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Vinyltetrazoles: III.* Metal-Catalyzed Arylation, a New Method of Vinyltetrazoles Functionalization

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Abstract—New functionalization procedure was developed for *C*- and *N*-vinyltetrazoles based on Heck reaction. Applying this method diverse (*E*)-styryl- and (*E*)-distyryltetrazoles were obtained for the first time in 76–85% yields. *C*-Vinyltetrazoles are more reactive in Heck cross-coupling than *N*-vinyltetrazoles. The arylation of 1-vinyltetrazole along Heck reaction proceeds with a C–H-activation and leads to the formation of 5-phenyl-1-[2-(*E*)-phenylethenyl]tetrazole.

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Vinyl derivatives of tetrazole are first of all regarded as monomers for the synthesis of macromolecular compounds [1–5]. Polymers underlain by vinyltetrazoles are included in the composition of promising energy-rich materials, polymer gas-separation membranes, unwoven filter materials for medicine, and the other composite materials [3–5]. Besides the vinyltetrazoles can be utilized as intermediate reagents in the procedures of the total synthesis of new compounds exhibiting the biological action [4, 6–8].

Vinyltetrazoles possess simultaneously several reaction sites: endocyclic nitrogen atoms and a carbon of the heterocycle, and also contain in their structure an exocyclic $CH=CH_2$ group. The reactions involving the nitrogen atoms of the ring are well known [4, 9]. These are the alkylation, the acetylation, quaternization, Mannich condensation, complexing with metals through the donor-acceptor interactions [3]. These processes do not affect the double bond and can be used for the preparation of new tetrazole-containing monomers and polymers.

Unlike that the vinyltetrazole reactions involving the $CH=CH_2$ group attracted less attention. Individual instances are published of the addition of the electrophilic and nucleophilic reagents to the double bond of the vinyltetrazoles, namely, the hydration [10], the addition of trichloroacetonitrile in the presence of copper catalysts [11], the reaction with hypobromous acid [12] and with the elemental bromine [13]. In all these reactions the products are formed as a result of the opening of the double bond.

Lately an interest arose to styryltetrazoles. For instance, some fluoroquinolones containing a styryltetrazole fragment are regarded as bioisosteric analogs of the drug Levofloxacin [7]. Similar bioisosteric tetrazole-containing analogs were also described for chromones [8]. These compounds possess pronounced antibacterial and antiallergic properties [7, 8]. However the methods of the preparation of styryltetrazoles described in [7, 8] are of particular character and cannot be applied to a targeted functionalization of vinyltetrazoles.

In this connection the development and examination of new method of vinyltetrazoles functionalization at the exocyclic $CH=CH_2$ group with the retention of the double bond leading to styryltetrazoles is an urgent task.

To this end we developed a metal-catalyzed monoarylation of vinyltetrazoles underlain by Heck reaction that provided a possibility to obtain previously unavailable isomeric *C*- and *N*-styryltetrazoles. The Heck cross-coupling is an efficient and stereoselective reaction that is widely used for solving similar problems in the alkene chemistry [14–17].

As initial compounds for Heck arylation we selected

* For Communication II, see [1].

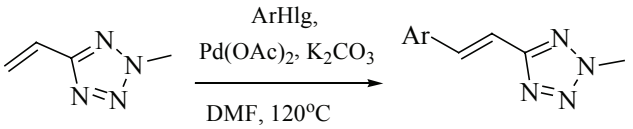
5-vinyl-2-methyltetrazole (**I**), a typical example of *C*-vinyltetrazoles, and also various *N*-vinyltetrazoles. The following reagents were used in the arylation: catalyst $Pd(OAc)_2$, aryl iodides, aryl bromides, and aryl chlorides with electron-donor and electron-acceptor substituents in the aromatic ring, K_2CO_3 as the base, DMF as solvent. The reactions were carried out under an inert atmosphere, in argon.

We showed that the arylation of tetrazole **I** with aryl halides afforded (*E*)-styryltetrazoles **IIa–IIe** in 79–85% yields (Table 1).

At the use of aryl iodides as the arylating agents the reaction time was minimal, 2.5–3 h. The completion of the tetrazole **I** reaction with aryl bromides containing electron-acceptor substituents required 4–7 h. The aryl bromides lacking the electron-acceptor substituents, and also aryl chlorides did not react in the applied conditions. The results obtained are in agreement with the published data on the reactivity of aryl halides in the Heck reaction [14–17].

In order to obtain the corresponding *N*-styryltetrazoles we extended the conditions of the arylation of the *C*-vinyltetrazole to the *N*-vinyltetrazoles. However in this case the reaction duration was 20–25 h. In this event the arylation of *N*-vinyltetrazoles made it possible to obtain

Table 1. Arylation by Heck reaction of 5-vinyl-2-methyltetrazole (**I**)



I **IIa**–**IIIe**

Ar = Ph (**a**), *o*-FC_6H_4 (**b**), *p*-$O_2NC_6H_4$ (**c**), *m*-$HO_2CC_6H_4$ (**d**), *m*-NCC_6H_4 (**e**).

ArHlg	Time, h	Compound no.	Yield, %
PhI	3	**IIa**	80
o-FC_6H_4I	2.5	**IIb**	81
PhBr	7	**IIa**	85
p-$O_2NC_6H_4Br$	4	**IIc**	79
m-$HO_2CC_6H_4Br$	6	**IId**	83
m-NCC_6H_4Br	5.5	**IIe**	85
p-BrC_6H_4Br	15	–	0
p-$MeOC_6H_4Br$	15	–	0
p-$O_2NC_6H_4Cl$	15	–	0

N-(*E*)-styryltetrazoles with yields exceeding 65%.

We believe that the relatively low activity of the *N*-vinyltetrazoles in Heck reaction may be due to the combination of several factors. The data on the study of the electronic structure of vinyltetrazoles show in general that the electron-aceptor effect of the tetrazolyl substituent on the double bond weakens in going from the *C*-vinyl- to the *N*-vinyltetrazoles [3, 5] resulting in the deactivation of the $CH=CH_2$ group of *N*-vinyltetrazoles in Heck reaction. Besides it is known that tetrazoles are capable of forming complexes with various metals. In this event the metal ion is coordinated to the nitrogen atom in the position *4* of the heterocycle [4]. Hence a possibility exists that in the arylation of *N*-vinyltetrazoles a coordination occurs of the tetrazole ring to $Pd(OAc)_2$ catalyst thus removing the catalyst from the zone of Heck reaction.

The analysis of the published data on the metal-catalyzed arylation of deactivated alkenes showed that the above mentioned problem might be solved by introducing into the reaction mixture of triphenylphosphine and copper(I) iodide [14, 16, 17]. These reagents stabilize the formed in situ palladium complexes and as we presume screen the nitrogen atom of the ring in the position *4* preventing the side processes of this atom coordination to the catalyst.

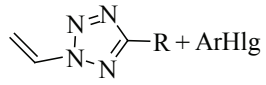
On these assumptions we developed the reaction conditions for the preparation of *N*-styryltetrazoles which reduced the arylation time of the initial *N*-vinyltetrazoles to 8 h and raised the yield of the target compounds to 85% (Tables 2 and 3).

The data obtained allow the estimation of the relative reactivity of *N*-vinyl-5-R-tetrazoles **IIIa–IIIg**, **Va**–**Vd** in Heck reaction. The arylation time of 2-vinyl-5-aryltetrazoles **IIIa–IIId** is shorter (on the average by 2 h) than that of alkylanalogs **IIIe, IIIf**. A similar rule was found for 1-vinyl-5-aryl- (**Va**) and -5-alkyltetrazoles **Vb, Vc** (Table 3).

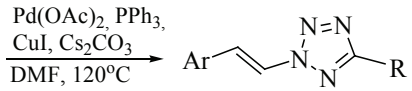
At the arylation of 2-vinyl-5-aryltetrazoles **IIIa–IIId** the duration of the reaction is notably affected by the character of the substituent in the phenyl ring of the azole. For instance, at the introduction of the electron-donor substituent (reagent **IIIb**, R = *p*-$CH_3C_6H_4$) the reaction completion required more time, on the average, by 5 h (cf. R = Ph, **IIIa**). In contrast, the tetrazoles with the electron-acceptor substituents (R = *p*-$CF_3C_6H_4$, *o*-NCC_6H_4) reacted faster with the haloarenes.

Besides the completion of the arylation of 1-vinyltetrazoles requires less time (up to 3 h) than that of the

Table 2. Arylation by Heck reaction of 2-vinyl-5-R-tetrazoles **IIIa–IIIg**



IIIa–IIIg

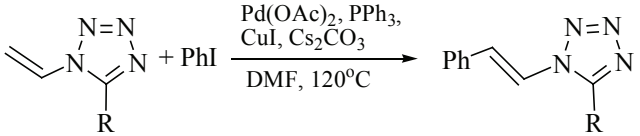


IVa–IVj

III, R = Ph (**a**), *p*-MeC_6H_4 (**b**), *p*-$F_3CC_6H_4$ (**c**), *o*-NCC_6H_4 (**d**), Me (**e**), Et (**f**), H_2N (**g**); **IV**, R = Ph: Ar = *o*-FC_6H_4 (**a**), Ph (**b**), *o*-$F_3CC_6H_4$ (**c**); R = *p*-MeC_6H_4: Ar = *o*-FC_6H_4 (**d**), Ph (**e**); R = *p*-$F_3CC_6H_4$: Ar = *o*-FC_6H_4 (**f**), Ph (**g**); R = *o*-NCC_6H_4, Ar = Ph (**h**); R = Me, Ar = *o*-FC_6H_4 (**i**); R = Et, Ar = Ph (**j**).

Compound no.	ArHlg	Time, h	Reaction product	Yield, %
IIIa	*o*-FC_6H_4I	7	**IVa**	78
	PhI	7	**IVb**	82
	o-$F_3CC_6H_4Br$	9	**IVc**	81
IIIb	*o*-FC_6H_4I	12	**IVd**	79
	PhBr	17	**IVe**	82
IIIc	*o*-FC_6H_4I	5.5	**IVf**	84
	PhBr	10	**IVg**	81
IIId	PhI	6	**IVh**	85
	PhBr	14		84
IIIe	*o*-FC6H4I	8	**IVi**	78
IIIf	PhI	9	**IVj**	80
IIIg	PhI	20	–	–

Table 3. Arylation by Heck reaction of 1-vinyl-5-R-tetrazoles **Va–Vd**



Va–Vd **VIa–VIc**

R = Ph (**a**), Me (**b**), Et (**c**), H_2N (**d**).

Compound no.	Time, h	Reaction product	Yield, %
Va	4	**VIa**	82
Vb	6	**VIb**	80
Vc	7	**VIc**	81
Vd	20	–	0

2-vinyl-5-aryl(alkyl)tetrazoles.

The attempt at performing Heck arylation of 5-amino-*N*-vinyl-tetrazoles **IIIg, Vd** failed: no reaction products were detected.

Thus the highest activity in Heck reaction was observed in *C*-vinyltetrazoles, the reaction of *N*-vinyl-tetrazoles required more severe conditions.

The structure and homogeneity of all compounds obtained were confirmed by a complex of methods: HPLC-MS, ^1H, ^{13}C NMR spectroscopy, XRD analysis.

The spin-spin coupling constants of the protons of the CH=CH group in the ^1H NMR spectra of obtained styryltetrazoles **IIa–IIe, IVa–IVi, VIa–VIc** were in the range 14.6–16.5 Hz characteristic of the disubstituted alkenes of the *E*-configuration [18].

The exhaustive information on the structure of the synthesized compounds was obtained by the XRD anlysis of single crystals of compounds **IIa, VIc** (Figs. 1, 2). The crystallographic data and the man parameters of refinement for compounds **IIa, VIc** are listed in Table 4. According to the XRD data the styryltetrazoles exist in the *E*-configuration.

At the next stage of the research we used as terminal alkenes in Heck reaction *C*,*N*-divinyltetrazoles **VII**, **VIII** containing in the structure two double bonds providing a possibility of both selective and exhaustive arylation.

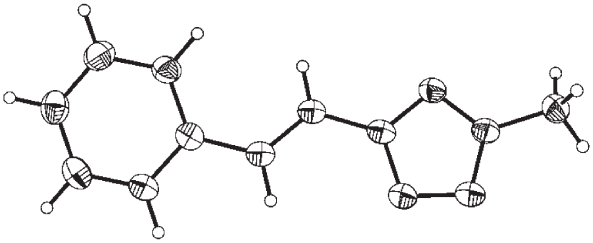


Fig. 1. Molecular structure of (*E*)-2-methyl-5-styryltetrazole (**IIa**) according to XRD data.

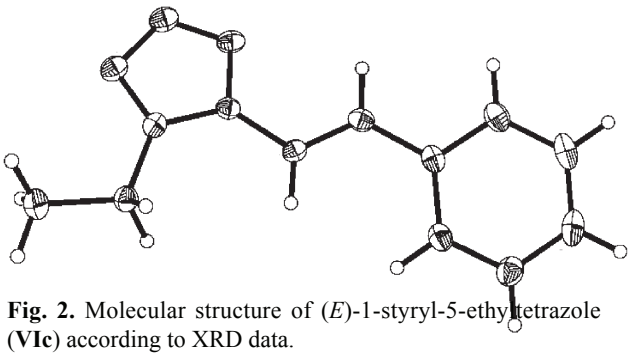


Fig. 2. Molecular structure of (*E*)-1-styryl-5-ethyltetrazole (**VIc**) according to XRD data.

Table 4. Crystallographic data and refinement parameters for tetrazoles **IIa, VIc**

Data and refinement parameters	Compound no.	
	IIa	**VIc**
Empirical formula	$C_{10}H_{10}N_4$	$C_{11}H_{12}N_4$
Molecular weight	186.22	200.25
Crystal system	Monoclinic	Rhombic
Space group	$P2_1/c$	Pbca
Temperature, K	120(2)	100(2)
a, Å	6.0310(6)	12.0020(6)
b, Å	8.5432(8)	6.8047(4)
c, Å	18.453(2)	25.811(1)
β, deg	93.967(2)	90
V, Å^3	948.5(2)	2107.9(2)
Z	*4*	*8*
D_{calc}, g cm^{-3}	1.304	1.262
$2\theta_{max}$, deg	58	52
μ, cm^{-1}	0.84	0.81
Number of independent reflections (R_{int})	2524 (0.0340)	2069 (0.0403)
R_1 [with respect to *F* for reflections with $I > 2\sigma(I)$]	0.0510 (1939)	0.0355 (1665)
wR_2 (with respect to F^2 for all reflections)	0.1349	0.0932
Number of refined parameters	128	136
GOF	1.064	1.002

The arylation of tetrazoles **VII, VIII** under the conditions of the reaction with *N*-vinyltetrazoles furnished the products of the exhaustive arylation, tetrazoles **IX, X**, in the yieldes up to 80% (Scheme 1).

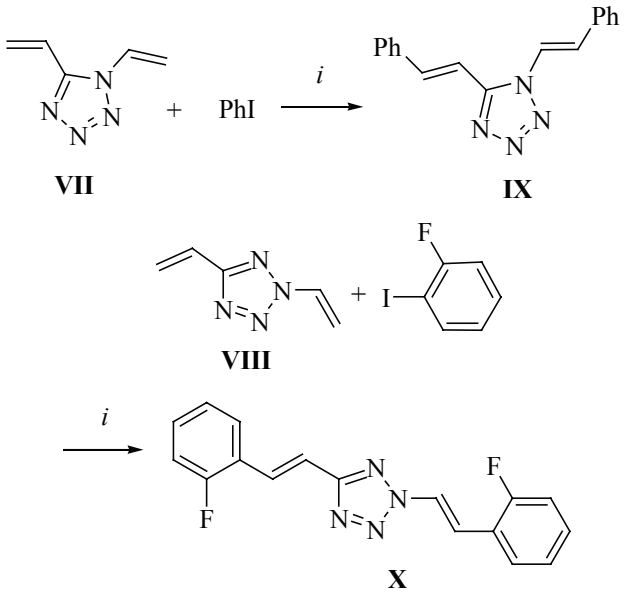
The selective arylation of tetrazoles **VII, VIII** was possible at the application of an excess of the terminal alkene with respect to the arylating agent.

We detected the formation of the selective arylation product by means of HPLC-MS and NMR spectroscopy; only in the case of tetrazole **XI** we were able to isolate the product from the reaction mixture (Scheme 2).

Styryltetrazole **IX–XI** according to the data of ^{1}HNMR spectra[1] exist in the *E*-configuration, same as the above described *C*- and *N*-styryltetrazoles.

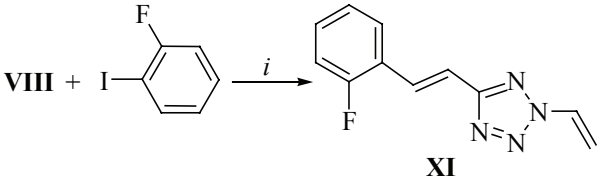
[1] Coupling constants of the protons of group CH=CH in styryltetrazoles **IX–XI** were 14.8–16.1 Hz.

Scheme 1.



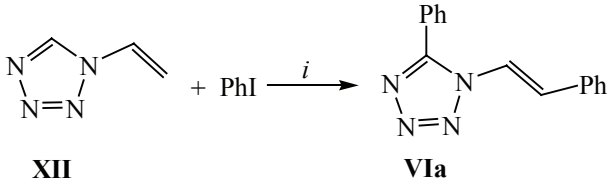
i: 4.0 mol% $Pd(OAc)_2$, 12.0 mol% PPh_3, CuI, Cs_2CO_3, DMF, 120°C.

Scheme 2.



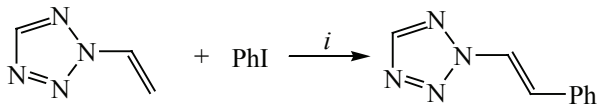
i: 4.0 mol% $Pd(OAc)_2$, 12.0 mol% PPh_3, CuI, Cs_2CO_3, DMF, 120°C.

Interesting results were obtained at Heck arylation of 1(2)-vinyltetrazoles **XII, XIII**. The arylation of 1-vinyltetrazole (**XII)** at the double bond under the conditions developed for the reaction with *N*-vinyltetrazoles was accompanied by a C,H-arylation and afforded 1-(*E*)-styryl-5-phenyltetrazole (**VIa**). The metal-catalyzed C,H-arylation of 1-R-tetrazoles was described by an example of the reaction of aryl and vinyl halides with 1-phenyltetrazole [19].



i: 3.0 mol% $Pd(OAc)_2$, 9.0 mol% PPh_3, CuI, Cs_2CO_3, DMF, 100°C

Unlike that the arylation of 2-vinyltetrazole (**XIII**) occurred exclusively at the double bond with the formation of 2-(*E*)-styryltetrazole (**XIV**).



XIII **XIV**

i: 3.0 mol% $Pd(OAc)_2$, 9.0 mol% PPh_3, CuI, Cs_2CO_3, DMF, 100°C

The obtained styryl tetrazoles **VIa, XIV** according to the ^{1}H NMR data also exist in the *E*-configuration like the above described *C*- and *N*-styryltetrazoles.

Therefore we have developed a new version of the chemical modification of vinyltetrazoles based on the metal-catalyzed arylation of monsubstituted alkenes along Heck reaction providing a possibility to obtain in high yields previously unavailable (*E*)-styryltetrazoles.

EXPERIMENTAL

^{1}H and ^{13}C NMR spectra were registered on a spectrometer Bruker DPX-300 at operating frequencies 300.1 (^{1}H) and 75.5 MHz (^{13}C). The signals of solvents served as internal references: DMSO-d_6 (δ_H 2.50, δ_C 39.52 ppm), $CDCl_3$ (δ_H 7.26, δ_C 77.16 ppm). Mass spectra were obtained on a spectrometer Waters LCT Premier (ESI, TOF). The melting points were measured on an instrument PTP with the heating rate in the melting range of 1 deg/min. The characteristics of tetrazoles **I, IIIa–IIIg, Va–Vd, VII, VIII, XII, XIII** are consistent with the published data [20].

Al reactions were carried out in an inert atmosphere (argon). The consumption of vinyltetrazoles and the accumulation of the reaction products were monitored by TLC on Merck Kieselgel 60F_{254} plates, visualization of spots under UV irradiation (λ 254 nm). All compounds obtained were isolated and purified by column chromatography on a sorbent Merck Silica Gel 60 for Column Chromatography (0.063–0.200). The eluent for the column chromatography always was the same as used in TLC. After the chromatographic purification the product was recrystallized from ethanol.

XRD analysis of tetrazoles IIa, VIc. The experimental arrays of data were obtained on a diffractometer Bruker Smart Apex II [graphite monochromator, λ(MoK_α) 0.71073 E, ω-scanning] [21]. The structures were solved by the direct method and were refined by the full-matrix root-mean-square method with respect to F^2_{hkl} with the anisotropic thermal parameters for all nonhydrogen atoms. Hydrogen atoms were placed in the geometrically calculated positions and were included in the refinement in the rider model. All calculations were performed on a PC applying SHELXTL software [22]. The complete tables of atomic coordinates, bond lengths, bond angles, and anisotropic thermal parameters are deposited in the Cambridge Crystallographic Data Center, CCDC 906717 (**IIa**), 906718 (**VIc**).

5-[2-(*E*)-Arylethenyl]-2-methyltetrazoles IIa–IIe. To a solution of 9.0 mmol of ArHlg in 2 ml of DMF was added 0.072 mmol of $Pd(OAc)_2$, and the mixture was stirred for 20 min at 50°C, then 1.8 mmol of tetrazole **I** and 3.6 mmol of K_2CO_3 was added. The slurry was stirred at 120°C till the completion of the reaction, it was cooled, poured at a vigorous stirring into 20 ml of water, and filtered through celite. The precipitate was washed with water (2 × 5 ml). The filtrate was extracted with ethyl acetate (3 × 10 ml), the combined extract was dried with anhydrous Na_2SO_4 and evaporated to dryness in a vacuum.

2-Methyl-5-[2-(*E*)-phenylethenyl]tetrazole (IIa). Yield 0.27 g (80%), colorless crystals, mp 87–88°C. R_f 0.4 (hexane–dichloromethane–ethyl acetate, 7:2.5:0.5). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 4.36 s (3H, CH_3), 7.14 d (1H, C<u>H</u>=CHPh, *J* 16.5 Hz), 7.34–7.42 m (3H, Ph), 7.54–7.58 m (2H, Ph), 7.73 d (1H, CH=C<u>H</u>Ph, *J* 16.5 Hz). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 39.48 (CH_3), 113.46 (<u>C</u>H=CHPh), 127.23, 128.93, 129.14, 135.75 (Ph), 136.37 (CH=<u>C</u>HPh), 164.46 (C^5). Found: *m/z* 187.0921 [*M* + H]$^+$. $C_{10}H_{10}N_4$. Calculated: *M* 186.2132.

2-Methyl-5-[2-(*E*)-(2-fluorophenyl)ethenyl]-tetrazole (IIb). Yield 0.3 g (81%), colorless crystals, mp 74–75°C. R_f 0.3 (hexane–dichloromethane–ethyl acetate, 9:0.5:0.5). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 4.36 C (3H, CH_3), 7.07–7.32 m (4H, C<u>H</u>=CHAr, Ar), 7.58–7.62 m (1H, Ar), 7.85 d (1H, CH=C<u>H</u>Ar, *J* 16.5 Hz). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 39.45 (CH_3), 115.92–116.35 m (<u>C</u>H=CHAr, Ar), 123.73 d (Ar, *J* 0.23 Hz), 124.45 d (Ar, *J* 0.04 Hz), 128.26 (Ar), 129.09 (CH=<u>C</u>HAr), 130.39 d (Ar, *J* 0.17 Hz), 160.29 d (Ar, *J* 3.3 Hz), 164.35 (C^5). Found: *m/z* 205.0831 [*M* + H]$^+$. $C_{10}H_9FN_4$. Calculated: *M* 204.2136.

2-Methyl-5-[2-(*E*)-(4-nitrophenyl)ethenyl]tetrazole (IIc). Yield 0.33 g (79%), colorless crystals, mp 201–

202°C. R_f 0.2 (hexane–ethyl acetate, 7:3). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 4.36 s (3H, CH_3), 7.25 d (1H, C<u>H</u>=CHAr, *J* 16.4 Hz), 7.28 d (2H, Ar, *J* 8.6 Hz), 7.74 d (1H, CH=C<u>H</u>Ar, *J* 16.4 Hz), 8.23 d (2H, Ar, *J* 8.6 Hz). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 39.58 (CH_3), 117.85 (<u>C</u>H=CHAr), 124.27, 127.74 (Ar), 133.70 (CH=<u>C</u>HAr), 142.03, 147.80 (Ar), 163.54 (C^5). Found: *m/z* 232.0801 [*M* + H]$^+$. $C_{10}H_9N_5O_2$. Calculated: *M* 231.2107.

Methyl 3-[2(*E*)-(2-methyltetrazol-5-yl)ethenyl] benzoate (IId). Yield 0.35 g (83%), colorless crystals, mp 148–149°C. R_f 0.2 (hexane–ethyl acetate, 8:2). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 3.93 s (3H, CO_2CH_3), 4.35 s (3H, CH_3), 7.20 d (1H, C<u>H</u>=CHAr, *J* 16.4 Hz), 7.44–7.48 m (1H, Ar), 7.71–7.75 m (2H, CH=C<u>H</u>Ar, Ar), 7.99 m (1H, Ar), 8.23 C (1H, Ar). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 39.50 (2-CH_3), 52.36 ($CO_2\underline{C}H_3$), 114.81 (<u>C</u>H=CHAr), 128.17, 129.03, 129.96, 130.93, 131.43 (Ar), 135.21 (CH=<u>C</u>HAr), 136.15 (Ar), 164.13 (C^5), 166.77 (Ar). Found: *m/z* 245.1123 [*M* + H]$^+$. $C_{12}H_{12}N_4O_2$. Calculated: *M* 244.2492.

3-[2-(*E*)-(2-Methyltetrazol-5-yl)ethenyl] benzonitrile (IIe). Yield 0.32 g (85%), colorless crystals, mp 135–136°C. R_f 0.2 (hexane–dichloromethane, 7:3). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 4.36 s (3H, CH_3), 7.18 d (1H, C<u>H</u>=CHAr, *J* 16.5 Hz), 7.48–7.61 m (2H, Ar), 7.67 d (1H, CH=C<u>H</u>Ar, *J* 16.5 Hz), 7.75–7.80 m (2H, Ar). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 39.54 (CH_3), 113.28 (Ar), 116.17 (C<u>H</u>=CHAr), 118.47, 129.80, 130.55, 131.11, 132.13 (Ar), 133.73 (CH=<u>C</u>HAr), 137.05 (CN), 163.35 (C^5). Found: *m/z* 212.0919 [*M* + H]$^+$. $C_{11}H_9N_5$. Calculated: *M* 211.2226.

1(2)-[2-(*E*)-Arylethenyl]-5-R-tetrazoles IVa–IVj, VIa–VIc. To a slurry of 1.8 mmol of CuI and 1.8 mmol of tetrazole **IIIa–IIIg, Va–Vd** in 2 ml of DMF was added 0.072 mmol of $Pd(OAc)_2$, 0.21 mmol of PPh_3, 9.0 mmol of ArHlg, and 2.7 mmol of Cs_2CO_3, the mixture was stirred at 120°C till the completion of the reaction. On cooling the mixture was poured at vigorous stirring into 20 ml of water, and the slurry was filtered through celite. The precipitate on the filter was washed with water (2 × 5 ml). The filtrate was extracted with ethyl acetate (3 × 15 ml), the combined extract was dried with anhydrous Na_2SO_4 and evaporated to dryness in a vacuum.

5-Phenyl-2-[2-(*E*)-(2-fluorophenyl)ethenyl] tetrazole (IVa). Yield 0.37 g (78%), colorless crystals, mp 139–140°C. R_f 0.1 (hexane–ethyl acetate, 95 : 5). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 7.12–7.21 m (2H, Ar), 7.33 m (1H, Ar), 7.49–7.52 m (4H, Ph, Ar), 7.72 d (1H, C<u>H</u>=CHHt, *J* 14.7 Hz), 8.14 d (1H, CH=C<u>H</u>Ht, *J* 14.7 Hz), 8.21 d (2H, Ph). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 116.30 d (Ar, *J* 0.3 Hz), 118.46 (<u>C</u>H=CHHt), 121.20 d (Ar, *J* 0.2 Hz), 124.75 (CH=<u>C</u>HHt), 124.80 (Ar), 127.01, 127.22, 129.08 (Ph), 129.30 d (Ar, *J* 0.3 Hz), 130.72 (Ar), 130.81 (Ph), 161.03 d (Ar, *J* 3.3 Hz), 165.11 (C^5). Found: *m/z* 267.1121 [*M* + H]$^+$. $C_{15}H_{11}FN_4$. Calculated: *M* 266.2730.

5-Phenyl-2-[2-(*E*)-phenylethenyl]tetrazole (IVb). Yield 0.36 g (82%), colorless crystals, mp 113–114°C. R_f 0.2 (hexane–ethyl acetate, 8:2). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 7.26–7.56 m ($8H_{arom}$), 7.69 d (1H, C<u>H</u>=CHHt, *J* 14.5 Hz), 7.99 d (1H, CH=C<u>H</u>Ht, *J* 14.5 Hz), 8.21–8.23 m ($2H_{arom}$). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 122.53 (<u>C</u>H=CHHt), 124.95 (CH=<u>C</u>HHt); 127.13, 127.23, 127.33, 129.10, 129.24, 129.31, 130.77, 133.20 (Ph); 164.96 (C^5). Found: *m/z* 249.2121 [*M* + H]$^+$. $C_{15}H_{12}N_4$. Calculated: *M* 248.2825.

2-{2-(*E*)-[3-(Trifluoromethyl)phenyl]ethenyl}-5-phenyltetrazole (IVc). Yield 0.45 g (81%), colorless crystals, mp 160–161°C. R_f 0.2 (hexane–ethyl acetate, 9:1). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 7.52–7.64 m (5H, Ph, Ar), 7.71–7.75 m (1H, C<u>H</u>=CHHt, 1H, Ar, *J* 13.9 Hz), 7.80 s (1H, Ar), 8.05 d (1H, CH=C<u>H</u>Ht, *J* 13.9 Hz), 8.22–8.24 m (2H, Ph). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 123.28 (CH=CHHt), 123.89 (Ar), 124.10 d (Ar, $_J$ 0.05 Hz), 125.96 m (Ar), 126.93, 127.28, 129.17 (Ph), 129.81 (CH=<u>C</u>HHt), 130.24 (Ar), 130.96 (Ph), 134.12 (CF_3), 165.19 (C^5). Found: *m/z* 317.1108 [*M* + H]$^+$. $C_{16}H_{11}F_3N_4$. Calculated: *M* 316.0912.

5-(4-Methylphenyl)-2-[2-(*E*)-(2-fluorophenyl) ethenyl]tetrazole (IVd). Yield 0.39 g (79%), colorless crystals, mp 120–121°C. R_f 0.2 (hexane–ethyl acetate, 9:1). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 2.43 C (3H, CH_3), 7.13–7.22 m (2H, Ar), 7.31–7.35 m (3H, Ar, Tol), 7.53 m (1H, Ar), 7.72 d (1H, C<u>H</u>=CHHt, *J* 14.7 Hz), 8.10–8.16 m (3H, Tol, CH=C<u>H</u>Ht, *J* 14.7 Hz). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 21.69 (CH_3), 116.41 d (Ar, *J* 0.3 Hz), 118.28 (<u>C</u>H=CHHt), 121.30 d (Ar, *J* 0.2 Hz), 124.24 (Tol), 124.82 (CH=<u>C</u>HHt), 125.10 (Ar), 127.18, 129.39, 129.82 (Tol), 130.75 d (Ar, *J* 0.3 Hz), 141.09 (Ar), 161.23 (Ar, *J* 3.4 Hz), 165.13 (C^5). Found: *m/z* 281.2151 [*M* + H]$^+$. $C_{16}H_{13}FN_4$. Calculated: *M* 280.2996.

5-(4-Methylphenyl)-2-[2-(*E*)-phenylethenyl] tetrazole (IVe). Yield 0.38 g (82%), colorless crystals, mp 118–119°C. R_f 0.2 (hexane–ethyl acetate, 8 : 2).

^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 2.42 s (3H, CH_3), 7.30–7.43 m (5H, Ph, Tol), 7.54 m (2H, Ph), 7.67 d (1H, CH=CHHt, *J* 14.7 Hz), 7.97 d (1H, CH=CHHt, *J* 14.7 Hz), 8.10 d (2H, Tol). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 21.68 (CH_3), 122.58, 124.35 (Tol), 124.74 (CH=CHHt), 127.16 (Tol), 127.31, 129.24 (Ph), 129.46 (CH=CHHt), 129.82, 133.29 (Ph), 141.03 (Tol), 165.06 (C^5). Found: *m/z* 263.1301 [*M* + H]$^+$. $C_{16}H_{14}N_4$. Calculated: *M* 262.3091.

5-[4-(Trifluoromethyl)phenyl]-2-[2-(*E*)-(2-fluorophenyl)ethenyl]tetrazole (IVf). Yield 0.48 g (84%), colorless crystals, mp 129–130°C. R_f 0.1 (hexane–ethyl acetate, 9:1). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 7.16–7.22 m (2H, Ar), 7.36 m (1H, Ar), 7.54 m (1H, Ar), 7.74–7.79 m (3H, Ar, CH=CHHt, *J* 14.7 Hz), 8.16 d (1H, CH=CHHt, *J* 14.7 Hz), 8.35 d (2H, Ar). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 116.42 d (Ar, *J* 0.3 Hz), 119.15 (CH=CHHt), 121.10 d (Ar, *J* 0.2 Hz), 122.18 q (Ar, *J* 7.1 Hz), 124.71, 124.85 (Ar), 124.90 (CH=CHHt), 126.11 m (Ar), 127.55 (Ar), 129.53 (Ar, *J* 0.3 Hz), 130.45, 131.05 (Ar), 161.12 (Ar, *J* 3.3 Hz), 163.84 (C^5). Found: *m/z* 335.1101 [*M* + H]$^+$. $C_{16}H_{10}F_4N_4$. Calculated: *M* 334.0711.

5-[4-(Trifluoromethyl)phenyl]-2-[2-(*E*)-phenylethenyl]tetrazole (IVg). Yield 0.46 g (81%), light-yellow crystals, mp 140–141°C. R_f 0.1 (hexane–ethyl acetate, 95:5). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 7.41–7.46 m (3H, Ph), 7.56 d (2H, Ar), 7.72 d (1H, CH=CHHt, *J* 14.7 Hz), 7.78 d (2H, Ph), 8.01 d (1H, CH=CHHt, *J* 14.7 Hz), 8.35 d (1H, Ar). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 122.17 q (Ar, *J* 7.1 Hz), 122.34 (Ar), 125.54 (CH=CHHt), 126.11 m (Ar), 127.39 (Ar), 127.49, 129.28 (Ph), 129.72 (CH=CHHt), 130.47 (Ph), 132.55 (Ar), 132.94 (Ph), 163.72 (C^5). Found: *m/z* 317.1221 [*M* + H]$^+$. $C_{16}H_{11}F_3N_4$. Calculated: *M* 316.0905.

2-{2-[(*E*)-2-Phenylethenyl]tetrazol-5-yl}benzonitrile (IVh). Yield 0.42 g (85%), light-yellow crystals, mp 124–125°C. R_f 0.2 (hexane– ethyl acetate, 9:1). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 7.38–7.44 m (3H, Ph), 7.55–7.63 m (3H, Ar, Ph), 7.74–7.78 t (2H, Ar, CH=CHHt, *J* 14.7 Hz), 7.87 m (1H, Ar), 8.04 d (1H, CH=CHHt, *J* 14.7 Hz), 8.36 m (1H, Ar). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 110.51 (Ar), 117.60 (CN), 122.46 (CH=CHHt), 125.90 (Ar), 127.49 (Ph), 129.02 (Ar), 129.11 (Ph), 129.50, 129.61 (Ar), 130.88 (CH=CHHt), 132.72, 133.30 (Ph), 134.86 (Ar), 161.98 (C^5). Found: *m/z* 275.0912 [*M* + H]$^+$. $C_{16}H_{11}N_5$. Calculated: *M* 274.1120.

5-Methyl-2-[2-(*E*)-(2-fluorophenyl)ethenyl]tetrazole (IVi). Yield 0.29 g (78%), light-yellow crystals, mp 88–89°C. R_f 0.2 (hexane–ethyl acetate, 9:1). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 2.60 s (3H, CH_3), 7.11–7.20 m (2H, Ar), 7.32 m (1H, Ar), 7.48 m (1H, Ar), 7.61 d (1H, CH=CHHt, *J* 14.7 Hz), 8.05 d (1H, CH=CHHt, *J* 14.7 Hz). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 11.09 (CH_3), 116.35 d (Ar, *J* 0.3 Hz), 118.08 d (CH=CHHt, *J* 0.2 Hz), 121.23 d (Ar, *J* 0.2 Hz), 124.74, 124.93 (Ar), 129.37 (CH=CHHt), 130.69 d (Ar, *J* 0.1 Hz), 161.14 (Ar, *J* 3.3 Hz), 163.17 (C^5). Found: *m/z* 205.1103 [*M* + H]$^+$. $C_{10}H_9FN_4$. Calculated: *M* 204.0736.

2-[2-(*E*)-Phenylethenyl]-5-ethyltetrazole (IVj). Yield 0.28 g (80%), colorless crystals, mp 160–161°C. R_f 0.2 (hexane–ethyl acetate, 8:2). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 1.41 t (3H, CH_3), 2.96 q (2H, CH_2), 7.33–7.40 m (3H, Ph), 7.48 m (2H, Ph), 7.55 d (1H, CH=CHHt, *J* 14.7 Hz), 7.88 d (1H, CH=CHHt, *J* 14.7 Hz). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 12.41 (CH_3), 19.24 (CH_2), 122.56 (Ph), 124.44 (CH=CHHt), 127.22, 129.19 (Ph), 129.37 (CH=CHHt), 133.26 (Ph), 167.98 (C^5). Found: *m/z* 201.2199 [*M* + H]$^+$. $C_{11}H_{12}N_4$. Calculated: *M* 200.2397.

5-Phenyl-1-[2-(*E*)-phenylethenyl]tetrazole (VIa). Yield 0.36 g (82%), colorless crystals, mp 160–161°C. R_f 0.2 (hexane–ethyl acetate, 8:2). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 7.38–7.45 m (6H, Ph, CH=CHHt, *J* 14.5 Hz), 7.58–7.60 m (4H, Ph), 7.77 m (2H, CH=CHHt, Ph). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 119.81 (CH=CHHt), 123.25, 127.40 (Ph), 127.98 (CH=CHHt), 128.86, 129.19, 129.30, 131.47, 133.13 (Ph), 152.87 (C^5). Found: *m/z* 249.1911 [*M* + H]$^+$. $C_{15}H_{12}N_4$. Calculated: *M* 248.2825.

5-Methyl-1-[2-(*E*)-phenylethenyl]tetrazole (VIb). Yield 0.27 g (80%), colorless crystals, mp 168–169°C. R_f 0.3 (hexane–ethyl acetate, 8:2). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 7.34 d (1H, CH=CHHt, *J* 14.4 Hz), 7.41–7.52 m (7H, Ph, CH=CHHt). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 9.38 (CH_3), 117.64 (CH=CHHt), 127.00 (CH=CHHt), 127.11, 129.22, 129.57, 133.12 (C_6H_4), 150.52 (C^5). Found: *m/z* 187.1391 [*M* + H]$^+$. $C_{10}H_{10}N_4$. Calculated: *M* 186.0932.

1-[2-(*E*)-Phenylethenyl]-5-ethyltetrazole (VIc). Yield 0.27 g (81%), colorless crystals, mp 112–113°C. R_f 0.3 (hexane–ethyl acetate, 8:2). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 1.47 t (3H, CH_3), 2.99 m (2H, CH_2), 7.30 d (1H, CH=CHHt, *J* 14.5 Hz), 7.39–7.52 m (7H,

Ph, CH=CHHt). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 11.48 (CH_3), 17.33 (CH_2), 117.51 (CH=CHHt), 127.02 (CH=CHHt), 127.13, 129.23, 129.56, 133.22 (C_6H_4), 154.86 (C^5). Found: *m/z* 201.1198 [*M* + H]$^+$. $C_{11}H_{12}N_4$. Calculated: *M* 200.0497.

1,2(5)-Bis[2-(*E*)-arylethenyl]tetrazoles IX, X. To a slurry of 1.8 mmol of CuI and 1.8 mmol of tetrazole **VII, VIII** in 3 ml of DMF was added 0.072 mmol of $Pd(OAc)_2$, 0.21 mmol of PPh_3, 18.0 mmol of ArHlg, and 5.4 mmol of Cs_2CO_3, the mixture was stirred at 120°C till the completion of the reaction. On cooling the mixture was poured at vigorous stirring into 25 ml of water, and the slurry was filtered through celite. . The precipitate on the filter was washed with water (2 × 7 ml). The filtrate was extracted with ethyl acetate (2 × 20 ml), the combined extract was dried with anhydrous Na_2SO_4 and evaporated to dryness in a vacuum.

1,5-Bis[2-(*E*)-phenylethenyl]tetrazole (IX). Yield 0.4 g (80%), colorless crystals, mp 118–119°C. R_f 0.2 (hexane–ethyl acetate, 8:2). ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 7.38–7.49 m (6H, Ph), 7.55 d (1H, CH=CHHt, *J* 14.4 Hz), 7.67 d (1H, CH=CHHt, *J* 16.0 Hz), 7.76–7.86 m (4H, Ph), 7.90 d (1H, CH=CHHt, *J* 16.1 Hz), 8.27 d (1H, CH=CHHt, *J* 14.1 Hz). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 108.34 (CH=CHHt), 119.21 (CH=CHHt), 124.99 (CH=CHHt), 127.45, 128.11, 128.82, 128.89, 129.01, 130.05 (Ph), 133.61 (CH=CHHt), 134.94, 139.83 (Ph), 151.47 (C^5). Found: *m/z* 275.3181 [*M* + H]$^+$. $C_{17}H_{14}N_4$. Calculated: *M* 274.3198.

1,2-Bis[2-(*E*)-(2-fluorophenyl)ethenyl]tetrazole (X). Yield 0.42 g (76%), colorless crystals, mp 134–135°C. R_f 0.1 (hexane–ethyl acetate, 9:1). ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 7.22–7.29 m (4H, Ar, CH=CHHt, *J* 15.8 Hz), 7.43 m (3H, Ar), 7.68 d (1H, CH=CHHt, *J* 14.8 Hz), 7.85–7.95 m (3H, Ar, CH=CHHt, *J* 15.8 Hz), 8.49 d (1H, CH=CHHt, *J* 14.8 Hz). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm: 116.40 d (CH=CHHt, *J* 0.1 Hz), 116.53, 116.92 (Ar), 117.73 d (CH=CHHt, *J* 0.05 Hz), 125.59–125.81 m (Ar, CH=CHHt), 129.30 d (Ar, *J* 0.05 Hz), 129.69 d (CH=CHHt, *J* 0.05 Hz), 129.73 (Ar), 132.01 d (Ar, *J* 0.1 Hz), 161.03 d (Ar, *J* 3.3 Hz), 163.26 (C^5). Found: *m/z* 311.3881 [*M* + H]$^+$. $C_{17}H_{12}F_2N_4$. Calculated: *M* 310.3007.

2-Vinyl-5-[2-(*E*)-(2-fluorophenyl)ethenyl]-tetrazole (XI) was obtained from 1.8 mmol of *o*-FC_6H_4I, 3.5 mmol of tetrazole **VIII**, 0.072 mmol of $Pd(OAc)_2$, 0.216 mmol of PPh_3, 1.8 mmol of CuI, 1.9 mmol of Cs_2CO_3. Yield 0.31 g (80%), colorless crystals, mp 69–70°C. R_f 0.2 (hexane–ethyl acetate, 9 : 1). ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 5.50 d (1H, CH_2=CHHt, *J* 7.8 Hz), 6.16 d (1H, CH_2=CHHt, *J* 14.7 Hz), 7.21–7.27 m (2H, Ar, CH=CHHt, *J* 15.7 Hz), 7.38–7.42 m (2H, Ar, CH_2=CHHt), 7.77–7.90 m (3H, Ar, CH=CHHt). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 109.30 (CH_2=CHHt), 115.69 (CH=CHHt), 116.51 (Ar), 122.63 d (Ar, *J* 0.2 Hz), 124.91 (Ar), 128.36 (CH=CHHt), 128.52 (Ar), 130.11 (CH_2=CHHt), 131.25 d (Ar, *J* 0.2 Hz), 160.38 d (Ar, *J* 3.3 Hz), 162.59 (C^5). Found: *m/z* 217.1139 [*M* + H]$^+$. $C_{11}H_9FN_4$. Calculated: *M* 216.0743.

***N*-[2-(*E*)-Arylethenyl]tetrazoles VIa, XIV.** To a slurry of 1.8 mmol of CuI and 1.8 mmol of tetrazole **XII, XIII** in 1 ml of DMF was added 0.054 mmol of $Pd(OAc)_2$, 0.16 mmol of PPh_3, 18.0 mmol of ArHlg, and 5.1 mmol of Cs_2CO_3, the mixture was stirred at 100°C till the completion of the reaction. On cooling the mixture was poured at vigorous stirring into 15 ml of water, and the slurry was filtered through celite. . The precipitate on the filter was washed with water (2 × 5 ml). The filtrate was extracted with ethyl acetate (2 × 15 ml), the combined extract was dried with anhydrous Na_2SO_4 and evaporated to dryness in a vacuum.

2-[2-(*E*)-Phenylethenyl]tetrazole (XIV). Yield 0.25 g (80%), light-yellow crystals, mp 40–41°C. R_f 0.3 (hexane–ethyl acetate, 8:2). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 7.38–7.43 m (3H, Ph), 7.52–7.55 m (2H, Ph), 7.68 d (4H, CH=CHN, *J* 14.7 Hz), 7.99 d (1H, CH=CHCN, *J* 14.7 Hz), 8.58 s (1H, H^5). ^{13}C NMR spectrum, δ, ppm: 122.43 (CH=CHHt); 125.67, 127.39, 129.26, 129.68 (Ph); 132.94 (CH=CHHt), 152.75 (C^5). Found: *m/z* 173.1211 [*M* + H]$^+$. $C_9H_8N_4$. Calculated: *M* 172.0766.

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REFERENCES

1. Aleshunin, P.A., Dmitrieva, U.N., and Ostrovskii, V.A., *Zh. Org. Khim*., 2011, vol. 47, p. 1846.
2. Ostrovskii, V.A., Podkameneva, M.E., Poplavskii, V.S., and Trifonov, R.E., *Izv. Akad. Nauk, Ser. Khim.,* 2009, p. 2082.
3. Kizhnyaev, V.N. and Vereshchagin, L.I., *Usp. Khim*., 2003, vol. 72, p. 159.

4. Ostrovskii, V.A., Koldobskii, G.I., and Trifonov, R.E., *Comprehensive Heterocycl. Chem. III*, 2008, vol. 6, p. 257.
5. Kizhnyaev, V.N. and Vereshchagin, L.I., *Viniltetrazoly* (Vinyltetrazoles), Irkutsk: Izd. Irkut. Gos. Univ., 2003, p. 41.
6. Casey, M., Moody, C.J., and Rees, C.W., *J. Chem. Soc., Chem. Commun.,* 1982, p. 714.
7. Nakayama, K., Kuru, N., Ohtsuka, M., Yokomizo, Y., Sakamoto, A., Kawato, H., a, Yoshida, K., Ohta, T., Hoshino, K., Akimoto, K., Itoh, J., Ishida, H., Cho, A., Palme, M.H., Zhang, J.Z., Leeb, V.J., and Watkins, W.J., *Bioorg. Med. Chem. Lett.,* 2004, vol. 14, p. 2496.
8. Diwakar, S.D., Bhadwat, S.S., Shingare, M.S., and Gill, C.H., *Bioorg. Med. Chem. Lett*., 2008, vol. 18, p. 4678.
9. Koldobskii, G.I. and Ostrovskii, V.A., *Usp. Khim*., 1994, vol. 63, p. 847.
10. Hermann, S.H., US Patent 3564005, 1971; *Chem. .Abstr*., 1971, vol. 74, 112805.
11. Shvekhgeimer, G.A., Kobrakov, K.I., Mityagina, O.G., Korolev, V.K., and Promonenkov, V.K., *Khim. Geterotsikl. Soedin*., 1986, p. 711.
12. Bratilov, S.B., Kovaleva, S.M., Shchetinina, T.V., Petrov, V.V., Poplavskii, V.S., and Ostrovskii, V.A., *Zh. Org. Khim*., 1992, vol. 28, p. 2344.
13. Buzilova, S.R., Shul'gina, V.M., Gareev, G.A., and Vereshchagin, L.I., *Khim. Geterotsikl. Soedin*., 1980, p. 842.
14. *Metal Catalyzed Cross-Coupling Reactions,* Diederich, F. and Stang, P.J., Eds., New York: Wiley Intersci., 1998, p. 99.
15. Beletskaya, I.P. and Cheprakov, A.V., *Chem. Rev*., 2000, vol. 100, p. 3009.
16. *Handbook of Organopalladium Chemistry for Organic Synthesis,* Negishi, E.I., New York: Wiley Intersci., 2002.
17. *The Mizoroki–Heck Reaction,* Oestreich, M., Ed., New York: Wiley Intersci., 2009, p. 1.
18. Gunther, H., NMR *Spectroscopy: an Introduction*, Chichester: Wiley, 1980.
19. Spulak, M., Lubojacky, R., Senel, P., Kunes, J., and Pour, M., *J. Org. Chem*., 2010*,* vol. 75, p. 241.
20. Vereshchagin, L.I., Kizhnyaev, V.N., and Pokatilov, F.A., *Nekondensirovannye tetrazoly: spravochnoe izdanie*, Irkutsk: Izd. Irkut. Gos. Univ., 2007, p. 8.
21. APEX II Software Package, Bruker AXS Inc., USA, 2005.
22. Sheldrick, G.M., *Acta Cryst. A*, 2008, vol. 64, p. 112.