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A general synthetic method for the formation of arylaminotetrazoles using natural natrolite zeolite as a new and reusable heterogeneous catalyst

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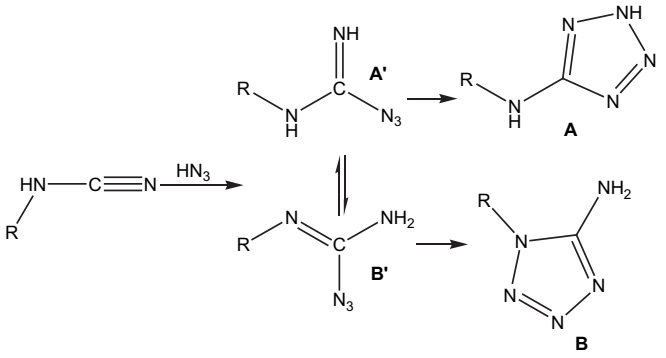
ABSTRACT

An efficient method for preparation of arylaminotetrazoles is reported using natrolite zeolite as a natural catalyst. Generally, isomer of 5-arylamino-1*H*-tetrazole can be obtained from arylcyanamides carrying electron-withdrawing substituent on aryl ring and as the electropositivity of substituent is increased, the product is shifted toward the isomer of 1-aryl-5-amino-1*H*-tetrazole. This method has the advantages of high yields, simple methodology, short reaction times and easy work-up. The catalyst can be recovered by simple filtration and reused in good yields.

1. Introduction

5-Substituted tetrazoles (RCN_4H) may serve as a non-classical isostere for the carboxylic acid moiety (RCO_2H) in biologically active molecules.[1–7] Hansch has shown that anionic tetrazoles are almost ten times more lipophilic than corresponding carboxylates, which is an important factor to bear in mind when designing a drug molecule to pass through cell membranes.[8] There is considerable interest in the medicinal and biological applications of tetrazoles,[4,6,9] including 5-aminotetrazoles, due to their reported anti-allergic and anti-asthmatic,[10] antiviral, and anti-inflammatory,[11] anti-neoplastic,[12] and cognition disorder activities.[13] Tetrazoles are also applied as ligands in coordination chemistry,[14–16] as explosives and rocket propellants.[17–19] Another important application of tetrazoles is the preparation of imidoylazides.[20] The earliest published methods for the preparation of aminotetrazole derivatives were reactions including the following: (1) addition of $NaNO_2$ to aminoguanidine[21] (2) addition of NaN_3 to carbodiimides[21c] or cyanamides[22] (3) reactions of amines with a leaving group in the tetrazoles 5-position[23] (4) nucleophilic substitution by N_3^- of (a) chlorine in α-chloroformamidines[24] and (b) sulfur from thioureas in the presence of mercury[25,26] or lead salts.[21a]

The addition of the azide anion to nitriles, cyanates and cyanamides is the most common route for preparing 5-substituted tetrazoles, 5-aryl/alkyl oxytetrazoles and 5-aryl/alkyl aminotetrazoles, respectively.[3,4,9,20,27–29] In most of them, the reaction actually proceeds in solutions of hydrazoic acid in solvents such as benzene, toluene, xylene, and chloroform. Herbst and Garbrecht have shown that cyanamides may be converted to aminotetrazoles using hydrazoic acid, which often result in a mixture of isomers (Scheme 1).[22b]



Scheme 1.

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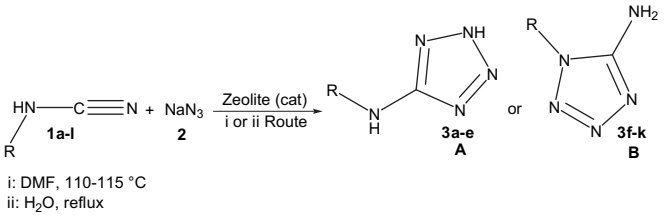
More previously, the 5-monosubstitutedamino-1*H*-tetrazoles were synthesized by thermal isomerization of 1-substituted-5-amino-1*H*-tetrazoles in boiling ethylene glycol or melt state (180–200 °C).[21a,30] Miller and co-workers have reported synthesis of some amino-1*H*-tetrazoles from the treatment of amino-iminomethanesulfonic acid derivatives with sodium azide in acetic acid at 50 °C, but with 4–59% yields.[31] Another possible method of obtaining the 5-monoalkylaminotetrazoles was an adaption of the von Braun degradation of tertiary amines with cyanogens bromide. In this way, it might be possible to eliminate an alkyl group from a 5-dialkylaminotetrazoles.[22b,32] These methods suffer from one or more disadvantages, such as low yield, long reaction times, harsh reaction conditions, difficult to obtain and/or prepare starting materials, use of expensive and toxic reagents, and the in situ generated hydrazoic acid is highly toxic and explosive. If hydrazoic acid is used, care must be taken by monitoring the concentration of hydrazoic acid in the reaction mixture to avoid an explosion.[3,4,9,17,29]

Later Congreve has reported a two-step synthesis of 1-aryl-5-amino-1*H*-tetrazoles from the corresponding 1-aryltetrazoles via cyanamide intermediates.[33] The reaction suffers from some drawbacks such as harsh reaction conditions, low temperatures (−70 °C), use of large excess of sodium azide and organolithium reagents that are potentially dangerous. Vorobiov and co-workers published a three-step synthesis of 1-aryl-5-amino-1*H*-tetrazoles in low yields from the corresponding aromatic amines via isolation of intermediate cyanamides.[34] Unfortunately, this approach is not well developed due to insufficient stability of the intermediate cyanamides. In most cases, *N*-arylureas and other by-products were mostly formed and the intermediate cyanamides were not stable enough to be isolated. Therefore, the 1-aryl-5-amino-1*H*-tetrazoles were produced in low yields. To resolve this problem, more recently, Vorobiov and co-workers have described a sufficiently simple and convenient one-step synthesis of 1-aryl-5-amino-1*H*-tetrazoles from the decomposition of 1-aryltetrazoles by consecutive ring-opening, azidation and intramolecular cyclization, without isolating intermediate cyanamides.[35] The above mentioned syntheses require the use of highly toxic and explosive hydrazoic acid. On the other hand, in most of these cases only the 1-aryl-5-amino-1*H*-tetrazoles or mixtures of isomers (5-aryl-amino-1*H*-tetrazole and 1-aryl-5-amino-1*H*-tetrazoles) were obtained. Due to safety considerations, we required a method that did not use of hydrazoic acid or an azide source that produced hydrazoic acid in situ because of the associated hazards. Therefore, it is desirable to develop a more efficient and convenient method for the regiospecific synthesis of arylaminotetrazoles.

Zeolites are crystalline hydrated aluminosilicates of the alkaline earths. Natural zeolites are formed in several geological environments such as hydrothermal, burial melamorphic, closed system (including alkaline earths), open system, and weathering profiles. The application of inorganic solid acids, especially zeolites, as effective heterogeneous catalysts for organic synthesis has received considerable attention in the recent decades due to their unique physical and chemical properties such as shape, selectivity, acidic, and basic nature and their thermal stability.[36] The advantages of these catalyst systems over homogeneous systems are well known, such as stability, ease of handling, lack of corrosion and other environmental hazards, ease of recovery and regeneration. Natrolite, $Na_2[Al_2Si_3O_{10}]\cdot 2H_2O$, is one of the fibrous zeolites with the framework constructed from the chains of corner-sharing Al and Si oxygen tetrahedra.[37]

In continuation of our recent work on the synthesis of heterocycles[38] and application of heterogeneous reagents for development of the useful synthetic methodologies,[39] we herein report the synthesis of arylaminotetrazoles **3a**–**k** from a wide variety of arylcyanamides **1a**–**k** with sodium azide **2** under thermal conditions in DMF or H_2O using natrolite zeolite as a reusable and natural catalyst (Table 1 and Scheme 2). This catalyst (from Sistan and Baluchestan province, Iran) is safe, easy to handle, environmentally benign with fewer disposals problems. However, to the best of our knowledge, there has been no report on the use of the zeolite as catalyst in synthesis of aminotetrazoles.



Scheme 2.

2. Result and discussion

The cyanamides **1a**–**k** were prepared according to literature.[40] In order to include a reasonable range of electrical and steric effects, the aryl substituted cyanamides **1a**–**k** studied included various groups in *ortho*, *meta*, and *para* positions, Table 1. Several aromatic cyanamides carrying either electron-donating or electron-withdrawing substituents reacted and gave the products in good yields (Table 1).

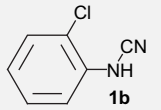
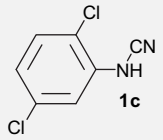
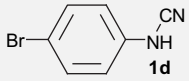
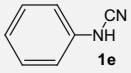
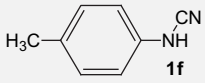
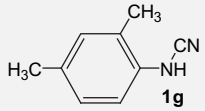
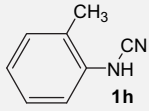
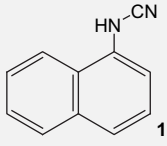
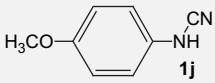
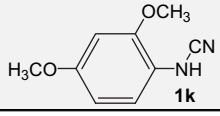
To show the advantages of natrolite zeolite as a catalyst in comparison with other materials, we compared the reaction of natrolite zeolite with PPh_3, LiCl, SiO_2–$HClO_4$, Al_2O_3–SO_3H, glacial acetic acid and $FeCl_3$–SiO_2 in the synthesis of 5-(2-chlorophenyl)amino-1*H*-tetrazole (**3b**, Table 1, Entry 2). As shown in Table 2, natrolite zeolite is a better catalyst in the synthesis of arylaminotetrazole, while PPh_3, LiCl, SiO_2–$HClO_4$, Al_2O_3–SO_3H, glacial acetic acid, and $FeCl_3$–SiO_2 aren't suitable for this reaction and result in a mixture of isomers. In addition, in order to improve yield and due to the biological importance of aminotetrazole derivatives, we started to study this reaction by examining the different amounts of natrolite zeolite as a catalyst for the reaction involving 2-chlorophenylcyanamide (**1b**, Table 1, Entry 2) (2 mmol) and sodium azide (3 mmol) to afford the product under thermal conditions, which best result was obtained with a 0.1 g of natrolite zeolite and gave 5-(2-chlorophenyl)amino-1*H*-tetrazole (**3b**, Table 1) in high yield. Not many organic solvents are stable at the high temperatures necessary for cycloaddition reactions (sometimes as high as 130 °C), and for this reason DMF is most commonly used for this purpose.[9,17,29]

Recently, Sharpless and co-workers reported a relatively simple, convenient and safe procedure for the synthesis of tetrazoles by the addition of sodium azide to nitriles using stoichiometric amounts or 50 mol % of Zn(II) salts.[29c–e] However, zinc(II) chloride or bromide being homogeneous Lewis acids and could not be recycled from the reaction mixture, while in every experiment, the whole of the natrolite zeolite was easily recovered from the reaction mixture. The reusability of the catalysts is one of the most important benefits and makes them useful for commercial applications.

The following important results can be extracted from data in Table 1:

1. As shown in Table 1, in the reaction between sodium azide with secondary arylcyanamides using natrolite zeolite at 110–115 °C in DMF, the presence of electron-withdrawing groups and electron-releasing groups on the aryl rings did exhibit significant effects on reaction time. While, in the reaction between sodium azide with secondary arylcyanamides using zeolite as a catalyst in water, the nature of the substituent on the aryl rings did not affect the time of reaction completion (Table 1,

Table 1
Synthesis of arylaminotetrazoles **3** in the presence of natrolite zeolite by reaction between sodium azide and cyanamides **1a–k** at 110–115 °C

Entry	Substrate	Route[a]	**3** (**A** or **B**)	Yield[b] %	Time
1	 **1a**	i	**3a** (**A**)	80	115 min
		ii	**3a** (**A**)	46	9 h
2	 **1b**	i	**3b** (**A**)	80	95 min
		ii	**3b** (**A**)	48	9 h
3	 **1c**	i	**3c** (**A**)	81	95 min
		ii	**3c** (**A**)	49	9 h
4	 **1d**	i	**3d** (**A**)	82	95 min
5	 **1e**	i	**3e** (**A**)	81	95 min
		ii	**3e** (**A**)	49	9 h
6	 **1f**	i	**3f** (**B**)	80	65 min
		ii	**3f** (**B**)	48	9 h
7	 **1g**	i	**3g** (**B**)	81	65 min
		ii	**3g** (**B**)	50	9 h
8	 **1h**	i	**3h** (**B**)	79	65 min
		ii	**3h** (**B**)	47	9 h
9	 **1i**	i	**3i** (**B**)	82	65 min
		ii	**3i** (**B**)	47	9 h
10	 **1j**	i	**3j** (**B**)	83	65 min
		ii	**3j** (**B**)	46	9 h
11	 **1k**	i	**3k** (**B**)	81	65 min
		ii	**3k** (**B**)	48	9 h

[a] Route (i) DMF, 110–115 °C; (ii) H_2O, reflux.
[b] Yields refer to the pure isolated products.

Table 2
Comparison of different amounts of natrolite zeolite catalyst with PPh_3, $FeCl_3$–SiO_2, SiO_2–$HClO_4$, Al_2O_3–SO_3H, glacial acetic acid and LiCl in the synthesis of 5-(2-chlorophenyl)amino-1*H*-tetrazole (**3b**) at 110–115 °C

Entry	Reagent or catalyst	Solvent	Time (min)	Product (**A** or **B**)	Yield[a] (%)
1	PPh_3	DMF	120	**A**+**B**	64
2	$FeCl_3$–SiO_2	DMF	120	**A**+**B**	75
3	SiO_2–$HClO_4$	—[b]	30	**A**+**B**	87
4	Al_2O_3–SO_3H	—[b]	30	**A**+**B**	88
5	LiCl	DMF	100	**A**+**B**	65
6	CH_3COOH[c]	CH_3COOH	24 h[d]	**A**+**B**	86
7	Zeolite (0.05 g)	DMF	95	**A**	72
8	Zeolite (0.07 g)	DMF	95	**A**	77
9	Zeolite (0.1 g)	H_2O	95	**A**	48
10	Zeolite (0.1 g)	DMSO	95	**A**	80
11	Zeolite (0.1 g)	DMF	95	**A**	80
12	Zeolite (0.13 g)	DMF	95	**A**	81
13	Zeolite (0.16 g)	DMF	95	**A**	81

[a] Isolated yield.
[b] Solvent-free.
[c] Glacial acetic acid as both solvent and proton donor source.
[d] Room temperature.

Entries 1–11). In general, when the substitution was electron-donating, the reaction was completed in less time (starting material (cyanamide) is consumed faster) than when the substitution was electron-withdrawing (compare Entries 6–11 with 1–4 in Table 1).

2. In this work, we have observed that the regiospecificity of cycloaddition of azide ion to the cyanamides is strongly affected by the type of catalysts. In other words, in both cases the process was completely regiospecific, Tables 1 and 2. This is in contrast with the reports that were presented for the synthesis of aminotetrazoles using hydrazoic acid, which often results in mixture of isomers **A** and **B**.[22b]
3. Perhaps the most remarkable feature of the reaction of the monosubstituted cyanamides with hydrazoic acid is the unidirectional character of the cyclization.[3,4,9,21a,22b,27,30,41] The nature of the substituent appears to play at best a minor role in directing the course of the reaction. Substituents as different in their electrical effects as the methyl group and the *p*-nitrophenyl group permit the formation of the same type of compound, presumably through the intermediate formation of a guanyl azide. Surprisingly, ring closure of the substituted guanyl azide in all of these methods yields the 1-alkyl- or 1-aryl-5-aminotetrazole as the major product (as much as 95% in certain cases). No serious consideration appears to have been given by previous workers to the isolation or detection of the other isomer, although Stolle and Heintz reported the isolation of 5-anilinotetrazole in very small yield from the reaction of phenylthiourea with lead oxide and sodium azide.[42]

In contrast with the reports that have previously been published, in our methods, the nice distinction is that tetrazoles **3** are strongly under the effect of the type of substituents in arylcyanamides **1a–k** and isomer **A** or **B** is just obtained, Table 1. In other words, there is an excellent correlation between the effect of substitution on the benzene ring and the major product. Generally, when the substitution on the aryl ring is electron-donating in arylcyanamides **1a–k**, the formation of 1-aryl-5-amino-1*H*-tetrazoles (**B**) is favored via guanidine azide intermediate **B′** (Table 1 and Entries 6–11) and as the electronegativity of substituent is increased, the product is shifted toward the 5-arylamino-1*H*-tetrazole (**A**) (Table 1 and Entries 1–4). In other words, if cyclization were to involve the nitrogen carrying the aryl substituent in guanidine azide intermediate **B′**, 1-aryl-5-amino-1*H*-tetrazoles (**B**) would result. On the other hand, involvement of the terminal unsubstituted nitrogen in the

cyclization would result in 5-arylamino-1*H*-tetrazoles (**A**) via guanidine azide intermediate **A**′. This is similar to the substituent effect on the aryl ring of mechanism that was presented by Henry and coworkers for thermal isomerization.[30]

In a typical experiment, after the reaction was completed, natrolite zeolite as a catalyst was isolated from the reaction mixture by simple filtration in the work-up stage. We found that natrolite zeolite can be reused several times without the loss of activity, by simply filtering the catalyst, washing with water and ethanol, drying and immediately reusing. In fact, the reaction 4-methylphenylcyanamide (Table 1, Entry 6) with NaN_3 in DMF has been repeated five times using the same catalyst with respectably high yields: 76–80%.

The products were characterized by ^{1}H NMR, ^{13}C NMR, IR, FTIR, elemental analysis (CHN) and melting points. Elimination of one strong and sharp absorption bands (CN stretching band), and appearance of two absorption bands in the range of 3139–3550 cm^{-1} (NH stretching bands) in IR spectrum, confirmed the formation of arylaminotetrazoles. ^{13}C NMR spectra displayed signals about δ=154–157.5 ppm for C5 of tetrazole ring.[43]

3. Conclusions

In conclusion, we have developed two efficient procedures for preparation of substituted arylaminotetrazoles using natrolite zeolite as a natural and reusable heterogeneous catalyst. These methods have the advantages of high yields, simple methodology, easy work-up and no chromatographic separation is necessary to get the spectra-pure compounds. Natrolite Zeolite as a catalyst is important from an environmental point of view and from the view point of economic considerations, because it produces little waste. It also has excellent activity on an industrial scale and in most cases can be recovered from reaction mixtures and reused.

4. Experimental

4.1. General

All reagents were purchased from Merck and Aldrich and used without further purification. Products were characterized by spectroscopy data (IR, FTIR, ^{1}H NMR and ^{13}C NMR spectra), elemental analysis (CHN) and melting points. The NMR spectra were recorded in DMSO and acetone. ^{1}H NMR spectra were recorded on a Bruker Avance DRX 300 and 500 MHz instruments. The chemical shifts (δ) are reported in ppm relative to the TMS as internal standard. *J* values are given in Hertz. ^{13}C NMR spectra were recorded at 125 and 75 Hz. IR (KBr) and FTIR (KBr) spectra were recorded on a Shimadzu 470 and Perkin–Elmer 781 spectrophotometer, respectively. Melting points were taken in open capillary tubes with a BUCHI 510 melting point apparatus and were uncorrected. The elemental analysis was performed using Heraeus CHN–*O*-Rapid analyzer. TLC was performed on silica gel polygram SIL G/UV 254 plates. Natural Iranian natrolite zeolite from the Hormak area (Zahedan city, Sistan & Baluchestan province, Iran) was used in this work.[44]

4.2. Catalyst characterization

This catalyst has recently been found in the Hormak area (Zahedan city, Sistan and Baluchestan province, Iran) and was used as catalyst in this work. Noroozifar and co-workers studied the characterization of the natural zeolite (Natrolite) using powder XRD, XRF, TG-DTA, and FTIR spectroscopy.[44]

4.3. General procedure for the synthesis of arylaminotetrazoles 3 using natrolite zeolite

Natrolite zeolite (0.1 g) was added to a mixture of appropriate cyanamide **1** (2 mmol), NaN_3 **2** (3 mmol) in 8 mL of distilled dimethylformamide (DMF) and stirred at 110–115 °C for the appropriate time (Table 1). After completion (as monitored by TLC), the reaction mixture was cooled to room temperature, the catalyst was centrifuged and the centrifugate was treated with ethyl acetate (35 mL) and 4 N HCl (20 mL), and then the mixture stirred vigorously. The resultant organic layer was separated and the aqueous layer was again extracted with ethyl acetate (25 mL). The combined organic layers were washed with water and concentrated to give the crude solid arylaminotetrazole. After concentration, a crystallization step was performed using aqueous ethanol. Similarly, to a 50 mL round-bottomed flask, the cyanamide **1** (2 mmol), sodium azide **2** (2.5 mmol), zeolite (0.1 g) and 16 mL of water were added. The reaction mixture was stirred at reflux for 9 h. After consumption of cyanamide **1**, the mixture was cooled to room temperature, the solid residue was filtered from the reaction mixture and then was washed with water. In continuation of work-up, the solid residue was treated with 10 mL 3 N HCl to obtain pure arylaminotetrazole derivatives.

*4.3.1. 1-Naphthylcyanamide (**1i**, Table 1).* Mp 143–145 °C; FTIR (KBr): *v* 3382, 3165, 3079, 2961, 2897, 2226, 1613, 1515, 1436, 1409, 1302, 1256, 1181, 1108, 1016, 859, 835, 811, 771 cm^{-1}; ^{1}H NMR (300 MHz, DMSO-d_6): δ=7.21 (d, *J*=7.4 Hz, 1H), 7.47 (t, *J*=7.8 Hz, 1H), 7.54–7.59 (m, 3H), 7.89–7.93 (m, 1H), 8.09–8.12 (m, 1H); ^{13}C NMR (75 MHz, DMSO-d_6): δ=136.4, 134.4, 128.7, 127.0, 126.6, 126.3, 124.1, 122.8, 121.7, 114.3, 111.5; Anal. Calcd for $C_{11}H_8N_2$: C, 78.55; H, 4.79; N, 16.65. Found: C, 78.66; H, 4.90; N, 16.53.

*4.3.2. 5-(4-Nitrophenyl)amino-1H-tetrazole (**3a**, Table 1).* Mp 218–220 °C; IR (KBr): *v* 3550, 3235, 3100, 1635, 1572, 1488, 1337, 1290, 1257, 1111, 1052, 839, 745 cm^{-1}; ^{1}H NMR (500 MHz, DMSO-d_6): δ=7.76 (d, *J*=7.3 Hz, 2H), 8.21 (d, *J*=9.3 Hz, 2H), 10.96 (br s, 1H); ^{13}C NMR (125 MHz, DMSO-d_6): δ=155.2, 147.1, 140.3, 124.9, 116.8; Anal. Calcd for $C_7H_6N_6O_2$: C, 40.78; H, 2.93; N, 40.77. Found: C, 40.90; H, 3.03; N, 40.64.

*4.3.3. 5-(2-Chlorophenyl)amino-1H-tetrazole (**3b**, Table 1).* Mp 228–230 °C; IR (KBr): *v* 3260, 3210, 3140, 3100, 1626, 1573, 1551, 1470, 1440, 1286, 1233, 1134, 1052, 796, 742, 674, 633 cm^{-1}; ^{1}H NMR (500 MHz, DMSO-d_6): δ=7.04 (t, *J*=7.7 Hz, 1H), 7.33 (t, *J*=8.4 Hz, 1H), 7.46 (d, *J*=7.9 Hz, 1H), 8.00 (d, *J*=8.2 Hz 1H), 9.12 (s, 1H), 14.86 (br s, 1H); ^{13}C NMR (125 MHz, DMSO-d_6): δ=154.8, 136.6, 129.6, 127.9, 123.5, 122.6, 120.2; Anal. Calcd for $C_7H_6N_5Cl$: C, 42.98; H, 3.09; N, 35.80. Found: C, 43.10; H, 3.19; N, 35.68.

*4.3.4. 5-(2,5-Dicholorophenyl)amino-1H-tetrazole (**3c**, Table 1).* Mp 272–274 °C; IR (KBr): *v* 3245, 3184, 3156, 3115, 1620, 1592, 1569, 1544, 1467, 1411, 1090, 1054, 1038, 836, 799, 772, 664, 563, 538 cm^{-1}; ^{1}H NMR (500 MHz, DMSO-d_6): δ=7.06 (d, *J*=8.5 Hz, 1H), 7.48 (d, *J*=8.6 Hz, 1H), 8.19 (s, 1H), 9.38 (br s, 1H), 14.72 (br s, 1H); ^{13}C NMR (125 MHz, DMSO-d_6): δ=154.4, 137.8, 132.3, 130.8, 122.5, 120.3, 118.7; Anal. Calcd for $C_7H_5N_6Cl_2$: C, 36.52; H, 2.17; N, 30.43. Found: C, 36.66; H, 2.22; N, 30.56.

*4.3.5. 5-(4-Bromophenyl)amino-1H-tetrazole (**3d**, Table 1).* Mp 249–250 °C; IR (KBr): *v* 3285, 3205, 1617, 1574, 1534, 1485, 1240, 1054, 1023, 828, 772, 720 cm^{-1}; ^{1}H NMR (300 MHz, DMSO-d_6): δ=7.45–7.53 (m, 4H), 9.98 (br s, 1H), 15.57 (br s, 1H); ^{13}C NMR (75 MHz, DMSO-d_6): δ=112.8, 119.2, 132.2, 140.3, 156.1; Anal. Calcd for $C_7H_6N_5Br$: C, 35.02; H, 2.52; N, 29.17. Found: C, 35.11; H, 2.64; N, 29.24.

*4.3.6. 5-Phenylamino-1H-tetrazole (**3e**, Table 1).* Mp 215–217 °C, lit.,[10] 211–212 °C; IR (KBr): *v* 3325, 3220, 1620, 1580, 1533, 1498,

1243, 1053, 785, 742, 735, 688, 660 cm^{-1}; ^1H NMR (500 MHz, DMSO-d_6): δ=6.93 (t, J=7.3 Hz, 1H), 7.29 (t, J=7.9 Hz, 2H), 7.49 (d, J=8.2 Hz, 2H), 9.74 (s, 1H), 15.33 (br s, 1H); ^{13}C NMR (DMSO-d_6, 125 MHz): δ=155.8, 140.3, 128.9, 121.0, 116.7.

*4.3.7. 1-(4-Methylphenyl)-5-amino-1H-tetrazole (**3f**, Table 1).* Mp 178–179 °C, lit.,[30a] 175.5–177 °C, lit.,[35] 174–175 °C; FTIR (KBr): ν 3306, 3141, 1655, 1594, 1572, 1519, 1467, 1320, 1306, 1142, 1090, 1017, 839, 818, 618, 545, 483 cm^{-1}; ^1H NMR (500 MHz, DMSO-d_6): δ=2.40 (s, 3H), 6.80 (s, 2H), 7.41 (d, J=8.4 Hz, 2H), 7.45 (d, J=8.4 Hz, 2H); ^{13}C NMR (125 MHz, DMSO-d_6): δ=155.8, 139.8, 131.8, 131.1, 124.8, 21.6.

*4.3.8. 1-(2,4-Dimethylphenyl)-5-amino-1H-tetrazole (**3g**, Table 1).* Mp 199–201 °C, lit.,[11] 199–201 °C; IR (KBr): ν 3310, 3150, 1651, 1573, 1506, 1458, 1377, 1312, 1134, 1088, 1027, 868, 823, 614, 562 cm^{-1}; ^1H NMR (500 MHz, DMSO-d_6): δ=1.99 (s, 3H), 2.36 (s, 3H), 6.63 (s, 2H), 7.22 (d, J=8.1 Hz, 1H), 7.19 (d, J=8.3 Hz, 1H), 7.28 (s, 1H); ^{13}C NMR (125 MHz, DMSO-d_6): δ=155.6, 140.0, 134.9, 131.7, 129.4, 127.6, 127.1, 20.6, 16.7.

*4.3.9. 1-(2-Methylphenyl)-5-amino-1H-tetrazole (**3h**, Table 1).* Mp 191–192 °C, lit.,[11,10] 191–192 °C, lit.,[14] 189–190 °C; FTIR (KBr): ν 3323, 3158, 1655, 1593, 1575, 1503, 1473, 1313, 1126, 1091, 1026, 772, 757, 715, 673, 564 cm^{-1}; ^1H NMR (300 MHz, DMSO-d_6): δ=2.06 (s, 3H), 6.74 (s, 2H), 7.36–7.51 (m, 4H); ^{13}C NMR (75 MHz, DMSO-d_6): δ=17.4, 127.7, 127.9, 130.9, 131.8, 132.5, 135.8, 156.1.

*4.3.10. 1-(1-Naphthyl)-5-amino-1H-tetrazole (**3i**, Table 1).* Mp 220–221 °C; FTIR (KBr): ν 3322, 3139, 1655, 1598, 1577, 1509, 1483, 1397, 1085, 806, 772, 662 cm^{-1}; ^1H NMR (500 MHz, DMSO-d_6): δ=6.78 (br s, 2H), 7.28 (d, J=8.3 Hz, 1H), 7.74–7.62 (m, 4H), 8.14 (d, J=8.2 Hz, 1H), 8.22 (d, J=7.5 Hz, 1H); ^{13}C NMR (125 MHz, DMSO-d_6): δ=157.3, 134.8, 131.6, 129.9, 129.3, 128.8, 127.9, 126.7, 126.6, 122.7; Anal. Calcd for $C_{11}H_9N_5$: C, 62.56; H, 4.26; N, 33.17. Found: C, 62.64; H, 4.38; N, 33.29.

*4.3.11. 1-(4-Methoxyphenyl)-5-amino-1H-tetrazole (**3j**, Table 1).* Mp 211–213 °C; IR (KBr): ν 3300, 3125, 2975, 2925, 1657, 1608, 1588, 1573, 1518, 1458, 1441, 1382, 1293, 1248, 1180, 1169, 1139, 1104, 1084, 1042, 1020, 840, 635, 620, 580, 550 cm^{-1}; ^1H NMR (500 MHz, acetone-d_6): δ=3.89 (s, 3H), 6.14 (s, 2H), 7.14 (d, J=8.9 Hz, 2H), 7.49 (d, J=8.9 Hz, 2H); ^{13}C NMR (125 MHz, acetone-d_6): δ=56.19, 115.9, 127.1, 127.7, 156.2, 161.5; Anal. Calcd for $C_8H_9N_5O$: C, 50.25; H, 4.74; N, 36.63. Found: C, 50.21; H, 4.81; N, 36.75.

*4.3.12. 1-(2,4-Dimethoxyphenyl)-5-amino-1H-tetrazole (**3k**, Table 1).* Mp 183–185 °C; FTIR (KBr): ν 3378, 3276, 3222, 3139, 3058, 1689, 1612, 1593, 1524, 1456, 1435, 1297, 1263, 1211, 1161, 1118, 1047, 1023, 986, 933, 837 cm^{-1}; ^1H NMR (300 MHz, DMSO-d_6): δ=3.78 (s, 3H), 3.85 (s, 3H), 6.67 (d, J=8.5 Hz, 1H), 6.78 (d, 3H), 7.30 (d, J=8.6 Hz, 1H); ^{13}C NMR (75 MHz, DMSO-d_6): δ=56.2, 56.4, 100.0, 105.9, 114.7, 129.7, 155.9, 156.4, 162.5; Anal. Calcd for $C_9H_{11}N_4$: C, 48.87; H, 5.01; N, 31.66. Found: C, 48.95; H, 5.12; N, 31.55.

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