy, coupled with IR spectroscopy, was potentially the best analytical technique to provide confirmatory structural evidence for their formation.

The absence of carbonyl absorption (C=O) in the infrared spectra of the reaction products and the absence of the ^{13}C NMR spectral evidence for the 1,4-diketone systems suggest the complete reaction of the diketones, while the presence of the appropriate aromatic ^{13}C NMR signals indicated the formation of the five-membered heterocyclic rings (pyrrole, thiophene and furan). Elemental analytic data also showed that the Paal-Knorr reactions were completed. ^{1}H NMR spectrum of heterocyclic rings exhibited a doublet readily recognized as arising from C-3-H and C-4-H of pyrroles (in the region 5.2 and 6.8 ppm), thiophene (in the region 6.6 and 7.3 ppm), and furan (in the region 5.9 and 6.9 ppm). The peaks from ^{1}H spectra of imidazole, thiazole and quinoline rings were assigned as follows: at 7.3 ppm to the protons of C-4-H and C-5-H of imidazole ring, at 7.2 and 8.0 ppm to the protons C-4-H and C-5-H of thiazole ring and

between 7.3 - 8.8 ppm to the protons of quinoline ring. Tables 2-3 show the comparison of the spectroscopic data of the novel substituted rings with those of the unsubstituted rings. The ^{1}H and ^{13}C NMR spectra of **1-16** are consistent with the proposed structures and the comparisons of the spectroscopic data of the substituted rings with those of the unsubstituted rings[48,49] are very appropriate.

Table 2. ^{13}C Chemical shifts (ppm) for the substituted imidazole, thiazole, or quinoline rings **(5-16)** and related unsubstituted rings

	Imidazole, Thiazole or Quinoline Ring									Imidazole, Thiazole or Quinoline Rings				
Compound	C2	C3	C4	C5	C6	C7	C8	C9	C10	C2'	C3'	C4'	C5'	CH_3
Pyrrole [a]	-	-	-	-	-	-	-	-	-	118.5	108.2	108.2	118.5	-
Thiophene [a]	-	-	-	-	-	-	-	-	-	127.2	125.4	125.4	127.2	-
Furan [a]	-	-	-	-	-	-	-	-	-	142.5	109.4	109.4	142.5	-
Imidazole [a]	135.(	-	121.6	121.6	-	-	-	-	-	-	-	-	-	-
2-Substituted Imidazole														
Methyl [a]	143.6	-	127.7	127.5	-	-	-	-	-	-	-	-	-	13.6
5-Methyl-2-Pyrrolyl, **5**	138.6	-	128.4	128.4	-	-	-	-	-	128.7	105.4	109.4	118.1	15.1
5-Methyl-2-Thienyl, **9**	126.6	-	122.0	122.0	-	-	-	-	-	132.8	113.3	113.3	161.7	30.9
5-Methyl-2-Furyl, **13**	139.8	-	128.8	128.8	-	-	-	-	-	152.5	107.9	108.9	143.4	13.4
Thiazole [a]	152.7	-	143.4	118.6		-	-	-	-		-	-	-	-
2-Substituted Thiazole														
Methyl [a]	168.1	-	142.1	118.7	-	-	-	-		-	-	-	-	11.6
5-Methyl-2-Pyrrolyl, **6**	156.7	-	141.9	115.5	-	-	-	-	-	131.6	108.4	110.7	125.2	13.0
5-Methyl-2-Thienyl, **10**	162.4	-	143.0	113.4	-	-	-	-	-	135.6	126.8	126.9	117.5	19.2
5-Methyl-2-Furyl, **14**	153.1	-	143.3	117.3	-	-	-	-	-	128.6	108.4	110.1	143.3	13.8
Quinoline [a]	149.9	121.5	136.4	128.5	128.3	127.0	129.9	128.9	146.8	-	-	-	-	-
3-Substituted Quinoline														
Methyl [a]	152.3	130.6	134.7	128.4	127.7	126.8	128.8	128.4	144.8	-	-	-	-	18.7
5-Methyl-2-Pyrrolyl**, 7**	147.8	127.1	130.9	127.9	128.3	127.4	129.1	128.4	146.2	128.8	108.1	108.6	126.2	13.3
5-Methyl-2-Thienyl, **11**	152.5	129.8	130.0	128.6	127.5	126.3	129.0	128.6	136.6	136.6	125.9	126.5	117.4	15.8
5-Methyl-2-Furyl, **15**	157.6	137.6	139.2	134.2	133.0	132.0	135.0	134.2	145.2	158.9	104.5	107.3	142.3	13.6
2-Substituted Quinoline														
Methyl [a]	158.8	122.0	135.6	126.5	127.8	125.9	129.7	128.3	138. 9	-	-	-	-	25.3
5-Methyl-2-Pyrrolyl, **8**	150.2	130.5	136.2	128.4	127.6	126.7	128.9	128.4	147. 8	128.8	108.7	110.1	117.5	13.9
5-Methyl-2-Thienyl, **12**	148.5	125.8	132.8	128.6	129.5	127.9	132.7	131.4	142.7	134.3	128.7	128.9	127.2	15.6
5-Methyl-2-Furyl, **16**	148.3	126.9	129.0	127.7	128.1	127.8	129.0	128.3	146.7	129.8	109.4	108.9	131.5	14.8

[a] From Reference 48.

As seen Tables 2 and 3, all the protons in the substituted imidazole, thiazole, and quinoline rings are shifted downfield with respect to the parent compound. In general, the chemical shifts

for the substituted imidazole, thiazole, and quinoline rings, relative to the unsubstituted rings, suggest that the mesomeric effect of the five-membered rings contributes less to the interaction between two rings than does their inductive effects. It would appear that the thiophene is more electron-withdrawing in its overall electronic effect than the furan ring, same result is also observed in the pyridine-thiophenes and furans.[21] The downfield shifts of the ^{13}C NMR signals for the carbon atom at the point of substitution on the thiazole, imidazole and quinoline rings are

Table 3. ^{1}H NMR Chemical shifts (ppm) for the substituted imidazole, thiazole, or quinoline rings (**5-16**) and related unsubstituted rings

	Imidazole, Thiazole or Quinoline Ring							Furan, Thiophene or Pyrrole Rings				
Compound	H-2	H-3	H-4	H-5	H-6	H-7	H-8	H2'	H3'	H4'	H5'	CH_3
Pyrrole [a]	-	-	-	-	-	-	-	6.71	6.25	6.25	6.71	-
Thiophene [a]	-	-	-	-	-	-	-	7.31	7.09	7.09	7.31	-
Furan [a]	-	-	-	-	-	-	-	7.42	6.48	6.48	7.42	-
2-Substituted Imidazole												
Imidazole [a]	7.86	-	7.25	7.25	-	-	-	-	-	-	-	-
Methyl [a]	-	-	6.97	6.97	-	-	-	-	-	-	-	2.44
5-Methyl-2-Pyrrolyl, **5**	-	-	7.31	7.31	-	-	-	-	5.28	5.77	-	2.37
5- Methyl-2-Thienyl, **9**	-	-	7.29	7.29	-	-	-	-	6.60	7.30	-	2.45
5- Methyl-2-Furyl, **13**	-	-	7.32	7.32	-	-	-	-	5.96	6.40	-	2.15
2-Substituted Thiazole												
Thiazole [b]	8.85	-	7.98	7.41	-	-	-	-	-	-	-	-
Methyl [b]	-	-	7.64	7.17	-	-	-	-	-	-	-	2.74
5-Methyl-2-Pyrrolyl, **6**	-	-	7.62	7.44	-	-	-	-	5.77	5.99	-	2.28
5-Methyl-2-Thienyl, **10**	-	-	7.71	7.19	-	-	-	-	6.54	6.72	-	2.50
5- Methyl-2-Furyl, **14**	-	-	8.01	7.36	-	-	-	-	5.89	6.53	-	2.18
3-Substituted Quinoline												
Quinoline [b]	8.92	7.38	8.14	7.80	7.53	7.71	8.11	-	-	-	-	-
Methyl [b]	8.76	-	7.88	7.71	7.49	7.63	8.06	-	-	-	-	2.48
5-Methyl-2-Pyrrolyl**, 7**	8.08	-	8.08	7.36	7.53	7.63	7.78	-	6.07	6.65	-	2.40
5-Methyl-2-Thienyl, **11**	8.13	-	8.13	7.76	7.48	7.69	7.76	-	6.85	7.58	-	2.60
5- Methyl-2-Furyl, **15**	8.65	-	7.90	7.72	7.50	7.62	8.12	-	6.35	6.85	-	2.50
2-Substituted Quinoline												
Methyl [b]	-	7.30	8.06	7.78	7.49	7.63	8.05	-	-	-	-	2.76
5-Methyl-2-Pyrrolyl, **8**	-	7.44	7.98	7.73	7.67	7.67	8.08	-	6.05	6.80	-	2.60
5-Methyl-2-Thienyl, **12**	-	7.69	8.26	8.00	7.80	7.80	8.40	-	6.76	6.84	-	2.50
5- Methyl-2-Furyl, **16**	-	7.31	8.07	7.80	7.50	7.62	8.07	-	6.04	6.61	-	2.42

[a] From Reference 48.

[b] From Reference 49.

consistent with significant inductive electron-withdrawing effects of the 2-heteroaryl rings. The chemical shifts of the difunctional bases imidazole and thiazole are some of interest. The ring protons of the substituted thiazole are deshielded relative to those of the substituted imidazole, same as unsubstituted rings. There is a downfield shift of 0.3-0.7 ppm for H-4 in thiazole (8.01 ppm for furan) compared to that in imidazole. The contribution the downfield shift of H-4 in thiazole is due to electronic effects of the sulfur atom.

Conclusions

Pyrrole, thiophene and furan derivatives, which possessed quinoline, thiazole or imidazole rings were synthesized for the first time in moderate yields from the 1,4-dicarbonyl compounds with ammonium acetate, Lawesson's reagent or polyphosphoric acid by the Paal-Knorr synthesis, respectively. The structures of the synthesized compounds were confirmed by IR, ^{13}H, ^{13}C NMR spectroscopies, and elemental analysis. The intermediary 1,4-dicarbonyl derivatives were also synthesized *via* the Stetter reaction in the presence of thiazolium salt as a catalyst. The readily availability of aldehydes of thiazole, imidazole and quinoline makes the approach more versatile and flexible. Furthermore, the simplicity of the present procedure makes it an interesting alternative for making polymer building blocks. We hope that the synthesis of monomers presented above can be generalized to obtain biologically active compounds.

Experimental Section

General Procedures. Commercially available reagents were used for further purification: solvents were dried by standard procedures as given in the literature.[50] Melting points (mp) were determined using a Sanyo GALLENKAMP apparatus and are uncorrected. Infrared spectra were recorded in the range 4000-600 cm^{-1} on a FT/IR 300E Asco FT-IR spectrometer using KBr disks for solid samples and thin films between NaCl plates for liquids samples. ^{1}H NMR and ^{13}C NMR spectra were recorded on a Bruker Avance DPX-400 spectrometer operating at 400.13 MHz for proton and at 100.62 MHz for carbon. ^{1}H NMR spectra were measured for *ca.*25-30% solutions in $CDCl_3$, unless otherwise indicated and all chemical shifts are expressed relative to Me_4Si. Flash chromatography was carried out using Fluka 60H silica and analytical thin layer chromatography was carried out using aluminum-backed plates coated with Merck Kieselgel 60 GF_{254}. Elemental analyses were performed on an ELEMENTAR VARIO EL III or a LECO CHNS 932 instruments.

General procedure for the synthesis of 1,4-dicarbonyl compounds (1-4)

1,4-Dicarbonyl compounds were prepared by using thiazolium chloride as explained in Stetter procedure. But-3-en-2-one (0.875 g, 0.0125 mol), 3-benzyl-5-(2-hydroxyethyl)-4-methyl-1,3-

thiazolium chloride (0.405 g, 0.0015 mol) and dry triethylamine (0.757 g, 0.0075 mol) in dry dioxane (20 ml) were heated at 90 ^{o}C under nitrogen. The carboxyaldehyde (0.01 mol), in dry dioxane (20 ml) was added dropwise slowly over a period of 2 h, and the mixture was then stirred at 90 ^{o}C for further 36 h. The mixture was cooled to room temperature and the solvents removed under vacuum. Water (30 ml) was added and the aqueous layer was extracted with dichloromethane (3 x 25 ml). The combined organic extracts were washed brine (2 x 25ml) and dried ($MgSO_4$). Filtration and removal of the solvent gave a crude product, and recrystallization twice from isopropyl alcohol gave the appropriate 1,4-dicarbonyl compounds. The structures of the products were confirmed by their spectral data.

1-(1*H*-Imidazol-2-yl)-1,4-pentanedione (1). This compound was obtained as dark brown needles (49%), mp 126-127 ^{o}C; *Anal*. Calcd. for $C_8H_{10}N_2O_2$: C, 57.82; H, 6.07; N, 16.86; O, 19.26. Found: C, 57.59; H, 6.17; N, 16.81; O, 19.43. IR (KBr): 3240 (C-NH of imidazole), 3025 (ring C-H stretching), 1699 and 1672 (C=O), 1555, 1504 and 1425 (ring C=C and C=N stretches), cm^{-1}; ^{1}H NMR ($CDCl_3$); δ 2.21 (s, 3H, CH_3), 2.69 (t, 2H, J = 6.0 Hz, CH_2), 3.40 (t, 2H, J = 6.0 Hz, CH_2), 7.21 (s, 2H, imidazole protons); 10.45 (s, 1H, NH); ^{13}C NMR ($CDCl_3$) δ 29.38, 34.38, 36.34, 126.79, 126.79, 144.00, 190.04, 207.12.

1-(1,3-Thiazol-2-yl)-1,4-pentanedione (2). This compound was obtained as dark brown needles (57%), mp 164-167 ^{o}C; *Anal*. Calcd. for $C_8H_9NO_2S$: C, 52.44; H, 4.95; N, 7.64; O, 17.46; S, 17.50. Found: C, 52.99, H, 5.15; N, 7.37; O, 17.18; S, 17.31. IR (KBr): 2995 (ring C-H stretching), 1717 and 1685 (C=O), 1542, 1481 and 1457 (ring C=C and C=N stretches) cm^{-1}; ^{1}H NMR ($CDCl_3$): δ 2.22 (s, 3H, CH_3), 2.74 (t, 2H, J = 6.0 Hz, CH_2), 3.33 (t, 2H, J = 6.0 Hz, CH_2), 7.79 (d, 1H, J = 3.1 Hz, thiazole proton), 8.06 (d, 1H, J = 3.1 Hz, thiazole proton); ^{13}C NMR ($CDCl_3$): δ 25.28, 29.60, 36.19, 126.63, 141.46, 160.92, 194.22, 206.87.

1-(3-Quinolinyl)-1,4-pentanedione (3). This compound was obtained as dark brown prisms (54%), mp 78-79 ^{o}C; *Anal*. Calcd. for $C_{14}H_{13}NO_2$: C, 73.99; H, 5.77; N, 6.16; O, 14.08. Found: C, 73.75; H, 5.86; N, 6.19; O, 14.20. IR (KBr): 3020-3080 (ring C-H stretching), 1695 and 1676 (C=O), 1595, 1570, 1462, 1417 (ring C=C and C=N stretches) cm^{-1}; ^{1}H NMR ($CDCl_3$): δ 2.26 (s, 3H, CH_3), 2.74 (t, 2H, J = 6.6 Hz, CH_2), 3.36 (t, 2H, J = 6.6 Hz, CH_2), 7.71 (t, 1H, J = 7.0 Hz, quinoline proton), 7.96 (t, 1H, J = 7.0 Hz, quinoline proton), 8.01 (d, 1H, J = 8.0 Hz, quinoline proton), 8.24 (d, 1H, J = 8.4 Hz, quinoline proton), 8.89 (d, 1H, J = 7.0 Hz, quinoline proton), 9.61 (d, 1H, J = 3.0 Hz, quinoline proton); ^{13}C NMR ($CDCl_3$): δ 30.11, 31.72, 36.69, 127.50, 129.05, 129.80, 129.80, 130.55, 132.60, 138.13, 149.92, 150.36, 197.57, 205.56.

1-(2-Quinolinyl)-1,4-pentanedione (4). This compound was obtained as dark brown prisms (49%), mp 115-116 ^{o}C; *Anal*. Calcd. for $C_{14}H_{13}NO_2$: C, 73.99; H, 5.77; N, 6.16; O, 14.08. Found: C, 73.76; H, 5.41; N, 6.35; O, 14.48. IR (KBr): 3010-3075 (ring C-H stretching), 1708 and 1619 (C=O), 1591, 1559, 1460 and 1420 (C=C and C=N) cm^{-1}; ^{1}H NMR ($CDCl_3$): δ 2.25 (s, 3H, CH_3), 2.94 (t, 2H, J = 6.0 Hz, CH_2), 3.35 (t, 2H, J = 6.0 Hz, CH_2), 7.37 (d, 1H, J = 7.0 Hz, quinoline proton), 7.53 (t, 1H, J = 7.5 Hz, quinoline proton), 7.63 (t, 1H, J = 7.5 Hz, quinoline proton), 7.78 (d, 1H, J = 8.0 Hz, quinoline proton), 8.07 (d, 2H, J = 7.0 Hz, quinoline protons);

^{13}C NMR ($CDCl_3$): δ 29.97, 34.53, 36.73, 121.68, 125.48, 126.66, 127.59, 129.75, 130.63, 132.10, 143.18, 150.50, 201.49, 206.76.

General procedure for the synthesis of pyrroles from 1,4-dicarbonyl compounds (5-8)

The appropriate 1,4-dicarbonyl compound (0.01 mol) and ammonium acetate (1.93 g, 25.1 mmol) were stirred and heated at 125 ^{o}C for 2h. The mixture was cooled to room temperature, and water (40 ml) was added and the aqueous layer was extracted with dichloromethane (3 x 25 ml). The combined organic extracts were dried ($MgSO_4$). Filtration and removal of the solvent gave a brown syrup, which was chromatographed (silica gel, ethyl acetate: dichloromethane (1:10)) to give the product. The structures of the products were confirmed by their spectral data.

2-(5-Methyl-1*H*-pyrrol-2-yl)-1*H*-imidazole (5). This compound was obtained as red-brown bright needles (47%), mp 149–150 ^{o}C; *Anal*. Calcd. for $C_8H_9N_3$: C, 65.29; H, 6.16; N, 28.55. Found: C, 65.17; H, 6.41; N, 28.42;. IR (KBr): 3395-3196 (ring C-H stretching), 3240 (C-NH stretching), 1554-1402 (ring C=C and C=N stretches), 1100 (NH) cm^{-1}; ^{1}H NMR ($CDCl_3$): δ 2.37 (s, 3H, CH_3), 5.28 (d, 1H, J = 3.0 Hz, pyrrole proton), 5.77 (d, 1H, J = 3.0 Hz, pyrrole proton), 7.31 (s, 2H, imidazole protons), 11.3 (br s, 2H, NH); ^{13}C NMR ($CDCl_3$): δ 15.09, 105.41, 109.43, 118.14, 128.42(d), 128.74, 138.55.

2-(5-Methyl-1*H*-pyrrol-2-yl)-1,3-thiazole (6). This compound was obtained as red-brown bright needles (52%), mp 221-222 ^{o}C; *Anal*. Calcd. for $C_8H_8N_2S$: C, 58.51; H, 4.91; N, 17.06; S, 19.53. Found: C, 58.37; H, 5.36; N, 16.92; S, 19.35. IR (KBr): 3409-3196 (ring C-H stretching), 3236 (C-NH stretching), 1519-1382 (ring C=C and C=N stretches), 1141 (N-H) cm^{-1}; ^{1}H NMR ($CDCl_3$): δ 2.28 (s, 3H, CH_3), 5.77 (d, 1H, J = 3.0 Hz, pyrrole proton), 5.99 (d, 1H, J = 3.0 Hz, pyrrole proton), 7.44 (d, 1H, J = 3.6 Hz, thiazole proton), 7.62 (d, 1H, J = 3.6 Hz, thiazole proton); 10.72 (br s, 1H, NH); ^{13}C NMR ($CDCl_3$): δ 12.96, 108.40, 110.71, 115.50, 125.15, 131.55, 141.89, 156.66.

3-(5-Methyl-1*H*-pyrrol-2-yl)-quinoline (7). This compound was obtained as red-brown bright needles (27%), mp 124-125 ^{o}C; *Anal*. Calcd. for $C_{14}H_{12}N_2$: C, 80.74; H, 5.81; N, 13.45. Found: C, 80.69; H, 5.92; N, 13.39. IR (KBr): 3409-3209 (C-H stretching), 3220 (C-NH stretching), 1512-1402 (ring C=C and C=N stretches), 1046 (N-H) cm^{-1}; ^{1}H NMR ($CDCl_3$): δ 2.40 (s, 3H, CH_3), 6.07 (d, 1H, J = 3.0 Hz, pyrrole proton), 6.65 (d, 1H, J = 3.0 Hz, pyrrole proton), 7.36 (d, 1H, J = 7.4 Hz, quinoline proton), 7.53 (t, 1H, J = 7.4 Hz, quinoline proton), 7.63 (t, 1H, J = 7.0 Hz, quinoline proton), 7.78 (d, 1H, J = 8.0 Hz, quinoline proton), 8.08 (s, 2H, quinoline protons); 9.13 (br s, 1H, NH); ^{13}C NMR ($CDCl_3$): δ 13.26, 108.06, 108.61, 126.19, 127.09, 127.42, 127.88, 128.26, 128.37, 128.75, 129.09, 130.86, 146.17, 147.79.

2-(5-Methyl-1*H*-pyrrol-2-yl)quinoline (**8).** This compound was obtained as red-brown bright needles (45%), mp 196-198 ^{o}C; *Anal*. Calcd. for $C_{14}H_{12}N_2$: C, 80.74; H, 5.81; N, 13.45. Found: C, 80.39; H, 5.77; N, 13.84. IR (KBr): 3388-3086 (ring C-H stretching), 3180 (C-NH stretching), 1554-1402 (ring C=C and C=N stretches), 1179 (N-H) cm^{-1}; ^{1}H NMR ($CDCl_3$): δ 2.60 (s, 3H, CH_3), 6.05 (d, 1H, J = 3.0 Hz, pyrrole proton), 6.80 (d, 1H, J = 3.0 Hz, pyrrole proton), 7.44 (d, 1H, J = 7.6 Hz, quinoline proton), 7.67 (t, 2H, J = 8.5 Hz, quinoline proton), 7.73 (d, 1H, J = 8.0

Hz, quinoline proton), 7.98 (d, 1H, J = 8.5 Hz, quinoline proton), 8.08 (d, 1H, J = 8.4 Hz, quinoline proton); 9.88 (br s, 1H, NH); ^{13}C NMR ($CDCl_3$): δ 13.88, 108.70, 110.06, 117.46, 126.72, 127.61, 128.36 (d), 128.75, 128.89, 130.50, 136.23, 147.80, 150.19.

General procedure for the synthesis of thiophenes from 1,4-dicarbonyl compounds (9-12)

The appropriate diketone (8 mmol) and Lawesson's reagent (2.30 g, 5.5 mmol) in dry toluene (100 ml) were kept under nitrogen at 110 ^{o}C for 50 h. When the reaction was complete, as indicated by TLC analysis, the mixture was allowed to cool to room temperature and the solvent removed. The crude product was purified by column chromatography from silica gel, using ethyl acetate: dichloromethane (1:5) as the eluant. Recrystallization from ethanol gave the pure products. The structures of the products were confirmed by their spectral data.

2-(5-Methyl-2-thienyl)-1*H*-imidazole (9). This compound was obtained as brown prisms (51%), mp 138-139 ^{o}C; *Anal*. Calcd. for $C_8H_8N_2S$: C, 58.51; H, 4.91; N, 17.06; S 19.53. Found: C, 58.32; H, 4.89; N, 17.11; S, 19.68. IR (KBr): 3416-3134 (ring C-H stretching), 3240 (C-NH stretching), 1512-1464 (ring C=C and C=N stretches) cm^{-1}; ^{1}H NMR ($CDCl_3$): δ 2.45 (s, 3H, CH_3), 6.60 (d, 1H, J = 3.5 Hz, thiophene proton), 7.29 (d, 2H, J = 5.5 Hz, imidazole protons), 7.30 (d, 1H, J = 3.5 Hz, thiophene proton); ^{13}C NMR ($CDCl_3$): δ 30.90, 113.34 (d), 122.0 (d), 126.6, 132.75, 161.74.

2-(5-Methyl-2-thienyl)-1,3-thiazole (10). This compound was obtained as brown prisms (48%), mp 200-202 ^{o}C; *Anal*. Calcd. for $C_8H_7NS_2$: C, 53.00; H, 3.89; N, 7.73; S, 35.38. Found: C, 53.20; H, 3.92; N, 7.69; S, 35.19. IR (KBr): 3374-2955 (C-H stretching), 1602-1512 (ring C=C and C=N stretches) cm^{-1}; ^{1}H NMR ($CDCl_3$): δ 2.50 (s, 3H, CH_3), 6.54 (d, 1H, J = 3.8 Hz, thiophene proton), 6.72 (d, 1H, J = 3.8 Hz, thiophene proton), 7.19 (d, 1H, J = 3.3 Hz, thiazole proton), 7.71 (d, 1H, J = 3.3 Hz, thiazole proton); ^{13}C NMR ($CDCl_3$): δ 19.20, 113.40, 117.49, 126.78, 126.90, 135.60, 142.99, 162.36.

3-(5-Methyl-2-thienyl)quinoline (11). This compound was obtained as brown prisms (25%), mp 124-125 ^{o}C; *Anal*. Calcd. for $C_{14}H_{11}NS$: C, 74.63; H, 4.92; N, 6.22; S, 14.23. Found: C, 74.27; H, 4.88; N, 6.18; S, 14.67. IR (KBr): 3395-3058 (ring C-H stretching), 1557-1436 (ring C=C and C=N stretches) cm^{-1}; ^{1}H NMR ($CDCl_3$): δ 2.60 (s, 3H, CH_3), 6.85 (d, 1H, J = 3.0 Hz, thiophene proton), 7.48 (t, 1H, J= 8.0 quinoline proton), 7.58 (d 1H, J = 3.0 Hz, thiophene proton), 7.69 (t, 1H, J = 8.0 Hz, quinoline proton), 7.76 (d, 2H, J = 8.0 Hz, quinoline proton), 8.13 (d, 2H, J = 8.4 Hz, quinoline protons), ^{13}C NMR ($CDCl_3$): δ 15.77, 117.40, 125.86, 126.26, 126.51, 127.46, 128.56 (d), 129.03, 129.81, 130.00, 136.57 (d), 152.46.

2-(5-Methyl-2-thienyl)quinoline (12). This compound was obtained as brown prisms (39%), mp 182-183 ^{o}C; *Anal*. Calcd. for $C_{14}H_{11}NS$: C, 74.63; H, 4.92; N, 6.22; S, 14.23. Found: C, 74.74; H, 4.97; N, 6.31; S, 13.98. IR (KBr): 3409-2921 (ring C-H stretching), 1570-1455 (ring C=C and C=N stretches) cm^{-1}; ^{1}H NMR ($CDCl_3$): δ 2.50 (s, 3H, CH_3), 6.76 (d, 1H, J = 6.0 Hz, thiophene proton), 6.84 (d, 1H, J = 6.0 Hz, thiophene proton), 7.69 (d, 1H, J = 7.0 Hz, quinoline proton), 7.80 (t, 2H, J = 7.5 Hz, quinoline protons), 8.00 (d, 1H, J = 8.4 Hz, quinoline proton), 8.26 (d, 1H, J = 8.4 Hz, quinoline proton), 8.40 (d, 1H, J = 7.0 Hz, quinoline proton); ^{13}C NMR ($CDCl_3$):

δ 15.57, 125.84, 127.19, 127.93, 128.55, 128.67, 128.88, 129.46, 131.37, 132.71, 132.81, 134.32, 142.67, 148.45.

General procedure for the synthesis of furans from 1,4-dicarbonyl compounds (13-16)

1,4-Dicarbonyl (0.01 mol) and polyphosphoric acid (8-10 g) were stirred and heated at 130-140 ^{o}C for 4-6h. The solution was poured into the crushed ice (100g) and neutralized with sodium carbonate solution. Then extracted with dichloromethane (2x50 ml), dried ($MgSO_4$), and evaporated to yield a crude product. Recrystallization from butanol gave the products. The structures of the products were confirmed by their spectral data.

2-(5-Methyl-2-furyl)-1*H*-imidazole (13). This compound was obtained as light brown prisms (48%), mp 129–130 ^{o}C; *Anal*. Calcd. for $C_8H_8N_2O$: C, 64.85; H, 5.44; N, 18.91; O, 10.80. Found: C, 64.76; H, 4.92; N, 18.85; O, 11.47. IR (KBr): 3436-2914 (C-H stretching), 1657-1320 (ring C=C and C=N stretches), 1011 (furan) cm^{-1}; ^{1}H NMR ($CDCl_3$): δ 2.15, (s, 3H, CH_3), 3.86 (br s, 1H, NH); 5.96 (d, 1H, J = 3.2 Hz, furan proton), 6.40 (d, 1H, J = 3.2 Hz, furan proton), 7.32 (d, 2H, J = 3.2 Hz, imidazole protons); ^{13}C NMR ($CDCl_3$): δ 13.41, 107.89, 108.92, 128.79 (d), 139.80, 143.42, 152.52.

2-(5-Methyl-2-furyl)-1,3-thiazole (14). This compound was obtained as light brown prisms (45%), mp 177-178 ^{o}C; *Anal*. Calcd. for C_8H_7NOS: C, 58.16; H, 4.27; N, 8.48; O, 9.68; S, 19.41. Found: C, 58.39; H, 4.12; N, 8.73; O, 9.68; S, 19.08. IR (KBr): 3395-3113 (ring C-H stretching), 1554-1335 (ring C=C and C=N stretches), 1018 (furan) cm^{-1}; ^{1}H NMR ($CDCl_3$): δ 2.18 (s, 3H, CH_3), 5.89 (d, 1H, J = 3.5 Hz, furan proton), 6.53 (d, 1H, J = 3.5 Hz, furan proton), 7.36 (d, 1H, J = 3.4 Hz, thiazole proton), 8.01 (d, 1H, J = 3.4 Hz, thiazole proton); ^{13}C NMR ($CDCl_3$): δ 13.79, 108.43, 110.13, 117.25, 128.56, 143.30 (d), 153.14.

3-(5-Methyl-2-furyl)quinoline (15). This compound was obtained as light brown prisms (25%), mp 80-81 ^{o}C; *Anal*. Calcd. for $C_{14}H_{11}NO$: C, 80.36; H, 5.30; N, 6.69; O, 7.65. Found: C, 80.86; H, 5.44; N, 6.75; O 6.95. IR (KBr): 3415-2919 (C-H stretching), 1547-1325 (ring C=C and C=N stretches), 1022 (furan) cm^{-1}; ^{1}H NMR ($CDCl_3$): δ 2.50 (s, 3H, CH_3), 6.35 (d, 1H, J = 3.0 Hz, furan proton), 6.85 (d, 1H, J = 3.0 Hz, furan proton), 7.50 (t, 1H, J = 7.4 Hz, quinoline proton), 7.62 (t, 1H, J = 7.4 Hz, quinoline proton), 7.72 (d, 1H, J = 8.0 Hz, quinoline proton), 7.90 (d, 1H, J = 7.5 Hz, quinoline proton), 8.12 (d, 1H, J = 7.5 Hz, quinoline proton), 8.65 (s, 1H, quinoline proton); ^{13}C NMR ($CDCl_3$): δ 13.57, 104.50, 107.32, 132.01, 133.00, 134.20 (d), 135.03, 137.62, 139.20, 142.30, 145.20, 157.60, 158.90.

2-(5-Methyl-2-furyl)quinoline (16). This compound was obtained as light brown prisms (41%), mp 175-176 ^{o}C; *Anal*. Calcd. for $C_{14}H_{11}NO$: C, 80.36; H, 5.30; N, 6.69; O, 7.65. Found: C, 80.65; H, 5.08; N, 6.71; O, 7.56. IR (KBr): 3416-2921 (ring C-H stretching), 1533-1330 (ring C=C and C=N stretches), 1017 (furan) cm^{-1}; ^{1}H NMR ($CDCl_3$): δ 2.42 (s, 3H, CH_3), 6.04 (d, 1H, J = 3.2 Hz, furan proton), 6.61 (d, 1H, J = 3.2 Hz, furan proton), 7.31 (d, 1H, J = 8.0 Hz, quinoline proton), 7.50 (t, 1H, J = 7.4 Hz, quinoline proton), 7.62 (t, 1H, J = 8.0 Hz, quinoline proton), 7.80 (d, 1H, J = 8.0 Hz, quinoline proton), 8.07 (d, 2H, J = 7.4 Hz, quinoline proton),

^{13}C NMR ($CDCl_3$): δ 14.78, 108.89, 109.44, 126.87, 127.74, 127.77, 128.09, 128.27, 128.96, 129.04, 129.77, 131.49, 146.73, 148.33.

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