Synthesis of some new phthalazines and their evaluation as corrosion inhibitors of steel

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A convenient synthesis has been achieved of 11 substituted phthalazines starting from the condensation of 2-(*p*-toluoyl)benzoic acid with hydrazine and some of its simple congeners, H_2NNHR. Four of the phthalazines showed activity as inhibitors of the corrosion of steel immersed in 5 M HCl solutions.

Keywords: 2-*p*-(toluoyl)benzoic acid, hydrazine derivatives, phthalazine derivatives, corrosion inhibitors

Addition of an inhibitor remains a necessary procedure to secure the metal against attack in chemical cleaning and pickling to remove mill scales from metallic surfaces. Inhibitors should be effective even under severe conditions such as concentrated HCl at temperature up to 60 °C.[1–3] Organic compounds rich in heteroatoms such as sulfur, nitrogen and oxygen generally exhibit the best protection against corrosion. They are adsorbed in metals by displacing water molecules on the surface, thereby blocking either cathodic, anodic or both reactions, and forming a compact barrier film.[4–6]

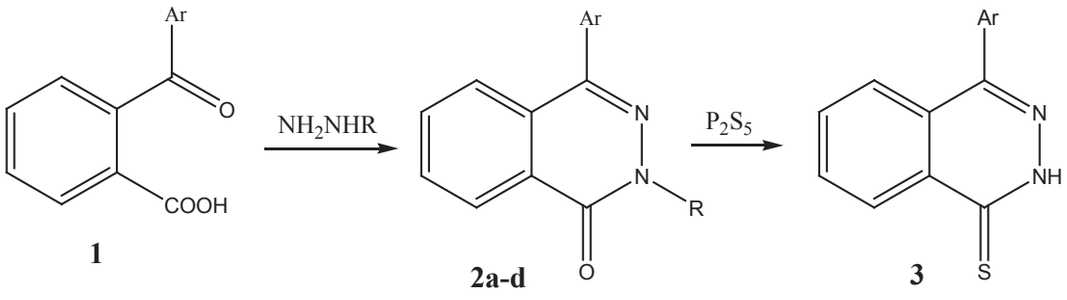
Phthalazine derivatives have been tested as corrosion inhibitors[7] of copper in 1 M H_2SO_4 using electrochemical polarisation and weight loss techniques. This study monitored the evolution of the inhibitory effect of the phthalazine derivatives according to their constitutions. The development of new synthetic methods for the efficient preparation of heterocycles containing a phthalazine ring fragment is therefore an interesting challenge. Therefore, a number of methods have been reported for the synthesis of phthalazine derivatives.[8–10]

In the present investigation, 11 new phthalazine derivatives were prepared starting from the reaction of 2-(*p*-toluoyl) benzoic acid with hydrazine and some of its derivatives H_2NNHR and their corrosion inhibition properties were evaluated by weight loss measurements of steel immersed in 5 M HCl solutions at room temperature.

Results and discussion

The reaction of 2-*p*-(toluoyl)benzoic acid **1** with hydrazine and some of its simple congeners H_2NNHR afforded 2-substituted-4-(*p*-tolyl)phthalazin-1(2H)-ones **2a**–**d** (Scheme 1). Refluxing of compound **2a** in dry acetonitrile with phosphorus pentasulfide in the presence of a catalytic amount of triethylamine gave the phthalazin-1(2H)-thione derivative **3** in a good yield as illustrated in Scheme 1. The structures of compounds **2a**–**d** and **3** (and all the others described below) were characterised by their microanalytical and spectral data. Thus, their IR spectra showed bands corresponding to NH, C=O and C=N as well as a band for C=S in case of **3**. Further support for the assigned structures of compounds **2** and **3** was gained from their ^{1}H NMR spectra, which exhibit signals characteristic for aliphatic and aromatic protons in addition to NH protons in the downfield region which were exchangeable with D_2O. Moreover, their mass spectral data are in accord with their proposed structures as they show the molecular ion peaks as well as some of the important fragmentation peaks. The formation of compounds **2a**–**d** can be explained on the basis of the cyclocondensation of hydrazine derivatives with the acid **1**.

Treatments of thione **3** with hydrazine derivatives such as hydrazine hydrate, 2-hydrazinopyridine, phenylhydrazine or benzoyl hydrazine furnished phthalazine derivatives **5a**–**d** with evolution of H_2S gas. Thus the formation of compounds **5a**–**d** can be understood on the basis of addition of the free NH_2 group of the hydrazines to the C=S group of **3** to give the non-isolable adduct **4** followed by elimination of an H_2S molecule. A chemical proof for the structure of compounds **5a**–**d** was obtained through their synthesis from hydrazines and the chloro phthalazine derivative **6** prepared by reaction of phthalazine derivative **2a** with $POCl_3$ as shown in Scheme 2. The IR spectra of compounds **5**, **6** showed absorption bands correlated with υ(C=N) and υ (NH) for **5a**–**d** in addition to



1 **2a-d** **3**

Ar = p-Me-C_6H_4

a) R = H, **b**) R = Ph,
c) R = 2-pyridyl, **d**) R = C(=S)NH_2

Scheme 1

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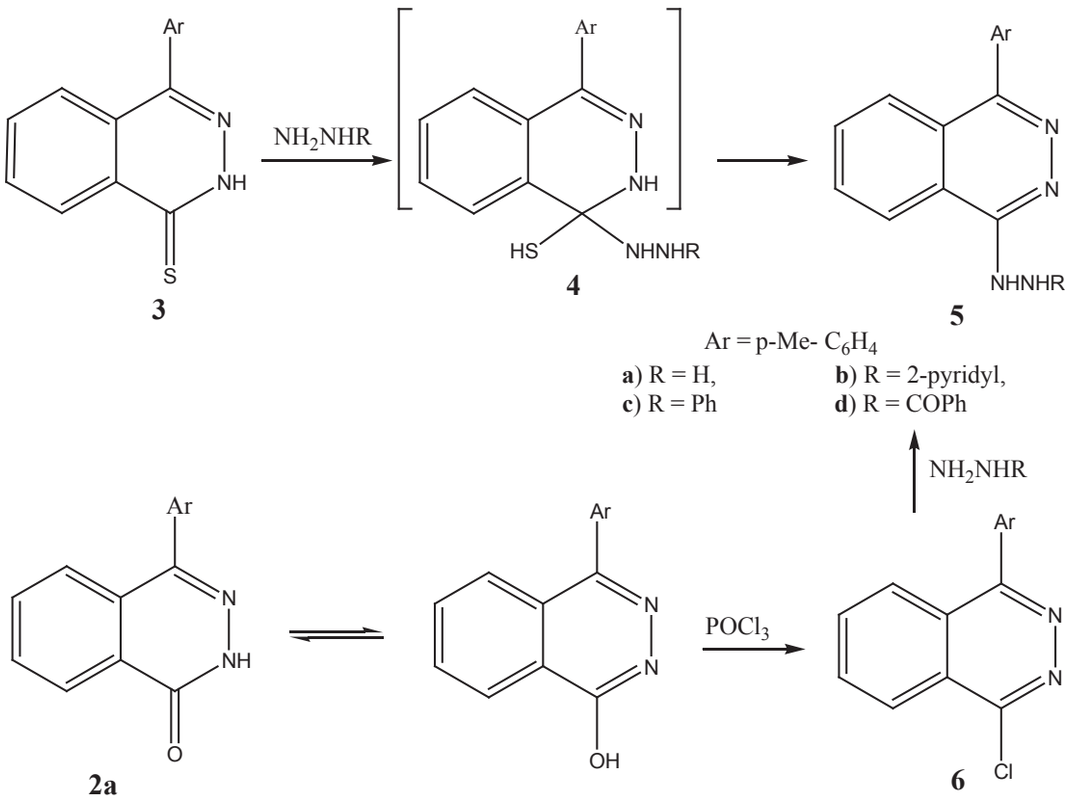


Scheme 2

υ(C=O) for **5d**. Their ^{1}H NMR and MS spectra were consistent with their proposed structures.

Refluxing of phthalazine derivative **5a** with benzoyl chloride in pyridine yielded triazolophthalazine derivative **7** in **a** one-pot reaction. Moreover, compound **7** was obtained through boiling **5d** in dry toluene for a long time. On the other hand, reaction of **5a** with acetylacetone afforded pyrazolophthalazine derivative **9** also in a one pot reaction. The IR spectra of **7** and **9** showed absorption bands correlated with υ C=N and the absence of absorption bands due to C=O and NH groups. Their ^{1}HNMR spectra displayed signals corresponding to aromatic and aliphatic protons. Further confirmation of the assigned structures were gained from their mass spectra which revealed the correct molecular ion peaks and some abundant fragmentation peaks. The mechanism of formation of compounds **7** and **9** can be visualised as a cyclocondensation of the intermediate tautomeric hydrazides (not isolated) as shown in Scheme 3.

Evaluation of the synthesised phthalazines as corrosion inhibitors

The corrosion inhibition tendency of the synthesised phthalazines was tested by studying the weight loss of steel coupons immersed in a solution of 5 M HCl throughout 100 h of immersion at room temperature. The results of weight loss of steel coupons with and without the addition of 0.02 M of different inhibitors at 25, 50, 75 and 100 h of immersion in 5 M HCl are summarised in Fig. 1.

The inhibition efficiency (% I) was calculated from the equation:

$$\%I = W_{free} - W_{inh} / W_{free} \times 100$$

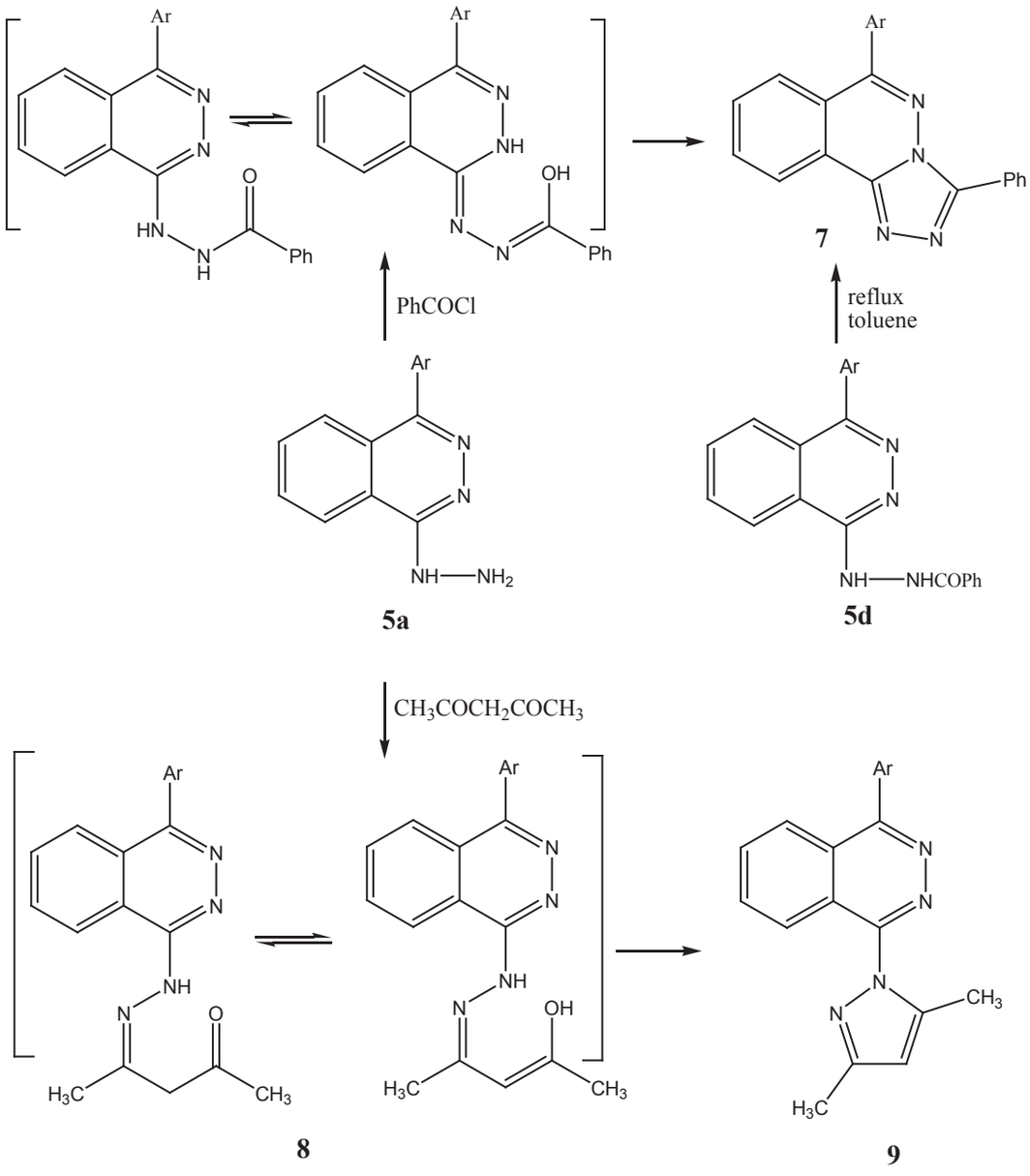
where W_{free} and W_{inh} are the weight loss without and with inhibitor, respectively. Table 1 shows the inhibition efficiency of the different inhibitors.

Data in Table 1 and Fig. 1 show that phthalazine derivatives **2c**, **5a**, **5c** and **7** were protecting steel from corrosion. The weight loss decreases and inhibition efficiency increases in the presence of inhibitors. The studied inhibitors are N-containing compounds which may be protonated in the working acidic media. Therefore, they easily reach the steel surface and are at once adsorbed upon it. The reactivity of the ring atoms and those of the substituents they carry are interlinked, and it is a matter of conjecture whether to regard certain reactions as chemical properties of the former or of the latter.[11] In most inhibition studies the formation of donor–acceptor surface complexes between the electrons of an inhibitor and the vacant d-orbital of a metal is postulated.[12–15] Nitrogen-based compounds are effective inhibitors for corrosion in aqueous solutions.[16] They adsorb through electrostatic interactions between the positively charged nitrogen atom and the negatively charged metal surface.[17] The greater inhibition properties of **2c** over the other phthalazines **5a**, **5b** and **7** is perhaps due to an increased number of centres of adsorption on the inhibitor molecule as well as the higher electron densities on both N-3 of the phthalazine ring **2c** and that on the pyridyl N-atom.

Table 1 Inhibition activity (%I)[a] of four of the synthesised phthalazines[b]

%I	Slope[c]	Compd
93.4	0.0904	**2c**
47.8	0.5528	**5a**
57.1	0.4748	**5b**
64.3	0.5568	**7**
–	0.9236	**B**

[a]For definition of %I see text.
[b]See Schemes 1–3.
[c]Slope refers to plots in Fig. 1.



Scheme 3

Experimental

Melting points were determined in open capillary tubes on a Gallenkemp melting point apparatus and are uncorrected. The elemental analyses were carried out using a PerkinElmer 2400 CHN elemental analyser. The IR spectra were recorded on PerkinElmer Spectrum RXIFTIR system as KBr discs. ^{1}H NMR spectra were obtained on a Varian Gemini 200 MHz instrument in DMSO-d_6. Chemical shifts (δ) are expressed in ppm downfield from TMS as internal standard and coupling constants *J* in Hz. Mass spectra were recorded on a Shimadzu GC-MS, QP 1000 EX instrument operating at 70 eV. TLC aluminium sheets coated with silica gel F_{254} (Merck) were used to monitor the progress of all reactions and to assess the homogeneity of the synthesised compounds.

*Reaction of 2-(*p*-toluoyl)benzoic acid 1 with hydrazines to give phthalazines* **2a**–**d***; general procedure*

A solution of 2-(*p*-toluoyl)benzoic acid **1** (2 mmol) in dry toluene (30 mL) and an equivalent amount of hydrazine hydrate, phenyl hydrazine, 2-pyridyl hydrazine or thiosemicarbazide was refluxed for 3–4 h. The solid product formed during the reaction was filtered off, washed with light petroleum ether and recrystallised from a suitable solvent to give compounds **2a**–**d.**

4-p-*Tolylphthalazin-1(2H)-one* (**2a**): Colourless crystals; yield 86%; m.p. 244–246 °C (EtOH); IR: 3297, 3154 (NH), 3001 (aryl-H), 2900 (alkyl-H), 1661 (C=O), 1620 (C=N) cm^{-1}; ^{1}H NMR: δ 2.43 (s, 3H, CH_3), 7.10–8.22 (m, 8H, ArH), 11.72 (br s, 1NH exchangeable); MS *m/z* (%): 236 (M^+, 80), 237 (M^+ +1, 9), 238 (M^+ + 2, 1), 235 (M^+ –1, 100), 208 (M^+ –CO, 7), 207 (11), 117 (22), 91 (37). Anal. calcd for $C_{15}H_{12}N_2O$ (236.27); C, 76.25; H, 5.12; N, 11.86; found: C, 75.98; H, 4.93; N, 11.64%.

2-Phenyl-4-p-*tolylphthalazin-1(2H)-one* (**2b**): Pale yellow crystals; yield 88%; m.p. 168–170 °C (EtOH); IR: 3067, 3031 (aryl-H), 2917 (alkyl-H), 1655 (C=O), 1589 (C=N) cm^{-1}; ^{1}H NMR: δ 2.41 (s, 3H, CH_3), 7.21–7.89 (m, 13H, ArH); MS *m/z* (%): 312 (M^+, 30), 313 (M^+ +1, 7), 284 (M^+–CO, 2), 221 (1), 207 (4), 179 (13), 178 (14), 78 (12), 77 (100), 76 (13), 65 (15). Anal. calcd for $C_{21}H_{16}N_2O$ (312.36); C, 80.75; H, 5.16; N, 8.97; found: C, 80.72; H, 4.87; N, 8.65%.

2-(Pyridin-2-yl)-4-p-t*olylphthalazin-1(2H)-one* (**2c**): Yellow crystals; yield 76%; m.p. 164–166 °C (EtOH); IR: 3100 (aryl-H), 2932 (alkyl-H), 1666 (C=O), 1583 (C=N) cm^{-1}; ^{1}H NMR: δ 2.40 (s, 3H, CH_3), 7.34–8.04

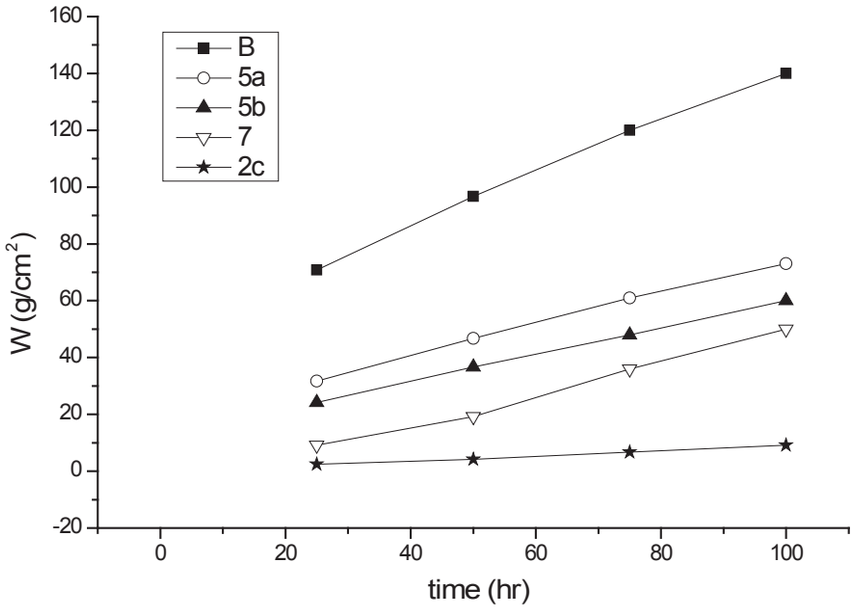


Fig. 1 Extent of corrosion of steel coupons by four phthalazines (0.02 M) in 5 M HCl determined as weight loss W (g cm^{-2})/h. W, the weight loss of steel coupons was determined after 25, 50, 75 and 100 h; B, a steel coupon without addition of inhibitors.

(m, 10H, ArH), 8.41–8.45 (m, 1H, ArH), 8.61–8.64 (m, 1H, ArH); MS *m/z* (%): 313 ($M^{+\cdot}$, 72), 299 (4), 298 (12), 285 ($M^{+\cdot}$ –CO, 17), 284 (25), 255 (14), 235 (35), 178 (27), 176 (21), 135 (13), 91 (6), 78 (100), 77 (23). Anal. calcd for $C_{20}H_{15}N_3O$ (313.35); C, 76.66; H, 4.82; N, 13.41; found: C., 76.47; H, 4.60; N, 13.47%.

1-Oxo-4-p-*tolylphthalazine-2(1H)-carbothioamide* (**2d**): Colourless crystals; yield 72%; m.p. 224–226 °C (EtOH); IR: 3296, 3154 (NH), 3041 (aryl-H), 2901 (alkyl-H), 1660 (C=O), 1559 (C=N) cm^{-1}; ^{1}H NMR: δ 2.49 (s, 3H, CH_3), 4.49, 7.22 (two br. s, 2H, NH_2, exchangeable), 7.35–8.62 (m, 8H, ArH); MS *m/z* (%): 295 ($M^{+\cdot}$, 19), 269 (44), 236 (38), 222 (44), 167 (40), 67 (25), 65 (63), 64 (100). Anal. calcd for $C_{16}H_{13}N_3OS$ (295.36); C, 65.06; H, 4.44; N, 14.23; found: C, 64.73; H, 4.16; N, 13.87%.

4-p-*Tolylphthalazine-1(2H)-thione* (**3**): A mixture of compound **2a** (2 mmol), a few drops of triethylamine and phosphorus pentasulfide (4 mmol) in dry toluene (30 mL) was refluxed for 1 h. The reaction mixture was cooled, and the solid that formed was filtered off and recrystallised to give compound **3**as yellow crystals; yield 88%; m.p. 230–232 °C (EtOH); IR: 3143 (NH), 3073 (aryl-H), 2938 (alkyl-H), 1644, 1562 (C=N), 1177 (C=S) cm^{-1}; ^{1}H NMR: δ 2.44 (s, 3H, CH_3), 7.35 (d, 2H, *J*=7.8 Hz), 7.49 (d, 2H, *J*=8.0 Hz), 7.72–7.76 (m, 1H, ArH), 7.89–7.98 (m, 2H, ArH), 8.82 (d, 1H, *J*=9.0 Hz), 14.55 (br s, 1NH exchangeable); MS *m/z* (%): 252 ($M^{+\cdot}$, 3), 251 ($M^{+\cdot}$ –1, 14), 219 (($M^{+\cdot}$ –SH, 10), 161 (17), 117 (12), 91 (38), 76 (51), 64 (39), 53 (100). Anal. calcd for $C_{15}H_{12}N_2S$ (252.33); C, 71.40; H, 4.79; N, 11.10; found: C, 71.11; H, 5.12; N, 10.88%.

General procedure

A solution of compounds **3** or **6** (2 mmol), in dry toluene (30 mL) and an equivalent amount of hydrazine hydrate, 2-pyridylhydrazine, phenylhydrazine or benzoyl hydrazine was refluxed for 1 h. The solid product that formed after cooling, was filtered off, then washed with light petroleum ether and recrystallised from a suitable solvent to give compounds **5a**–**d.**

1-(4-p-*Tolylphthalazin-1-yl)hydrazine* (**5a**): Orange crystals; yield 77%; m.p. 266–268 °C (toluene); IR: 3382 (NH), 3068, 3021 (aryl-H), 2920 (alkyl-H), 1621, 1569 (C=N) cm^{-1}; ^{1}H NMR: δ 2.44 (s, 3H, CH_3), 4.40 (br. s, 2H, NH_2 exchangeable), 7.35–7.68 (m, 6H, ArH), 8.84 (d, 2H, *J*=7.4 Hz), 11.9 (br. s, 1NH exchangeable); MS *m/z* (%): 250 ($M^{+\cdot}$, 2), 249 ($M^{+\cdot}$–1, 1), 230 (7), 209 (3), 172 (16), 141 (13), 91 (4), 83 (100), 55 (69). Anal. calcd for $C_{15}H_{14}N_4$ (250.3); C, 71.98; H, 5.64; N, 22.38; found: C, 71.72; H, 5.38; N, 22.04%.

1-(Pyridin-2-yl)-2-(4-p-*tolylphthalazin-1-yl)hydrazine* (**5b**): Yellow crystals; yield 66%; m.p. 298–300 °C (EtOH); IR: 3286, 3130 (NH), 3083, 3021 (aryl-H), 2946 (alkyl-H), 1612, 1587 (C=N) cm^{-1}; ^{1}H NMR: δ 2.44 (s, 3H, CH_3), 6.91–8.01 (m, 10H, ArH), 8.82–8.84 (m, 2H, ArH), 12.72 (br. s, 2NH exchangeable); MS *m/z* (%): 327 ($M^{+\cdot}$, 93), 326 ($M^{+\cdot}$ +1, 18), 312 (18), 311 (58), 297 (42), 234 (67), 163 (12), 91 (88), 78 (100), 77 (41). Anal. calcd for $C_{20}H_{17}N_5$ (327.38); C, 73.37; H, 5.23; N, 21.39; found: C, 73.41; H, 4.97; N, 21.18%.

1-Phenyl-2-(4-p-*tolylphthalazin-1-yl)hydrazine* (**5c**): Yellow crystals; yield 86%; m.p. 298–300 °C (toluene); IR: 3211, 3156 (NH), 3091 (aryl-H), 2963 (alkyl-H), 1631, 1587 (C=N) cm^{-1}; ^{1}H NMR: δ 2.43 (s, 3H, CH_3), 5.8, 6.11 (br. s, 2H, NH exchangeable), 6.97–7.87 (m, 11H, ArH), 8.78–8.0 (m, 2H, ArH); MS *m/z* (%): 326 ($M^{+\cdot}$, 30), 280 (21), 279 (26), 269 (35), 176 (35), 166 (31), 146 (83), 139 (44), 95 (26), 91 (22), 60 (100). Anal. calcd for $C_{21}H_{18}N_4$ (326.39); C, 77.28; H, 5.56; N, 17.17; found: C, 76.89; H, 5.49; N, 17.06%.

N′*-(4*-p-*Tolylphthalazin-1-yl)benzohydrazide* (**5d**): Yellow crystals; yield; 83%; m.p. > 300 °C (EtOH); IR: 3317, 3268 (NH), 3056 (aryl-H), 2960, 2915 (alkyl-H), 1703 (C=O), 1656, 1605 (C=N) cm^{-1}; ^{1}H NMR: δ 2.44 (s, 3H, CH_3), 7.53–8.70 (m, 13H, ArH), 10.60, 11.50 (br. s, 2H, NH exchangeable); MS *m/z* (%): 354 ($M^{+\cdot}$, 6), 337 ($M^{+\cdot}$–OH, 11), 336 ($M^{+\cdot}$– H_2O, 36), 241 (1), 240 (3), 106 (9), 105 (100), 78 (9), 77 (87), 51 (58). Anal. calcd for $C_{22}H_{18}N_4O$ (354.40); C, 74.56; H, 5.12; N, 15.81; found: C, 74.30; H, 4.78; N, 15.58%

1-Chloro-4-p-*tolylphthalazine* (**6**): In a 100 mL round-bottomed flask compound **2a** (1 g) was heated with $POCl_3$ (10 mL) on a boiling water bath for 5 h. The cooled reaction mixture was poured into ice/cold water, and then extracted with diethyl ether. Evaporation of diethyl ether under vacuum gave a solid product that was recrystallised to give compound **6**: Yellow crystals; yield 81%; m.p. 150–152 °C (toluene); IR: 3030 (aryl-H), 2909 (alkyl-H), 1662, 1601 (C=N) cm^{-1}; ^{1}H NMR: δ 2.43 (s, 3H, CH_3), 7.37–7.71 (m, 6H, ArH), 7.97–8.83 (m, 2H, ArH); MS *m/z* (%): 254 ($M^{+\cdot}$, 100), 256 ($M^{+\cdot}$ +2, 29), 165 (4), 163 (17), 117 (28), 91 (77), 67 (27). Anal. calcd for $C_{15}H_{11}ClN_2$ (254.71); C, 70.73; H, 4.35; N, 11.00; found: C, 70.43; H, 4.14; N, 10.79%.

3-Phenyl-6-p-tolyl-[1,2,4]triazolo[3,4-a]phthalazine (**7**): A mixture of compound **5a** (2 mmol) and benzoyl chloride (2 mmol) in dry pyridine (20 mL) was refluxed for 4 h. The reaction mixture was left to cool, and then poured onto an ice/HCl mixture. A brown precipitated was obtained which was filtered off and recrystallised to give compound **7**. Compound **7** was also prepared by refluxing **5d** in dry toluene for 7 h

and was obtained as pale brown crystals; yield 82%; m.p. 198–200 °C (toluene); IR: 3056 (aryl-H), 2960, 2913 (alkyl-H) 1656, 1605 (C=N) cm^{-1}; ^1H NMR: δ 2.1 (s, 3H, CH_3), 6.90–7.01 (m, 8H, ArH), 7.24–7.32) m, 5H, ArH); MS *m/z* (%): 336 (M^+, 5), 337 (M^++1, 1), 222 (5), 167 (1), 165 (6), 103 (68), 77 (100), 76 (34), 65 (10). Anal. calcd for $C_{22}H_{16}N_4$ (336.39); C, 78.55; H, 4.79; N, 16.66; found: C, 78.78; H, 4.61; N, 16.38%.

*1-(3,5-Dimethyl-1*H*-pyrazol-1-yl)-4-*p*-tolylphthalazine* (**9**): A mixture of compound **5a** (2 mmol) and acetyl acetone (2 mmol) in dry toluene (30 mL) was refluxed for 6 h. The reaction mixture was left to cool. The solid product that formed was filtered off and recrystallised to give compound **9**: Yellow crystals; yield; 80%; m.p. 278–280 °C (EtOH); IR: 3076 (aryl-H), 2960, 2913 (alkyl-H) 1607, 1540 (C=N) cm^{-1}; ^1H NMR: δ 2.1 (s, 3H, CH_3), 2.73 (s, 6H, 2 CH_3), 7.00 (s, 1H, pyrazol-H), 7.43–8.90 (m, 8H, ArH); MS *m/z* (%): 314 (M^+, 1), 293 (2), 278 (2), 234 (40), 219 (69), 205 (26), 190 (59), 178 (21), 91 (100), 65 (59). Anal. calcd for $C_{20}H_{18}N_4$ (314.38); C, 76.41; H, 5.77; N, 17.82; found: C, 76.31; H, 5.57; N, 17.63%.

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