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Synthesis of Some New 4,5-Substituted-4H-1,2,4-triazole-3-thiol Derivatives

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Abstract: In this study appropriate hydrazide compounds, furan-2-carboxylic acid hydrazide (**1**) and phenylacetic acid hydrazide (**2**) were converted into 1,4-substituted thiosemicarbazides **4a-e** and **5a-e** and 4-amino-5-(furan-2-yl or benzyl)-4H-1,2,4-triazole-3-thiols **7** and **10**. The 1,4-substituted thiosemicarbazides were then converted into 5-(furan-2-yl or benzyl)-4-(aryl)-4H-1,2,4-triazole-3-thiols **8a-e** and **9a-e**. In addition, the azomethines **11a-d** and **12a-d** were prepared from the corresponding arylaldehydes and the 4-amino-5-(furan-2-yl or benzyl)-4H-1,2,4-triazole-3-thiols **7** and **10**. The structures of all the synthesized compounds were confirmed by elemental analyses, IR, ^{1}H-NMR and ^{13}C-NMR spectra.

Keywords: 4H-1,2,4-triazole-3-thiols; azomethines; thiosemicarbazides.

Introduction

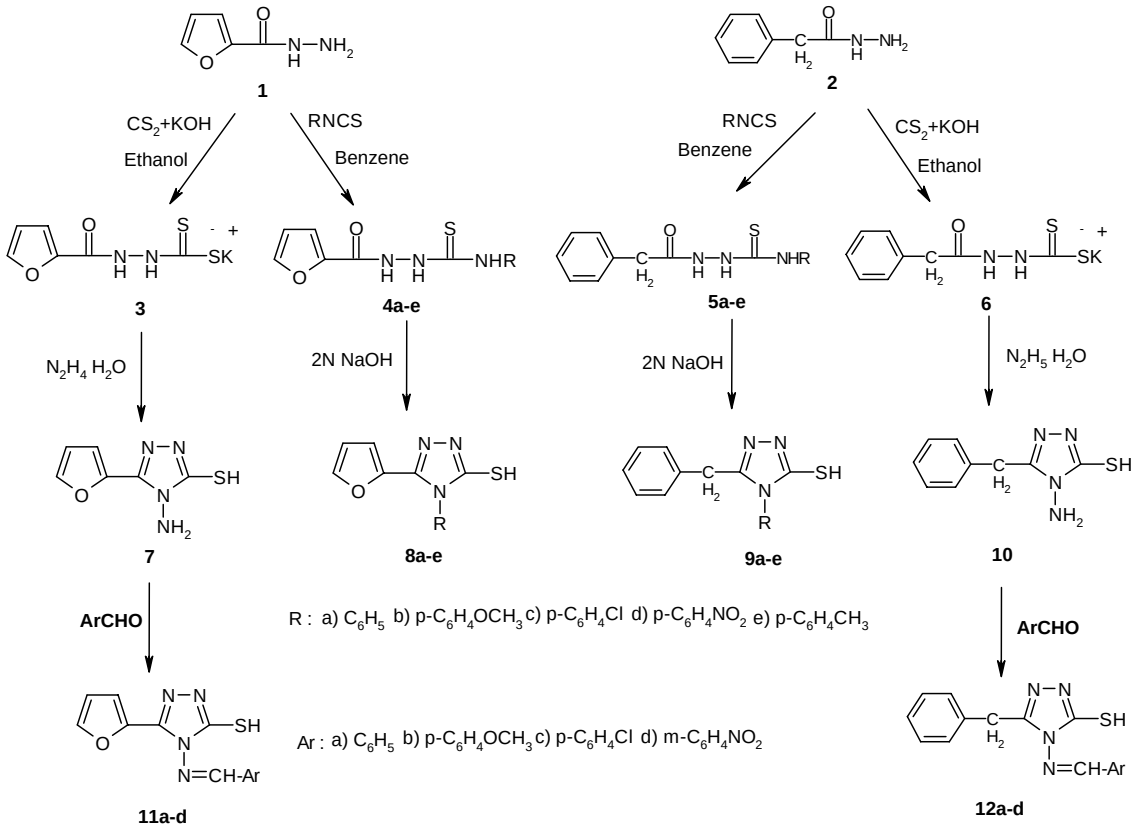
Derivatives of 1,2,4-triazole are known to exhibit anti-inflammatory [1,2], antiviral [3], analgesic [4], antimicrobial [5-7], anticonvulsant [8] and antidepressant activity [9], the latter being usually explored by the forced swim test [10,11]. Among the pharmacological profiles of 1,2,4-triazoles, their antimicrobial, anticonvulsant and antidepressant properties seem to be the best documented. New changing problems in plant protection technology have promoted research to discover more efficient pesticides. In particular the development of herbicides, now an unavoidable means to selectively control

the growth of weeds, resulted in a whole range of azoles exhibiting high levels of activity, application flexibility, crop tolerance and low levels of toxicity to mammals. Triazoles play an important role among this class of heterocycles. A series of 1,2,4-triazole derivatives [11] have been patented and extensively employed in agriculture. We now report the synthesis of 20 original compounds derived from furan-2-carboxylic acid hydrazide and phenylacetic hydrazide with the purpose of investigating in the future their possible antibacterial and antifungal activity.

Results and Discussion

The new derivatives were prepared following the reaction sequences depicted in Scheme 1. Initial compounds were prepared from available furan-2-carboxylic acid hydrazide (**1**), and phenylacetic acid hydrazide (**2**). Potassium 3-(2-furoyl) or (phenylacetyl) dithiocarbazates **3, 6** were prepared by reaction of compounds **1** and **2** with carbon disulfide in ethanolic potassium hydroxide. 1-(2-Furoyl or phenylacetyl)-4-substituted thiosemicarbazides **4a-e** and **5a-e** were prepared in yields ranging from 88 to 95% by the condensation of **1** and **2** with arylisothiocyanates. Ring closure of arylthiosemicarbazides in an alkaline medium is a well known method for the synthesis of 1,2,4-triazoles, and 5-(furan-2-yl or benzyl)-4-(aryl)-4H-1,2,4-triazole-3-thiols **8a-e** and **9a-e** were obtained in 62-79% yields from the respective **4a-e, 5a-e** by this method. Compounds **7** and **10** were obtained from the reaction of **3** and **6** with hydrazide hydrate under reflux in solution. When an arylaldehyde was added to **7** or **10** in ethanol, the reactions gave **11a-d, 12a-d**.

Scheme 1



The IR spectra of the 1,4-substituted-thiosemicarbazide derivatives **4a-e, 5a-e** have C=O stretching bands at 1687-1672 cm^{-1} and C=S stretching bands at 1290-1250 cm^{-1}. The N-H protons of **4a-e, 5a-e** were observed at 9.20-10.15 ppm, (O=C-NH-NH-C=S) and 8.00-8.25 ppm (S=C-NH-Ar). Compounds **7, 8a-e, 9a-e, 10, 11a-d, 12a-d** exist as thiol-thione tautomers as indicated by their IR spectra which showed a band due to SH and four bands due to N-C=S I, II, III, IV. The azomethine derivatives **11a-d, 12a-d** were charcterized by the presence of the methine protons (N=CH) at 9.18-10.33 ppm. The data of all the compounds are given in the Experimental section.

Experimental

General

Melting points were determined in open capillary tubes on a digital Gallenkamp melting point apparatus and are uncorrected. The IR spectra were recorded for KBr disks with a Mattson 1000 FT-IR spectrometer. ^{1}H-NMR spectra were recorded on a FX 90 JEOL 90 MHz NMR, spectrometer in $CDCl_3$ + DMSO-d_6 with TMS as an internal standard. Elemental analyses were done on a LECO-CHNS-938. Starting materials were obtained from Fluka or Aldrich.

General Procedure for Preparation of Potassium 3-(2-furoyl) or (phenylacetyl)dithiocarbazates **3** and **6**.

Carbon disulfide (0.15 mole) was added to a solution of potassium hydroxide (0.15 mole), absolute ethanol (200 mL) and the appropriate furan-2-carboxylic acid hydrazide (**1**) or phenylacetic acid hydrazide (**2**) (0.10 mole). This mixture was diluted with absolute ethanol (150 mL) and agitated for 12-18 hours. It was then diluted with dry ether (250 mL) and the products were filtered off and vacuum dried at 65 ºC. The salts prepared as described above were obtained in nearly quantitative yields and were used without further purification.

Potassium-3-(2-furoyl)dithiocarbazate (**3**): m.p. 222-225 ºC; IR υ (cm^{-1}): 3450, 3310 (N-H), 1639 (C=O), 1270 (C=S), 1248 (C-O-C).

Potassium-3-(Phenylacetyl)dithiocarbazate (**6**): m.p. 212-255 ºC; IR υ (cm^{-1}): 3375, 3225 (N-H), 1670 (C=O), 1275 (C=S), 1250 (C-O-C).

General procedure for Preparation of **4a-e, 5a-e.**

A mixture of **1** (or **2**) (0.01 mole) and the appropriate aryl isothiocyanate (0.01 mole) in dry C_6H_6 was refluxed for 6 hours. The solid material obtained on cooling was filtered off and recrystallized from methanol.

1-(2-furoyl)-4-Phenylthiosemicarbazide (**4a**): From phenylisothiocyanate, yield 92%; m.p. 184-185 ºC; IR υ (cm^{-1}): 3365, 3315 (N-H), 1672 (C=O), 1274 (C=S), 1251 (C-O-C); ^{1}H-NMR δ (ppm): 6.68-7.20 (m, 3H, furan), 7.42-7.92 (m, 5H, Ar-H), 8.11-8.19 (br, 1H, -NH-Ar), 9.20-9.92 (br, 2H, 2xNH). Calcd. for $C_{12}H_{11}N_3O_2S$ (261); (%): C, 55.16; H, 4.24; N, 16.08; S, 12.27; found (%): C, 55.27; H, 4.11, N, 15.97; S, 12.13.

1-(2-furoyl)-4-(4-methoxyphenyl)thiosemicarbazide (**4b**): From *p*-methoxphenylisothiocyanate, yield 93%; m.p. 162-163 ºC; IR υ (cm^{-1}): 3355, 3320 (N-H), 1678 (C=O), 1271 (C=S), 1253 (C-O-C); ^{1}H-NMR δ (ppm): 3.79 (s, 3H, -O-CH_3) 5.90-6.20 (m, 3H, furan), 6.55-6.90 (m, 4H, Ar-H), 8.21-8.25 (br, 1H, -NH-Ar), 9.21-9.92 (br, 2H, 2xNH). Calcd. for $C_{13}H_{13}N_3O_3S$ (291); (%): C, 53.60; H, 4.50; N, 14.42; S, 11.01; found (%): C, 53.45; H, 4.51, N, 14.47; S, 10.98.

1-(2-furoyl)-4-(4-chlorophenyl)thiosemicarbazide (**4c):** From *p*-chlorophenylisothiocyanate, yield 90%; m.p. 188-189 ºC; IR υ (cm^{-1}): 3354, 3321 (N-H), 1673 (C=O), 1268 (C=S), 1249 (C-O-C); ^{1}H-NMR δ (ppm): 6.67-7.21 (m, 3H, furan), 7.22-7.90 (m, 4H, Ar-H), 8.18-8.20 (br, 1H, -NH-Ar), 9.71-10.02 (br, 2H, 2xNH). Calcd. for $C_{12}H_{10}ClN_3O_2S$ (295); (%): C, 48.74; H, 3.41; N, 14.21; S, 10.84; found (%): C, 48.45; H, 3.43, N, 14.17; S, 10.88.

1-(2-furoyl)-4-(4-nitrophenyl)thiosemicarbazide (**4d**): From *p*-nitrophenylisothiocyanate, yield 95%; m.p. 210-211 ºC; IR υ (cm^{-1}): 3344, 3311 (N-H), 1422 (NO_2), 1679 (C=O), 1274 (C=S), 1254 (C-O-C); ^{1}H-NMR δ (ppm): 6.70-7.28 (m, 3H, furan), 7.56-7.76 (m, 4H, Ar-H), 8.00-8.14 (br, 1H, -NH-Ar), 9.21-10.11 (br, 2H, 2xNH). Calcd. for $C_{12}H_{10}N_4O_4S$ (306); (%): C, 47.06; H, 3.29; N, 18.29; S, 10.47; found (%): C, 47.10; H, 3.23, N, 18.27; S, 10.40.

1-(2-furoyl)-4-(4-methylphenyl)thiosemicarbazide (**4e**): From *p*-methylphenylisothiocyanate, yield 91%; m.p. 165-167 ºC; IR υ (cm^{-1}): 3449, 3321 (N-H), 1683 (C=O), 1269 (C=S), 1241 (C-O-C); ^{1}H-NMR δ (ppm): 2.28 (s, 3H, CH_3), 6.71-7.26 (m, 3H, furan), 7.54-7.72 (m, 4H, Ar-H), 8.20-8.25 (br, 1H, -NH-Ar), 9.97-10.15 (br, 2H, 2xNH). Calcd. for $C_{13}H_{13}N_3O_2S$ (275); (%): C, 56.71; H, 4.76; N, 15.26; S, 11.65; found (%): C, 56.54; H, 4.71, N, 14.97; S, 11.64.

1-Phenylacetyl-4-phenylhiosemicarbazide (**5a**): From phenylisothiocyanate, yield 94%; m.p. 160-161 ºC; IR υ (cm^{-1}): 3450, 3310 (N-H), 1687 (C=O), 1290 (C=S); ^{1}H-NMR δ (ppm): 3.35 (s, 2H, CH_2), 7.30-7.44 (m, 10H, Ar-H), 8.21-8.23 (br, 1H, -NH-Ar), 9.95-10.11 (br, 2H, 2xNH). Calcd. for $C_{15}H_{15}N_3OS$ (285); (%): C, 63.13; H, 5.30; N, 14.72; S, 11.24; found (%): C, 63.09; H, 5.35, N, 14.67; S, 11.19.

1-Phenylacetyl-4-(4-methoxyphenyl)thiosemicarbazide **(5b)**: From *p*-methoxphenylisothiocyanate, yield 92%; m.p. 157-159 ºC; υ (cm^{-1}): 3452, 3312 (N-H), 1686 (C=O), 1274 (C=S); ^{1}H-NMR δ (ppm): 3.39 (s, 2H, CH_2), 4.25 (s, 3H, -O-CH_3), 6.77-7.30 (m, 9H, Ar-H), 8.11-8.13 (br, 1H, -NH-Ar),

9.98-10.13 (br, 2H, 2xNH). Calcd. for $C_{16}H_{17}N_3O_2S$ (315); (%): C, 60.93; H, 5.43; N, 13.32; S, 10.47; found (%): C, 61.01; H, 5.25, N, 13.32; S, 10.49.

1-Phenylacetyl-4-(4-chlorophenyl)thiosemicarbazide (**5c**): From *p*-chlorophenylisothiocyanate, yield 90%; m.p. 164-165 ºC; IR υ (cm^{-1}): 3482, 3317 (N-H), 1675 (C=O), 1267 (C=S); ^{1}H-NMR δ (ppm): 3.40 (s, 2H, CH_2), 7.31-7.44 (m, 9H, Ar-H), 8.13-8.17 (br, 1H, -NH-Ar), 10.11-10.13 (br, 2H, 2xNH). Calcd. for $C_{15}H_{14}ClN_3OS$ (319); (%): C, 56.33; H, 4.41; N, 13.14; S, 10.03; found (%): C, 56.21; H, 4.39, N, 13.12; S, 9.99.

1-Phenylacetyl-4-(4-nitrophenyl)thiosemicarbazide (**5d**): From *p*-nitrophenylisothiocyanate, yield 93%; m.p. 187-188 ºC; IR υ (cm^{-1}): 3451, 3322 (N-H), 1672 (C=O), 1266 (C=S); ^{1}H-NMR δ (ppm): 3.74 (s, 2H, CH_2), 7.37-7.87 (m, 9H, Ar-H), 8.19-8.22 (br, 1H, -NH-Ar), 10.13-10.15 (br, 2H, 2xNH). Calcd. for $C_{15}H_{14}N_4O_3S$ (330); (%): C, 54.54; H, 4.27; N, 16.96; S, 9.71; found (%): C, 54.41; H, 4.29, N, 17.01; S, 9.69.

1-Phenylacetyl-4-(4-methylphenyl)thiosemicarbazide (**5e**): From *p*-methylphenylisothiocyanate, yield 88%; m.p. 160-161 ºC; IR υ (cm^{-1}): 3450, 3329 (N-H), 1678 (C=O), 1250 (C=S); ^{1}H-NMR δ (ppm): 2.28 (s, 3H, CH_3), 3.53 (s, 2H, CH_2), 7.30-7.45 (m, 9H, Ar-H), 8.17-8.24 (br, 1H, -NH-Ar), 10.13-10.15 (br, 2H, 2xNH). Calcd. for $C_{16}H_{17}N_3OS$ (299); (%): C, 64.19; H, 5.72; N, 14.03; S, 10.71; found (%): C, 64.11; H, .69, N, 14.01; S, 10.59.

General Procedure for the Preparation of Compounds **7** *and* **10**.

A suspension of the potassium salt **3** (or **6**) (20 mmoles), 95 % hydrazine (40 mmoles) and water (2 mL) was refluxed with stirring for 0.5 to 1 hours. The color of the reaction mixture changed to green, hydrogen sulfide was evolved and a homogeneous solution resulted. A white solid was precipitated by dilution with cold water (100 mL) and acidification with concentrated hydrochloric acid. This product was filtered, washed with cold water (2x30 mL) and recrystallized from ethanol or ethanol-water.

4-Amino-5-furan-2-yl-4H-1,2,4-triazole-3-thiol (**7**): Yield 45%; m.p. 202-203 ºC; IR υ (cm^{-1}): 3329 (N-H), 2775 (SH), 1618 (C=N), 1238 (C-O-C), 1533, 1262, 1051, 952 (N-C=S, amide I, II, III and IV bands); ^{1}H-NMR δ (ppm): 5.80 (s, 2H, NH_2), 6.70-7.91 (m, 3H, furan), 13.89 (s, 1H, SH); ^{13}C-NMR δ: 111.89, 11398, 139.90, 142.83, 145.20, 156.54. Calcd. for $C_6H_6N_4OS$ (182); (%): C, 39.55; H, 3.32; N, 30.75; S, 17.60; found (%): C, 39.49; H, 3.39, N, 31.01; S, 17.59.

4-Amino-5-benzyl-4H-1,2,4-triazole-3-thiol (**10**): Yield 53%; m.p. 207-209 ºC; IR υ (cm^{-1}): 3337 (N-H), 2350 (SH), 1620 (C=N), 1535, 1260, 1050, 950 (N-C=S, amide I, II, III and IV bands); ^{1}H-NMR δ (ppm): 5.01 (s, 2H, NH_2), 5.41 (s, 2H, CH_2), 6.72-7.02 (m, 5H, Ar-H), 13.01 (s, 1H, SH); ^{13}C-NMR δ: 35.41,

111.89, 113.98, 125.71, 127.91, 128.31, 139.90, 141.54, 142.83, 145.20, 156.54. Calcd. for $C_9H_{10}N_4S$ (206); (%): C, 52.41; H, 4.89; N, 27.16; S, 15.54; found (%): C, 52.49; H, 4.87, N, 27.25.01; S, 15.59.

General Procedure for the Preparation of Compounds **8a-e** *and* **9a-e.**

A stirring mixture of compound **4a** (or **4b-e, 5a-e**) (1 mmole) and sodium hydroxide (40 mg, 1 mmole, as a 2N solution) was refluxed for 4 hours. After cooling, the solution was acidified with hydrochloric acid and the precipitate was filtered. The precipitate was then crystallized from ethanol.

5-Furan-2-yl-4-phenyl-4H-1,2,4-triazole-3-thiol (**8a**): Yield 68%; m. p. 210-212 ºC; IR υ (cm^{-1}): 3321, 3250 (N-H), 2575 (SH), 1604 (C=N), 1249 (C-O-C), 1535, 1260, 1054, 948 (N-C=S, amide I, II, III and IV bands); ^{1}H-NMR δ (ppm): 5.97-6.34 (m, 3H, furan), 7.45-7.55 (m, 5H, Ar-H), 13.04 (s, 1H, SH). Calcd. for $C_{12}H_9N_3OS$ (243); (%): C, 59.24; H, 3.73; N, 17.27; S, 13.18; found (%): C, 58.99; H, 3.69, N, 17.25; S, 13.19.

5-Furan-2-yl-4-(4-methoxyphenyl)-4H-1,2,4-triazole-3-thiol (**8b**): Yield 78%; m. p. 245-246 ºC; IR υ (cm^{-1}): 3331, 3258 (N-H), 2564 (SH), 1618 (C=N), 1250 (C-O-C), 1538, 1259, 1048, 948 (N-C=S, amide I, II, III and IV bands); ^{1}H-NMR δ (ppm): 3.88 (s, 3H, OCH_3), 5.95-6.38 (m, 3H, furan), 7.09-7.55 (m, 4H, Ar-H), 14.00 (s, 1H, SH). Calcd. for $C_{13}H_{11}N_3O_2S$ (273); (%): C, 57.13; H, 4.06; N, 15.37; S, 11.73; found (%): C, 57.19; H, 3.99, N, 15.25; S, 11.79.

4-(4-Chlorophenyl-)5-Furan-2-yl)-4H-1,2,4-triazole-3-thiol (**8c**): Yield 72%; m. p. 264-265 ºC; IR υ (cm^{-1}): 3351, 3288 (N-H), 2564 (SH), 1625 (C=N), 1250 (C-O-C), 1535, 1260, 1050, 950 (N-C=S, amide I, II, III and IV bands); ^{1}H-NMR δ (ppm): 6.16-6.50 (m, 3H, furan), 7.45-7.78 (m, 4H, Ar-H), 13.98 (s, 1H, SH). Calcd. for $C_{12}H_8ClN_3OS$ (273); (%): C, 51.90; H, 2.90; N, 15.13; S, 11.54; found (%): C, 51.88; H, 2.99, N, 15.15; S, 11.49.

4-(4-Nitrophenyl-)5-Furan-2-yl)-4H-1,2,4-triazole-3-thiol (**8d**): Yield 62%; m. p. 187-188 ºC; IR υ (cm^{-1}): 3341, 3280 (N-H), 2580 (SH), 1625 (C=N), 1250 (C-O-C), 1528 (NO_2), 1537, 1263, 1057, 952 (N-C=S, amide I, II, III and IV bands); ^{1}H-NMR δ (ppm): 5.91-6.95 (m, 3H, furan), 7.51-8.08 (m, 4H, Ar-H), 12.98 (s, 1H, SH). Calcd. for $C_{12}H_8N_4O_3S$ (288); (%): C, 50.00; H, 2.80; N, 19.43; S, 11.12; found (%): C, 50.08; H, 2.89, N, 19.50; S, 11.15.

5-Furan-2-yl-4-(4-methylphenyl)-4H-1,2,4-triazole-3-thiol (**8e**): Yield 79%; m. p. 257-258 ºC; IR υ (cm^{-1}): 3351, 3285 (N-H), 2576 (SH), 1621 (C=N), 1250 (C-O-C), 1534, 1258, 1050, 951 (N-C=S, amide I, II, III and IV bands); ^{1}H-NMR δ (ppm): 2.46 (s, 3H, CH_3), 5.94-6.36 (m, 3H, furan), 7.31-7.47 (m, 4H, Ar-H), 14.01 (s, 1H, SH). Calcd. for $C_{13}H_{11}N_3OS$ (257); (%): C, 60.68; H, 4.31; N, 16.33; S, 12.46; found (%): C, 60.65; H, 4.39, N, 16.50; S, 12.42.

5-Benzyl-4-phenyl-4H-1,2,4-triazole-3-thiol (**9a**): Yield 73%; m. p. 197-198 ºC; IR υ (cm^{-1}): 3344, 3282 (N-H), 2548 (SH), 1620 (C=N), 1535, 1263, 1050, 951 (N-C=S, amide I, II, III and IV bands); ^{1}H-NMR δ (ppm): 3.81 (s, 2H, CH_2), 7.10-7.45 (m, 10H, Ar-H), 13.81 (s, 1H, SH). Calcd. for $C_{15}H_{13}N_3S$ (267); (%): C, 67.39; H, 4.90; N, 15.72; S, 11.99; found (%): C, 67.38; H, 4.87, N, 15.65; S, 12.09.

5-Benzyl-4-(4-methoxyphenyl)-4H-1,2,4-triazole-3-thiol (**9b**): Yield 79%; m.p. 177-178 ºC; IR υ (cm^{-1}): 3344, 3282 (N-H), 2570 (SH), 1606 (C=N), 1538, 1260, 1050, 950 (N-C=S, amide I, II, III and IV bands); ^{1}H-NMR δ (ppm): 3.80 (s, 2H, CH_2), 3.88(s, 3H, OCH_3), 6.95-7.25 (m, 9H, Ar-H), 13.06 (s, 1H, SH). Calcd. for $C_{16}H_{15}N_3OS$ (297); (%): C, 64.62; H, 5.08; N, 14.13; S, 10.78; found (%): C, 64.58; H, 4.97, N, 14.09; S, 10.72.

5-Benzyl-4-(4-chlorophenyl)-4H-1,2,4-triazole-3-thiol (**9c**): Yield 73%; m.p. 187-188 ºC; IR υ (cm^{-1}): 3354, 3292 (N-H), 2580 (SH), 1606 (C=N), 1535, 1260, 1050, 950 (N-C=S, amide I, II, III and IV bands); ^{1}H-NMR δ: 3.84 (s, 2H, CH_2), 6.94-7.42 (m, 9H, Ar-H), 12.96 (s, 1H, SH). Calcd. for $C_{15}H_{12}ClN_3OS$ (301); (%): C, 59.70; H, 4.01; N, 13.92; S, 10.62; found (%): C, 59.58; H, 4.07, N, 14.00; S, 10.62.

5-Benzyl-4-(4-nitrophenyl)-4H-1,2,4-triazole-3-thiol (**9d**): Yield 63%; m.p. 210-211 ºC; IR υ (cm^{-1}): 3354, 3291 (N-H), 2550 (SH), 1616 (C=N), 1535, 1260, 1050, 950 (N-C=S, amide I, II, III and IV bands); ^{1}H-NMR δ (ppm): 3.90 (s, 2H, CH_2), 6.92-8.29 (m, 9H, Ar-H), 14.01 (s, 1H, SH). Calcd. for $C_{15}H_{12}NO_2S$ (312); (%): C, 57.68; H, 3.87; N, 17.94; S, 10.27; found (%): C, 57.58; H, 3.87, N, 18.00; S, 10.27.

5-Benzyl-4-(4-methylphenyl)-4H-1,2,4-triazole-3-thiol (**9e**): Yield 71%; m.p. 182-183 ºC; IR υ (cm^{-1}): 3358, 3290 (N-H), 2550 (SH), 1605 (C=N), 1538, 1262, 1050, 950 (N-C=S, amide I, II, III and IV bands); ^{1}H-NMR δ (ppm): 2.42 (s, 3H, CH_3), 3.81 (s, 2H, CH_2), 6.97-7.29 (m, 9H, Ar-H), 12.91 (s, 1H, SH). Calcd. for $C_{16}H_{15}N_3S$ (312); (%): C, 68.30; H, 5.37; N, 14.93; S, 11.40; found (%): C, 63.38; H, 5.37, N, 15.00; S, 11.47.

General Procedure for the Preparation of Compounds **11a-d** *and* **12a-d**.

A mixture of **7** (or **10**) (0.01 mole) and the corresponding aryl aldehyde (0.01 mole) in ethanol (25 mL) was treated with concentrated HCl (0.5 mL) and refluxed for 2 hours. The reaction mixture on cooling was filtered and recrystallized from ethanol.

4-(Benzylideneamino)-5-furan-2-yl-4H-1,2,4-triazole-3-thiol (**11a**): Prepared from benzaldehyde, yield 59%; m.p. 197-198 ºC; IR υ (cm^{-1}): 3329 (N-H), 2625 (SH), 1630 (C=N), 1238 (C-O-C), 1535, 1262, 1051, 952 (N-C=S, amide I, II, III and IV bands); ^{1}H-NMR δ (ppm): 6.57-7.23 (m, 3H, furan), 7.55-7.97 (m, 5H, Ar-H), 10.18 (s, 1H, N=CH), 13.19 (s, 1H, SH). Calcd. for $C_{13}H_{10}N_4OS$ (270); (%): C, 57.76; H, 3.73; N, 20.73; S, 11.86; found (%): C, 57.69; H, 3.71, N, 20.69; S, 11.89.

5-furan-2-yl-4-[(4-methoxybenzylidene)amino]-4H-1,2,4-triazole-3-thiol (**11b**): Prepared from *p*-methoxybenzaldehyde, yield 53%; m.p. 205-206 ºC; IR υ (cm^{-1}): 3339 (N-H), 2525 (SH), 1630 (C=N), 1238 (C-O-C), 1545, 1262, 1050, 950 (N-C=S, amide I, II, III and IV bands); ^{1}H-NMR δ (ppm): 3.87 (s, 3H, OCH_3), 5.57-6.74 (m, 3H, furan), 7.07-7.97 (m, 4H, Ar-H), 9.18 (s, 1H, N=CH), 12.99 (s, 1H, SH). Calcd. for $C_{14}H_{12}N_4O_2S$ (300); (%): C, 55.99; H, 4.03; N, 18.65; S, 10.68; found (%): C, 56.01; H, 3.99, N, 18.69; S, 10.67.

4-[(4-Chlorobenzylidene)amino]-5-furan-2-yl-4H-1,2,4-triazole-3-thiol (**11c**): Prepared from *p*-chlorobenzaldehyde, yield 59%; m.p. 225-226 ºC; IR υ (cm^{-1}): 3359 (N-H), 2558 (SH), 1633 (C=N), 1238 (C-O-C), 1535, 1260, 1050, 950 (N-C=S, amide I, II, III and IV bands); ^{1}H-NMR δ (ppm): 5.71-6.84 (m, 3H, furan), 7.06-7.98 (m, 4H, Ar-H), 9.98 (s, 1H, N=CH), 13.99 (s, 1H, SH). Calcd. for $C_{13}H_9ClN_4OS$ (304); (%): C, 51.24; H, 2.98; N, 18.38; S, 10.52; found (%): C, 51.19; H, 3.00, N, 18.41; S, 10.55.

4-[(3-Nitrobenzylidene)amino]-5-furan-2-yl-4H-1,2,4-triazole-3-thiol (**11d**): Prepared from *m*-nitrobenzaldehyde, yield 51%; m.p. 165-166 ºC; IR υ (cm^{-1}): 3369 (N-H), 2563 (SH), 1631 (C=N), 1238 (C-O-C), 1535, 1260, 1050, 950 (N-C=S, amide I, II, III and IV bands); ^{1}H-NMR δ (ppm): 2.40 (s, 3H, CH_3), 5.82-6.72 (m, 3H, furan), 7.40-8.71 (m, 4H, Ar-H), 10.08 (s, 1H, N=CH), 13.97 (s, 1H, SH). Calcd. for $C_{13}H_9N_5O_3S$ (315); (%): C, 49.52; H, 2.88; N, 22.21; S, 10.17; found (%): C, 49.59; H, 3.00, N, 22.29; S, 10.25.

5-Benzyl-4-(benzylideneamino)-4H-1,2,4-triazole-3-thiol (**12a**): Prepared from benzaldehyde, yield 43%; m.p. 177-178 ºC; IR υ (cm^{-1}): 3350 (N-H), 2558 (SH), 1610 (C=N), 1535, 1260, 1050, 950 (N-C=S, amide I, II, III and IV bands); ^{1}H-NMR δ (ppm): 4.18 (s, 2H, CH_2), 7.28-7.90 (m, 10H, Ar-H), 10.31 (s, 1H, N=CH), 12.99 (s, 1H, SH). Calcd. for $C_{16}H_{14}N_4S$ (294); (%): C, 65.28; H, 4.79; N, 19.03; S, 10.89; found (%): C, 65.30; H, 4.81, N, 18.99.; S, 10.84.

5-Benzyl-4-[(4-methoxybenzylidene)amino]-4H-1,2,4-triazole-3-thiol (**12b**): Prepared from *p*-methoxybenzaldehyde, yield 53%; m.p. 191-192 ºC; IR υ (cm^{-1}): 3354 (N-H), 2566 (SH), 1605 (C=N), 1535, 1260, 1050, 950 (N-C=S, amide I, II, III and IV bands); ^{1}H-NMR δ (ppm): 4.16 (s, 2H, CH_2), 4.21 (s, 3H, OCH_3), 6.93-7.86 (m, 9H, Ar-H), 10.02 (s, 1H, N=CH), 12.79 (s, 1H, SH). Calcd. for $C_{17}H_{16}N_4S$ (324); (%): C, 62.94; H, 4.97; N, 17.27; S, 9.88; found (%): C, 63.00; H, 4.96, N, 17.29.; S, 9.86.

5-Benzyl-4-[(4-chlorobenzylidene)amino]-4H-1,2,4-triazole-3-thiol (**12c**): Prepared from *p*-chlorobenzaldehyde, yield 58%; m.p. 205-206 ºC; IR υ (cm^{-1}): 3355 (N-H), 2561 (SH), 1625 (C=N), 1533, 1261, 1050, 950 (N-C=S, amide I, II, III and IV bands); ^{1}H-NMR δ (ppm): 4.17 (s, 2H, CH_2), 7.27-7.96 (m, 9H, Ar-H), 10.33 (s, 1H, N=CH), 13.79 (s, 1H, SH). Calcd. for $C_{16}H_{13}ClN_4S$ (328); (%): C, 58.44; H, 3.98; N, 17.04; S, 9.75; found (%): C, 58.39; H, 3.96, N, 17.09.; S, 9.71.

5-Benzyl-4-[(3-nitrobenzylidene)amino]-4H-1,2,4-triazole-3-thiol (**12d**): Prepared from *m*-nitrobenzaldehyde, yield 69%; m.p. 181-182 ºC; IR υ (cm^{-1}): 3359 (N-H), 2563 (SH), 1621 (C=N), 1538, 1260, 1050, 950 (N-C=S, amide I, II, III and IV bands); ^{1}H-NMR δ (ppm): 2.44 (s, 3H, CH_3), 4.15 (s, 2H, CH_2), 7.27-7.96 (m, 9H, Ar-H), 10.33 (s, 1H, N=CH), 13.91 (s, 1H, SH). Calcd. for $C_{16}H_{13}N_5S$ (339); (%): C, 56.63; H, 3.86; N, 20.64; S, 9.45; found (%): C, 56.69; H, 3.96, N, 20.69.; S, 9.41.

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