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HECK-MIZOROKI REACTION OF 4-IODO-1*H*-PYRAZOLES

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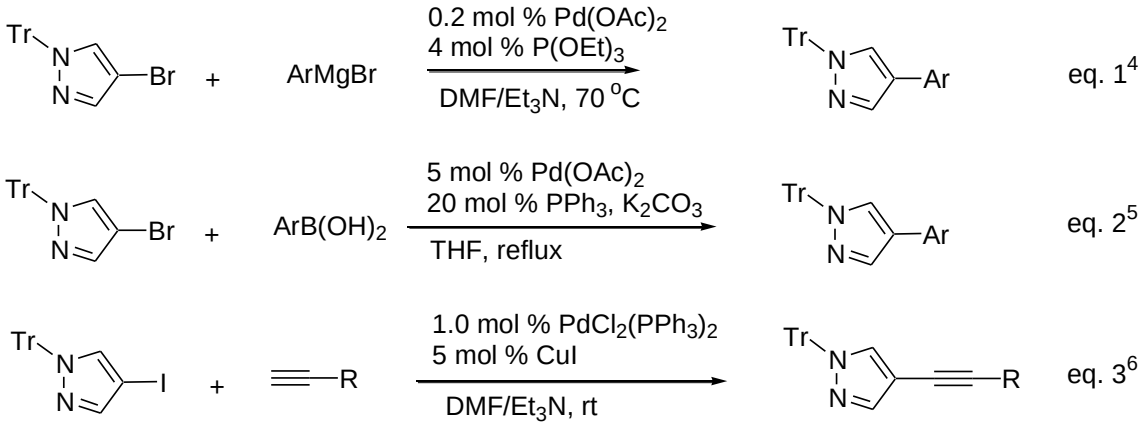
Abstract – The Heck-Mizoroki reaction of 1-protected-4-iodo-1*H*-pyrazoles with various kinds of alkenes was examined and found to yield 1-protected-4-alkenyl-1*H*-pyrazoles. $P(OEt)_3$ was a suitable ligand for the cross-coupling reaction, together with the trityl group that acted as an appropriate protecting group of 1*H*-pyrazole.

INTRODUCTION

The exploration of new methods for the synthesis of heterocyclic compounds is an important work for synthetic organic chemists, as most drugs or bioactive compounds possess one or more heterocyclic moieties in their molecules. Pyrazoles are one of the most important classes of heterocyclic compounds[1,2] and many pyrazole syntheses are based on the construction of a pyrazole ring by cycloaddition of hydrazines with 1,3-dicarbonyl compounds or diazomethane with acetylenes in the last step. A novel binuclear platinum(II) complex bearing 4-methylpyrazole (4mpz)[3] as the ligand showed enhanced antitumor activity in the cisplatin-resistant L1210/R cell line. The discovery of the 4mpz ligand encouraged us to develop practical cross-coupling methods for the synthesis of novel C-4 substituted pyrazoles. We have so far reported the synthesis of 4-arylpyrazoles by the Kumada coupling (Scheme 1, eq. 1)[4] or the Suzuki-Miyaura coupling (eq. 2),[5] and the synthesis of 4-alkynylpyrazoles by the Sonogashira coupling (eq. 3), which further provided 2*H*-indazoles by the double Sonogashira coupling of bisiodo-1*H*-pyrazoles followed by the Bergman-Masamune cycloaromatization.[6] As an extension of our synthetic studies of 4-functionalized 1*H*-pyrazoles, we next addressed the Heck-Mizoroki reaction, which is widely applied to the preparation of substituted alkenes by the cross-coupling reaction between

alkenyl compounds and arylhalides or aryltriflates in the presence of palladium(0) catalysts.[7-9] Ying and co-workers reported the Heck-Mizoroki reaction between 4-bromo-1,3,5-trimethylpyrazole and *tert*-butyl acrylate in the presence of IMes-Pd(dmba)Cl (4 mol %) in the development of a new Pd catalyst, but the yield was only 32%.[10] As far as we know, this is the only example of the Heck-Mizoroki reaction of 4-halopyrazole.[10-12] In this article, we describe the direct alkenylation of 4-iodo-1*H*-tritylpyrazole (**1a**) using the Heck-Mizoroki reaction.



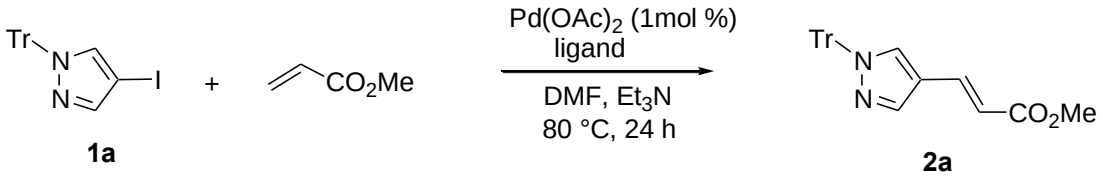
Scheme 1. Our previous work on the C-4 functionalization of 1*H*-tritylpyrazoles

RESULTS AND DISCUSSION

We first examined the Heck-Mizoroki reaction of 4-iodo-1*H*-tritylpyrazole (**1a**) with methyl acrylate in the presence of $Pd(OAc)_2$ (1 mol %), phosphine ligand, and triethylamine in DMF at 80 °C for 24 h. The results are summarized in Table 1. In the absence of the phosphine ligand, 4-(2-methoxycarbonylvinyl)-1-trityl-1*H*-pyrazole (**2a**) was obtained in only 46% yield (entry 1). **2a** was assigned the *E*-configuration from the coupling constant (15.9 Hz) between the double bond protons in the ^{1}H-NMR spectrum. Use of $P(OEt)_3$ (4 mol %) as a ligand improved the yield of **2a** to 95% (entry 4), whereas higher concentrations of $P(OEt)_3$ lowered the yield (entries 2 and 3). Reducing the amount of methyl acrylate from 5 to 1.2 equivalent in the presence of 4 mol % of $P(OEt)_3$ afforded **2a** in 95% yield (entry 5). Changing the ligand from $P(OEt)_3$ to PPh_3 decreased the yield to 50% (entry 6), and increasing the amount of $Pd(OAc)_2$ from 1 to 10 mol % had little effect on the yield (entry 7). From these results, we adopted the reaction conditions of entry 5 as the general procedure for further studies.

To clarify the scope and limitations of the Heck-Mizoroki reaction of **1**, the reactions of various 1-protected 4-iodo1*H*-pyrazoles **1a-f** with alkenes were carried out using the previous reaction conditions (Table 1, entry 5), and the results are summarized in Table 2. From the results of entries 1-6 in Table 2, the trityl group was confirmed to be a desirable *N*-1 protective group and benzyl groups were also an acceptable protective group (entry 2). In the cases of *p*-toluenesulfonyl and 2,4,6-trimethylbenzoyl groups

Table 1. Heck-Mizoroki reaction of **1a**



1a **2a**

entry	methyl acrylate (eq.)	ligand (mol %)	**2a** (yield, %)
1	5	**---**	46
2	5	$P(OEt)_3$ (20)	40
3	5	$P(OEt)_3$ (10)	65
4	5	$P(OEt)_3$ (4)	95
5	1.2	$P(OEt)_3$ (4)	95
6	5	PPh_3 (4)	50
7	3	$P(OEt)_3$ (15)	84[a]

a) In entry 7, 10 mol % of $Pd(OAc)_2$ was used.

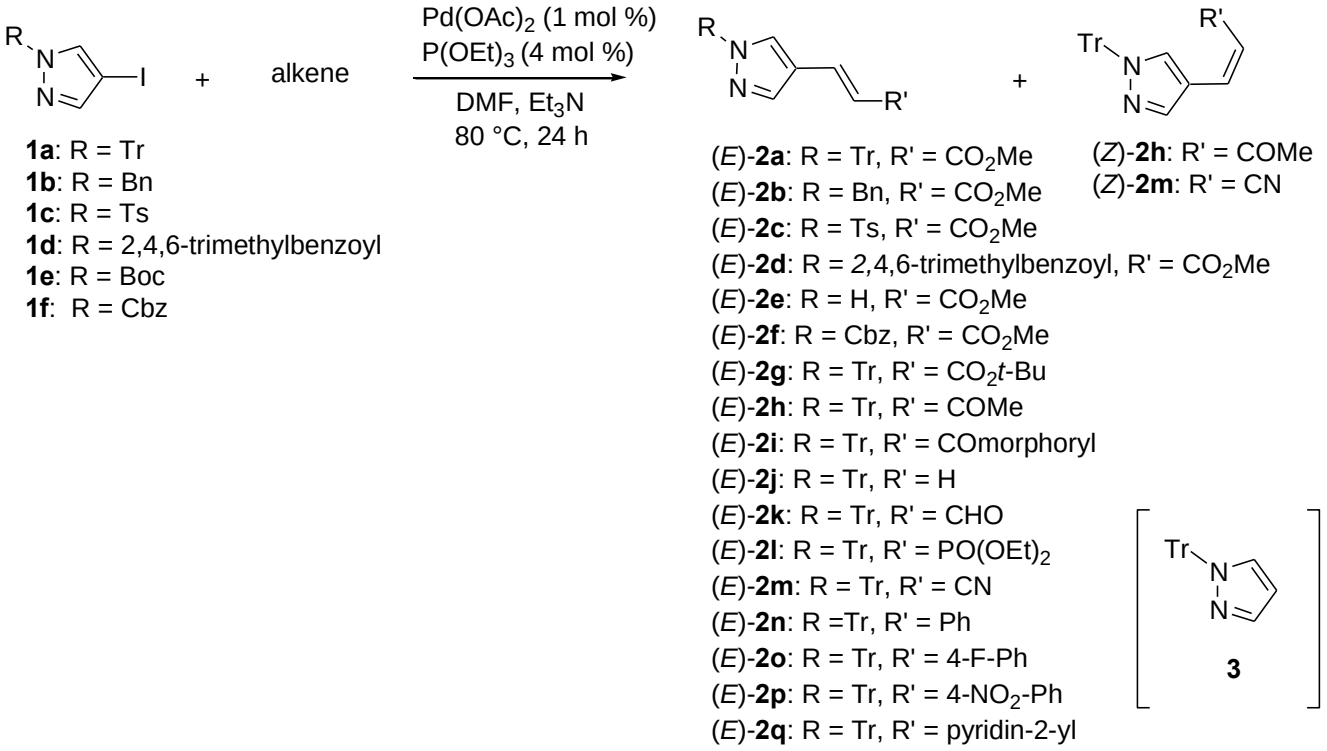
(entries 3 and 4), the corresponding products (*E*)-**2c** and **2d** were obtained in modest yields, whereas Boc- and Cbz-substituted carbamates **1e** and **1f** were unfavorable as an *N*-1 protective group (entries 5 and 6). We next focused on the reaction of **1a** with various alkenes (entries 7-18). *tert*-Butyl acrylate and methyl vinyl ketone were good coupling partners of **1a,** affording **2g** and **2h** in 90% and 85% yields, respectively (entries 7 and 8). Although most of the coupling reactions afforded selectively *E*-alkene products, the reactions of **1a** with methyl vinyl ketone (entry 8) or acrylonitrile (entry 13) gave a mixture of *E*- and *Z*-isomers. The reactions of **1a** with vinyl acetate (entry 10), acrolein (entry 11), diethyl vinylphosphonate (entry 12), or acrylonitrile (entry 13) gave Heck products in low yields, accompanied by starting material **1a** or dehalogenated 1-tritylpyrazole **3**.

Although the reactions of **1a** with some styrenes were examined (entries 14-17), the reactions gave (*E*)-**2n-q** in low yields. Increasing the amounts of $Pd(OAc)_2$ and $P(OEt)_3$ in the reaction of **1a** with styrene improved somewhat the yield (entry 18). The results in Table 2 indicated the scope and limitations of our procedure for the direct C-4 alkenylation of 1-protected -1*H*-pyrazoles *via* the Heck-Mizoroki reaction.

CONCLUSION

The synthesis of 1-protected-4-alkenyl-1*H*-pyrazoles from 1-protected-4-iodo-1*H*-pyrazoles using the Heck-Mizoroki reaction was investigated. The results indicated that $P(OEt)_3$, trityl group, and acrylates were appropriate for use as a ligand, a protective group, and coupling partner in this reaction, respectively. This study offered a new aspect in the direct functionalization of pyrazoles.

Table 2. Heck-Mizoroki reactions between 1-protected-4-iodo-1*H*-pyrazoles **1** and various alkenes



1a: R = Tr
1b: R = Bn
1c: R = Ts
1d: R = 2,4,6-trimethylbenzoyl
1e: R = Boc
1f: R = Cbz

(*E*)-**2a**: R = Tr, R' = CO_2Me
(*E*)-**2b**: R = Bn, R' = CO_2Me
(*E*)-**2c**: R = Ts, R' = CO_2Me
(*E*)-**2d**: R = *2,*4,6-trimethylbenzoyl, R' = CO_2Me
(*E*)-**2e**: R = H, R' = CO_2Me
(*E*)-**2f**: R = Cbz, R' = CO_2Me
(*E*)-**2g**: R = Tr, R' = CO_2t-Bu
(*E*)-**2h**: R = Tr, R' = COMe
(*E*)-**2i**: R = Tr, R' = COmorphoryl
(*E*)-**2j**: R = Tr, R' = H
(*E*)-**2k**: R = Tr, R' = CHO
(*E*)-**2l**: R = Tr, R' = $PO(OEt)_2$
(*E*)-**2m**: R = Tr, R' = CN
(*E*)-**2n**: R =Tr, R' = Ph
(*E*)-**2o**: R = Tr, R' = 4-F-Ph
(*E*)-**2p**: R = Tr, R' = 4-NO_2-Ph
(*E*)-**2q**: R = Tr, R' = pyridin-2-yl

(*Z*)-**2h**: R' = COMe
(*Z*)-**2m**: R' = CN

3

entry	substrate	alkene	product (yield)	recovery of **1**	recovery of **3**
1[a]	**1a**	CH_2=$CHCO_2Me$	(*E*)-**2a** (95%)		
2	**1b**	CH_2=$CHCO_2Me$	(*E*)-**2b** (75%)		
3	**1c**	CH_2=$CHCO_2Me$	(*E*)-**2c** (40%)		
4	**1d**	CH_2=$CHCO_2Me$	(*E*)-**2d** (56%)		
5	**1e**	CH_2=$CHCO_2Me$	(*E*)-**2e** (trace)		
6	**1f**	CH_2=$CHCO_2Me$	-		
7	**1a**	CH_2=$CHCO_2t$Bu	(*E*)-**2g** (90%)		
8	**1a**	methyl vinyl ketone	(*E*)-**2h** (81%), (*Z*)-**2h** (4%)		
9	**1a**	4-acryloylmorpholine	(*E*)-**2i** (53%)	23%	10%
10	**1a**	vinyl acetate	(*E*)-**2j** (6%)	47%	30%
11	**1a**	CH_2=CHCHO	(*E*)-**2k** (26%)	26%	
12	**1a**	CH_2=$CHPO(OEt)_2$	(*E*)-**2l** (8%)	47%	21%
13	**1a**	CH_2=CHCN	(*E*)-**2m** (28%), (*Z*)-**2m** (9%)	16%	25%
14	**1a**	CH_2=CHPh (styrene)	(*E*)-**2n** (9%)	69%	20%
15	**1a**	4-fluorostyrene	(*E*)-**2o** (16%)	48%	
16	**1a**	*p*-nitrostyrene	(*E*)-**2p** (5%)	34%	4%
17	**1a**	2-vinylpyridine	(*E*)-**2q** (2%)	81%	
18[b]	**1a**	CH_2=CHPh	(*E*)-**2n** (44%)		

a. The result is entry 5 in Table 1. b. 5 mol % of $(PdOAc)_2$ and 10 mol % of $P(OEt)_3$ were used in entry 18.

EXPERIMENTAL

Unless otherwise indicated, all starting materials were obtained from commercial suppliers (Aldrich, Kishida Chemical, Nacalai Tesque, Wako Pure Chemicals, and TCI) and used without further purification. IR spectra were obtained with a JEOL FT/IR-680 Plus spectrometer. HRMS was determined with a JEOL JMS-700 (2) mass spectrometer. NMR spectra were recorded at 27 ^{o}C on Varian UNITY INOVA-500 and Mercury-300 spectrometers in $CDCl_3$ with tetramethylsilane (TMS) as the internal standard. Melting points were determined on a Yanagimoto micromelting point apparatus and are uncorrected. Liquid column chromatography was conducted over silica gel (SiliCycle, SiliaFlash F60, 40-63 μm). Analytical TLC was performed on precoated Merck glass plates (silica gel 60 F_{254}) and compounds were detected by dipping the plates in an ethanol solution of phosphomolybdic acid, followed by heating.

Typical synthetic procedure (Table 1, entry 5): 4-Iodo-1*H*-tritylpyrazole (**1a**) (0.44 g, 1.0 mmol) and $Pd(OAc)_2$ (2.2 mg, 0.01 mmol) were dissolved in DMF (6 mL). The resulting solution was added dropwise to a mixture of Et_3N (1.2 mL), $P(OEt)_3$ (6.9 μL, 0.04 mmol), and methyl acrylate (108 μL, 1.2 mmol). The reaction mixture was heated to 80 °C with stirring for 24 h under nitrogen atmosphere and the resulting mixture was poured into water and extracted with CH_2Cl_2. The organic layer was washed with brine, dried over $MgSO_4$, filtered, and evaporated to furnish a crude product that was purified by silica gel column chromatography (eluent: hexane/EtOAc = 4:1) to give **2a** (0.36 g, 95%).

4-(2-Methoxycarbonylvinyl)-1-trityl-1*H*-pyrazole (2a): Colorless needles (CH_2Cl_2); mp 196–199 °C; IR (KBr) ν_{max} 1699 (C=O), 1643 (C=C), 1493 (C=C) cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.87 (1H, s, pyrazole-H), 7.55 (1H, s, pyrazole-H), 7.53 (1H, d, *J* = 15.9 Hz, -C*H*=CH-), 7.38–7.27 (9H, m, Tr-H), 7.20–7.12 (6H, m, Tr-H), 6.14 (1H, d, *J* = 15.9 Hz, -CH=C*H*-), 3.78 (3H, s, $COOCH_3$); ^{13}C-NMR (75 MHz, $CDCl_3$): δ 167.6, 142.6, 138.8, 135.4, 132.8, 130.0, 128.0, 127.9, 116.9, 115.6, 79.1, 51.5; HRMS *m/z* calcd for $C_{26}H_{22}N_2O_2$ (M^+) 394.1682, found 394.1673.

1-Benzyl-4-(2-methoxycarbonylvinyl)-1*H*-pyrazole (2b): Colorless needles; mp 68 °C; IR (KBr) ν_{max} 1707 (C=O), 1637 (C=C) cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.73 (1H, s, pyrazole-H), 7.54 (1H, d, *J* = 16.0 Hz, -C*H*=CH-), 7.536 (1H, s, pyrazole-H), 7.36–7.32 (2H, m Ph-H), 7.24–7.21 (2H, m, Ph-H), 6.15 (1H, d, *J* = 16.0 Hz, -CH=C*H*-), 5.28 (2H, s, NCH_2Ph), 3.75 (3H, s, -$COOCH_3$); ^{13}C-NMR (75 MHz, $CDCl_3$): δ 167.6, 138.8, 135.6, 135.1, 129.5, 128.9, 128.3, 127.8, 118.6, 115.5, 56.2, 51.4; HRMS *m/z* calcd for $C_{14}H_{14}N_2O_2$ (M^+) 242.1055, found 242.1054.

4-(2-Methoxycarbonylvinyl)-1-tosyl-1*H*-pyrazole (2c): Colorless needles (CH_2Cl_2); mp 159–160 °C; IR (KBr) ν_{max} 1716 (C=O), 1648 (C=C), 1588 (C=C) cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.22 (1H, s, pyrazole-H), 7.91 (2H, d, *J* = 8.2 Hz, Ts-H), 7.87 (1H, s, pyrazole-H), 7.49 (1H, d, *J* = 16.1 Hz, -C*H*=CH-),

7.34 (2H, d, *J* = 8.2 Hz, Ts-H), 6.24 (1H, d, *J* = 16.1 Hz, -CH=C*H*-), 3.76 (3H, s, -$COOCH_3$), 2.42 (3H, s, -PhCH_3); ^{13}C-NMR (75 MHz, $CDCl_3$): δ 166.8, 146.4, 143.3, 133.3, 132.9, 130.4, 130.2, 128.3, 120.6, 119.3, 51.7, 21.7; HRMS *m/z* calcd for $C_{14}H_{14}N_2O_4S$ (M^+) 306.0674, found 306.0670.

4-(2-Methoxycarbonylvinyl)-1-(2,4,6-trimethylbenzoyl)-1*H*-pyrazole (2d): Colorless crystals (CH_2Cl_2); mp 134–136 °C; IR (KBr) ν_{max} 1725 (C=O), 1712 (C=O), 1645 (C=C), 1609 (C=C) cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.50 (1H, br s, pyrazole-H), 7.89 (1H, s, pyrazole-H), 7.58 (1H, d, *J* = 16.1 Hz, -C*H*=CH-), 6.93 (2H, s, Ar-H), 6.33 (1H, d, *J* = 16.1 Hz, -CH=C*H*-), 3.80 (3H, s, $COOCH_3$), 2.33 (3H, s, $ArCH_3$), 2.15 (6H, s, 2x $ArCH_3$); ^{13}C-NMR (75 MHz, $CDCl_3$): δ 166.9, 143.2, 140.2, 134.7, 133.1, 130.4, 128.2, 121.7, 119.6, 116.3, 56.2, 51.7, 21.2, 19.1; HRMS *m/z* calcd for $C_{17}H_{18}N_2O_3$ (M^+) 298.1317, found 298.1307.

4-(2-Methoxycarbonylvinyl)-1*H*-pyrazole (2e): Colorless needles (CH_2Cl_2); mp 92–95 °C; IR (KBr) ν_{max} 1731 (C=O), 1649 (C=C) cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$): δ 9.00 (1H, br s, NH), 7.80 (2H, s, pyrazole-H), 7.62 (1H, d, *J* = 15.9 Hz, -C*H*=CH-), 6.22 (1H, d, *J* = 15.9 Hz, -CH=C*H*-), 3.78 (3H, s, $COOCH_3$); ^{13}C-NMR (75 MHz, $CDCl_3$): δ 167.7, 135.2, 133.7, 117.9, 116.1, 51.6; HRMS *m/z* calcd for $C_7H_8N_2O_2$ (M^+) 152.0586, found 152.0582.

4-(2-*tert*-Butoxycarbonylvinyl)-1-trityl-1*H*-pyrazole (2g): Colorless crystals (CH_2Cl_2); mp 148–152 °C; IR (KBr) ν_{max} 1704 (C=O), 1638 (C=C), 1499 (C=C) cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.88 (1H, s, pyrazole-H), 7.57 (1H, s, pyrazole-H), 7.46 (1H, d, *J* = 15.9 Hz, -C*H*=CH-), 7.37–7.28 (9H, m, Tr-H), 7.22–7.16 (6H, m, Tr-H), 6.13 (1H, d, *J* = 15.9 Hz, -CH=C*H*-), 1.53 (9H, s, -*t*Bu); ^{13}C-NMR (75 MHz, $CDCl_3$): δ 166.4, 142.6, 138.7, 133.9, 132.5, 130.0, 127.8, 127.1, 118.0, 117.0, 80.0, 79.0, 28.1; HRMS *m/z* calcd for $C_{29}H_{28}N_2O_2$ (M^+) 436.2151, found 436.2147.

4-[3-Oxo-(*E*)-1-butenyl]-1-trityl-1*H*-pyrazole [(*E*)-2h]: Colorless needles (CH_2Cl_2); mp 214–216 °C; IR (KBr) ν_{max} 1667 (C=O), 1625 (C=C), 1541 (C=C) cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.89 (1H, s, pyrazole-H), 7.59 (1H, s, pyrazole-H), 7.37 (1H, d, *J* = 16.8 Hz, -C*H*=CH-), 7.34–7.31 (9H, m, Tr-H), 7.25–7.13 (6H, m, Tr-H), 6.43 (1H, d, *J* = 16.8 Hz, -CH=C*H*-), 2.28 (3H, s, CH_3); ^{13}C-NMR (75 MHz, $CDCl_3$): δ 198.1, 142.4, 138.9, 134.1, 133.0, 130.0, 128.0, 127.9, 127.8, 125.6, 79.2, 27.0; HRMS *m/z* calcd for $C_{26}H_{22}N_2O$ (M^+) 378.1732, found 378.1734.

4-(3-Oxo-(*Z*)-1-butenyl)-1-trityl-1*H*-pyrazole ((*Z*)-2h): Colorless crystals (CH_2Cl_2); mp 163–166 °C; IR (KBr) ν_{max} 1676 (C=O), 1580 (C=C), 1541 (C=C) cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.47 (1H, s, pyrazole-H), 8.09 (1H, s, pyrazole-H), 7.40–7.27 (9H, m, Tr-H), 7.25–7.13 (6H, m, Tr-H), 6.55 (1H, d, *J* = 8.2 Hz, -C*H*=CH-), 6.07 (1H, d, *J* = 8.2 Hz, -CH=C*H*-), 2.22 (3H, s, CH_3); ^{13}C-NMR (75 MHz, $CDCl_3$): δ 197.5, 143.4, 142.6, 136.3, 131.9, 130.0, 127.8, 121.4, 116.7, 79.0, 31.3 (lack of a carbon signal probably because of overlap with one of the other aromatic carbon signals); HRMS *m/z* calcd for

$C_{26}H_{22}N_2O$ (M^+) 378.1732, found 378.1724.

4-(2-Morphorylcarbonylvinyl)-1-trityl-1*H*-pyrazole (2i): White powder (CH_2Cl_2); mp 138–141 °C; IR (KBr) ν_{max} 1649 (C=O), 1601 (C=C) cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.87 (1H, s, pyrazole-H), 7.55 (1H, d, *J* = 15.4 Hz, -C*H*=CH-), 7.54 (1H, s, pyrazole-H), 7.34–7.29 (9H, m, Tr-H), 7.18–7.12 (6H, m, Tr-H), 6.56 (1H, d, *J* = 15.4 Hz, -CH=C*H*-), 3.68 (4H,br s), 3.676 (4H, br s); ^{13}C-NMR (75 MHz, $CDCl_3$): δ 165.7, 142.6, 138.3, 133.7, 132.7, 130.0, 127.9, 127.8, 117.6, 114.2, 79.0, 66.8 (lack of a carbon signal probably because of overlap with the carbon signal at 66.8 ppm); HRMS *m/z* calcd for $C_{29}H_{27}N_3O_2$ (M^+) 449.2103, found 449.2100.

1-Trityl-4-vinyl-1*H*-pyrazole (2j): Colorless crystals (CH_2Cl_2); mp 127–130 °C; IR (KBr) ν_{max} 1641 (C=C), 1491 (C=C) cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.77 (1H, s, pyrazole-H), 7.36 (1H, s, pyrazole-H), 7.34–7.30 (9H, m, Tr-H), 7.26–7.12 (6H, m, Tr-H), 6.46 (1H, dd, *J* = 17.7, 11.0 Hz, -C*H*=CHH), 5.43 (1H, d, *J* = 17.7 Hz, -CH=CH_{trans}H), 5.04 (1H, d, *J* = 11.0 Hz, -CH=CHH_{cis}); ^{13}C-NMR (75 MHz, $CDCl_3$): δ 143.0, 137.3, 130.0, 127.9, 127.7, 126.8, 119.6, 111.9, 78.5 (lack of a carbon signal probably because of overlap with one of the other aromatic carbon signals); HRMS *m/z* calcd for $C_{24}H_{20}N_2$ (M^+) 336.1626, found 336.1620.

4-(2-Formylvinyl)-1-trityl-1*H*-pyrazole (2k): Pale yellow powder (CH_2Cl_2); mp 211–213 °C; IR (KBr) ν_{max} 1716 (C=O), 1676 (C=C), 1634 (C=C) cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$): δ 9.52 (1H, d, *J* = 7.9 Hz, -CHO), 7.91 (1H, s, pyrazole-H), 7.64 (1H, s, pyrazole-H), 7.34–7.14 (16H, m, Tr-H, -C*H*=CHCHO), 6.42 (1H, dd, *J* = 15.7, 7.0 Hz, -CH=C*H*CHO); ^{13}C-NMR (75 MHz, $CDCl_3$): δ 193.4 (193.3), 143.4, 142.3, 139.3 (138.9), 133.4 (133.2), 130.0, 129.9, 127.9, 126.8, 116.9, 79.3; HRMS *m/z* calcd for $C_{25}H_{20}N_2O$ (M^+) 364.1576, found 364.1580.

4-{2-(*P*,*P*-Diethoxyphosphonyl)vinyl}-1-trityl-1*H*-pyrazole (2l): Colorless crystals (CH_2Cl_2); mp 97–100 °C; IR (KBr) ν_{max} 1621 (C=C) cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.84 (1H, s, pyrazole-H), 7.52 (1H, s, pyrazole-H), 7.40–7.25 (9H, m, Tr-H), 7.18–7.11 (6H, m, Tr-H), 5.92 (1H, d, *J* = 18.0 Hz, -C*H*=CH-), 5.87 (1H, d, *J* = 18.0 Hz, -CH=C*H*-), 4.10 (2H, q, *J* = 7.1 Hz, -PO(OCH_2CH$_3$)OEt), 4.07 (2H, q, *J* = 7.1 Hz, -PO(OCH_2CH$_3$)OEt), 1.33 (6H, t, *J* = 7.1 Hz, -PO(OCH$_2$CH_3)$_2$); ^{13}C-NMR (75 MHz, $CDCl_3$): δ 142.5, 139.4 (d, $^2J_{C\text{-}P}$ = 6.9 Hz), 138.4, 132.5, 130.0, 127.8, 127.1, 117.8 (d, $^3J_{C\text{-}P}$ = 25.2 Hz), 110.1 (d, $^1J_{C\text{-}P}$ = 194 Hz), 79.1, 61.7 (d, $^2J_{C\text{-}P}$ = 4.6 Hz), 16.3 (d, $^3J_{C\text{-}P}$ = 5.7 Hz); HRMS *m/z* calcd for $C_{28}H_{29}N_2O_3P$ (M^+) 472.1916, found 472.1918.

4-[(*E*)-2-Cyanovinyl]-1-trityl-1*H*-pyrazole ((*E*)-2m): Colorless needles (EtOAc-hexane); mp 233–236 °C; IR (KBr) ν_{max} 2214 (CN), 1629 (C=C), 1597 (C=C) cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$): δ 7.84 (1H, s, pyrazole-H), 7.55 (1H, s, pyrazole-H), 7.38–7.28 (9H, m, Tr-H), 7.21 (1H, d, *J* = 16.6 Hz, -C*H*=CH-), 7.18–7.10 (6H, m, Tr-H), 5.55 (1H, d, *J* = 16.6 Hz, -CH=C*H*-); ^{13}C-NMR (75 MHz, $CDCl_3$): δ

142.3, 141.0, 138.0, 132.6, 130.0, 128.1, 127.9, 118.5, 116.6, 93.5, 79.3; HRMS *m/z* calcd for $C_{25}H_{19}N_3$ (M^+) 361.1579, found 361.1576.

4-[(*Z*)-2-Cyanovinyl]-1-trityl-1*H*-pyrazole [(*Z*)-2m]: colorless crystals (CH_2Cl_2); mp 182–185 °C; IR (KBr) ν_{max} 2211 (CN), 1615 (C=C), 1492 (C=C) cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.14 (1H, s, pyrazole-H), 7.96 (1H, s, pyrazole-H), 7.38–7.28 (9H, m, Tr-H), 7.18–7.10 (6H, m, Tr-H), 6.96 (1H, d, *J* = 11.7 Hz, -C*H*=CH-), 5.15 (1H, d, *J* = 11.7 Hz, -CH=C*H*-); ^{13}C-NMR (75 MHz, $CDCl_3$): δ 142.4, 140.1, 139.5, 133.5, 130.0, 127.9, 127.2, 118.2, 116.2, 91.6, 79.4; HRMS *m/z* calcd for $C_{25}H_{19}N_3$ (M^+) 361.1579, found 361.1570.

4-(2-Phenylvinyl)-1-trityl-1*H*-pyrazole (2n): Colorless crystals (CH_2Cl_2); mp 225–228 °C; IR (KBr) ν_{max} 1643 (C=C), 1490 (C=C) cm^{-1}; ^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.86 (1H, s, pyrazole-H), 7.46 (1H, s, pyrazole-H), 7.39 (2H, br d, *J* = 7.1 Hz, Ph-H), 7.35–7.25 (12H, m, Tr-H, Ph-H), 7.22–7.16 (6H, m, Tr-H), 6.90 (1H, d, *J* = 16.5 Hz, -C*H*=CH-), 6.80 (1H, d, *J* = 16.5 Hz, -CH=C*H*-); ^{13}C-NMR (125 MHz, $CDCl_3$): δ 143.5, 137.6, 130.4, 130.4, 130.1, 128.6, 127.9, 127.8, 127.6, 127.0, 125.8, 119.3, 118.7, 78.7; HRMS *m/z* calcd for $C_{30}H_{24}N_2$ (M^+) 412.1939, found 412.1940.

4-[2-(4-Fluorophenyl)vinyl]-1-trityl-1*H*-pyrazole (2o): Colorless needles (CH_2Cl_2); mp 239–242 °C; IR (KBr) ν_{max} 1641 (C=C), 1507 (C=C) cm^{-1}; ^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.85 (1H, s, pyrazole-H), 7.45 (1H, s, pyrazole-H), 7.38–7.31 (11H, m, Tr-H, Ph-H), 7.22–7.15 (6H, m, Tr-H), 7.01 (1H, d, *J* = 8.7 Hz, Ph-H), 6.97 (1H, d, *J* = 8.6 Hz, Ph-H), 6.83 (1H, d, *J* = 16.6 Hz, -C*H*=CH-), 6.73 (1H, d, *J* = 16.6 Hz, -CH=C*H*-); ^{13}C-NMR (125 MHz, $CDCl_3$): δ 143.0, 137.5, 130.4, 130.1, 130.0, 127.9, 127.8, 127.4, 127.3, 119.2, 115.5 (d, $^2J_{C\text{-}F}$ = 22.0 Hz), 78.7 (lack of a carbon signal probably because of overlap with one of the other aromatic carbon signals); HRMS *m/z* calcd for $C_{30}H_{23}FN_2$ (M^+) 430.1845, found 430.1848.

4-[2-(4-Nitrophenyl)vinyl]-1-trityl-1*H*-pyrazole (2p): Yellow plates (CH_2Cl_2); mp 163–168 °C; IR (KBr) ν_{max} 1637 (C=C), 1593 (C=C), 1509 (NO_2), 1342 (NO_2) cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.09 (2H, d, *J* = 8.8 Hz, -PhNO_2), 7.83 (1H, s, pyrazole-H), 7.46 (1H, s, pyrazole-H), 7.41 (2H, d, *J* = 8.8 Hz, -PhNO_2), 7.28–7.04 (15H, m, Tr-H), 7.01 (1H, d, *J* = 16.6 Hz, -C*H*=CH-), 6.75 (1H, d, *J* = 16.6 Hz, -CH=C*H*-); ^{13}C-NMR (75 MHz, $CDCl_3$): δ 142.8, 137.8, 131.4, 130.1, 129.0, 128.2, 127.9, 127.8, 126.1, 125.3, 124.5, 124.1, 118.6, 79.0; HRMS *m/z* calcd for $C_{30}H_{23}N_3O_2$ (M^+) 457.1790, found 457.1786.

4-[1-(Pyridin-2-yl)vinyl]-1-trityl-1*H*-pyrazole (2q): White powder; mp 165–168 °C; IR (KBr) ν_{max} 1636 (C=C), 1585 (C=C) cm^{-1}; ^{1}H-NMR (300 MHz, $CDCl_3$): δ 8.53 (1H, br d, *J* = 4.6 Hz, pyridinyl-H), 7.91 (1H, s, pyrazole-H), 7.69 (1H, m, pyridinyl-H), 7.55 (1H, s, pyrazole-H), 7.50 (1H, d, *J* = 16.1 Hz, -C*H*=CH-), 7.38–7.10 (17H, m, Tr-H, pyridinyl-H), 6.88 (1H, d, *J* = 16.1 Hz, -CH=C*H*-); ^{13}C-NMR (75 MHz, $CDCl_3$): δ 143.1, 142.8, 142.0, 138.2, 136.2, 134.6, 131.8, 130.2, 130.1, 128.0, 127.75, 121.6, 121.5, 118.6, 78.9; HRMS *m/z* calcd for $C_{29}H_{23}N_3$ (M^+) 413.1982, found 413.1887.

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