Two-step Synthesis of Imidazoles from Activated Alkynes

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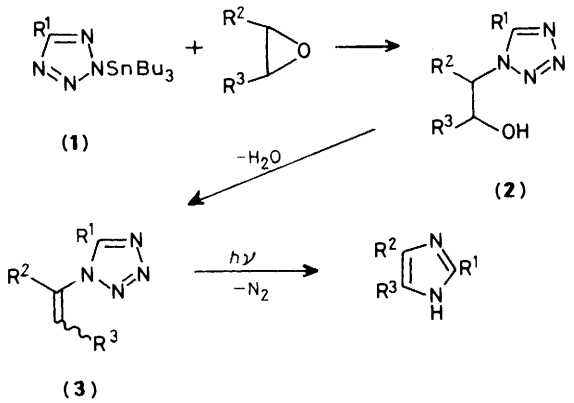
Conjugate addition of 2-(tri-n-butylstannyl) tetrazoles (**1**) to activated alkynes gives 1-alkenyltetrazoles (**4**) and (**5**) predominantly. Use of the *N*-tributylstannyl derivatives, rather than the parent tetrazole, gives a high ratio of 1- to 2-alkenyl isomers and avoids the complication of further addition of the tetrazole or the alkyne to the initial adduct. Irradiation of the (*Z*)- and (*E*)-1-alkenyltetrazoles (**4**) and (**5**) at 254 nm then gives the expected imidazoles in moderate yield. However, 5-phenyl-2-(tri-n-butylstannyl)tetrazole (**1a**) reacted only slowly with ethyl phenylpropiolate to give ethyl 3,5-diphenylpyrazole-4-carboxylate (**8**), presumably *via* the 2-alkenyltetrazole (**9**) formed in preference to the 1-isomer for steric reasons.

We have recently reported a new synthesis of imidazoles in which the key step is the photolysis of 1-alkenyltetrazoles (**3**).[1] The alkenyltetrazoles were prepared from alkenes *via* their epoxides as shown in Scheme 1. However, the route fails at the

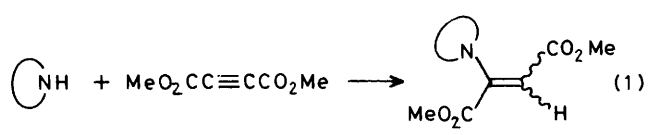


Scheme 1.

dehydration stage for substrates bearing an electron-withdrawing substituent at the β-position of the sidechain [e.g. (**2**; $R^3 = CO_2Et$)] since elimination of the tetrazole then occurs preferentially.[1] This ready elimination of tetrazoles from β-tetrazolyl esters is well known,[2,3] and it frustrated our attempts to prepare alkenyltetrazoles bearing a β-electron-withdrawing substituent from the alcohols (**2**). We have now prepared the required tetrazoles by Michael addition of 2-(tri-n-butylstannyl)tetrazoles to electrophilic alkynes, and we report full details of this work, together with the subsequent conversion of the tetrazoles into imidazoles, and the formation of pyrazoles from 2-alkenyltetrazoles.

Results and Discussion

Conjugate Addition of 2-(Tri-n-butylstannyl)tetrazoles to Activated Alkynes.—The formation of *N*-methoxycarbonylalkenyl heterocyclic compounds by conjugate addition to activated alkynes such as dimethyl acetylenedicarboxylate (DMAD) [equation (1)] is well known,[4] and although tetrazoles have not been reported to react with alkynes they are reported to undergo conjugate addition to α,β-unsaturated esters,[3] ketones,[5] and nitriles.[6] The yields in these reactions were low, and the major products resulted from attack on the tetrazole at N-2. However, it was hoped that the use of 2-(tri-n-butylstannyl)tetrazoles might overcome these difficulties by increasing the yield and by favouring reaction at N-1 much as it had done in the ring opening of epoxides (Scheme 1).[1]



Reaction of 5-phenyl-2-(tri-n-butylstannyl)tetrazole (**1a**) with an excess of methyl propiolate in refluxing benzene, followed by cleavage of the intermediate vinylstannanes with hydrogen chloride, gave the required 1-substituted tetrazoles (**4a**) and (**5a**) in good yield. The regioselectivity was satisfactory, with the 2-substituted products (**6a**) and (**7a**) being the minor isomers. Both *E*- and *Z*-alkenyl tetrazoles were formed, and all four isomers could be separated by column chromatography. The use of a more polar solvent (acetonitrile) was not beneficial.

The tetrazole (**1a**) reacted with DMAD to give the 1-substituted tetrazoles (**4b**)/(**5b**) as an *E*/*Z* mixture in good yield (Table 1). Conjugate addition of (**1a**) to acetylenic ketones proceeded similarly (entries 3 and 4) although methyl tetrolate (methyl but-2-ynoate) gave only a trace of addition products and dibenzoylacetylene gave none. The tetrazole (**1a**) reacted only slowly with ethyl phenylpropiolate, even in refluxing xylene; the product was not the expected tetrazole but the pyrazole (**8**) (39%), the structure of which was confirmed by hydrolysis and decarboxylation to give 3,5-diphenylpyrazole. It is likely that the pyrazole (**8**) is formed by conjugate addition of the tetrazole to give the tetrazol-2-ylacrylate (**9**), this 2-isomer being formed in preference to the 1-isomer for steric reasons. Loss of nitrogen from (**9**), followed by cyclisation of the nitrilimine to give a 4*H*-pyrazole, rapid migration of the stannyl group, and subsequent cleavage by HCl then accounts for the formation of the observed product (**8**) (Scheme 2).

The formation of nitrilimines from thermolysis of 2,5-disubstituted tetrazoles is well known,[7] and intramolecular cyclisation has been observed in 2,5-diaryl derivatives.[8] In support of the above mechanism, thermolysis of the tetrazol-2-ylacrylate (**7a**) in xylene gave methyl 3-phenylpyrazole-4-carboxylate (39%) [equation (2)].

In the case of the 5-unsubstituted tetrazole (**1b**) the yield of the conjugate addition to methyl propiolate was lower and the undesired 2-isomers (**6e**) and (**7e**) predominated (Table 1, entry

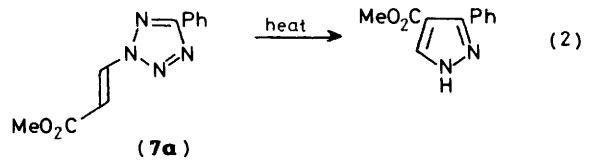
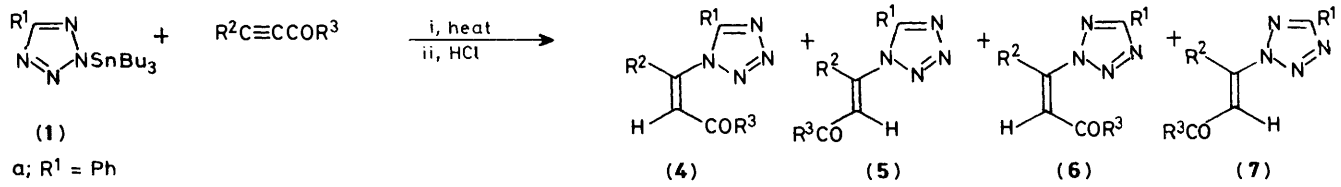


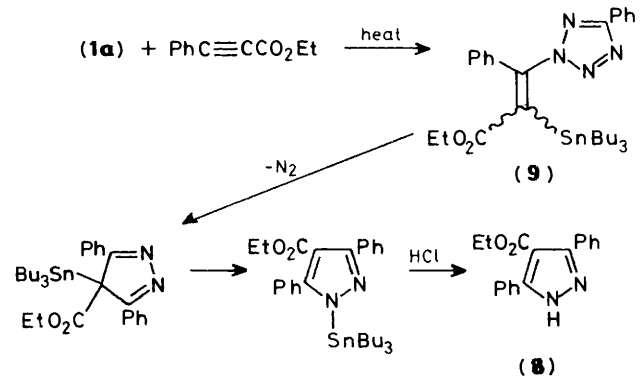
Table 1. Conjugate addition of 2-(tri-n-butylstannyl)tetrazoles to activated alkynes



(1)

a; R^1 = Ph
b; R^1 = H
c; R^1 = Me
d; R^1 = CO_2Me

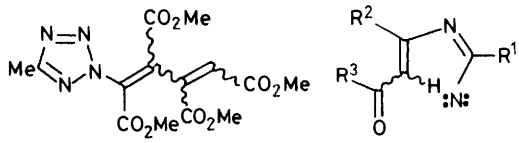
Entry	Compound (4)—(7)	R^1	R^2	R^3	% Yield	% Yield	% Yield	% Yield
1	**a**	Ph	H	OMe	35	35	12	14
2	**b**	Ph	CO_2Me	OMe	79		12	8
3	**c**	Ph	H	Me	20	35	9	2
4	**d**	Ph	H	Pr	0	63	0	17
5		Ph	Ph	OEt	see text			
6	**e**	H	H	OMe	17	0	21	20
7	**g**	Me	H	OMe	16	30	11	11
8	**h**	CO_2Me	H	OMe	20	20	9	19
9	**i**	CO_2Me	CO_2Me	OMe	8	4	1	0
10	**j**	CO_2Me	H	Pr	0	25	0	9



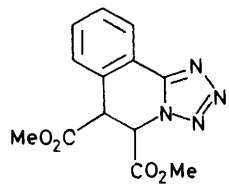
Scheme 2.

6). The 5-methyltetrazole (**1c**) added readily to methyl propiolate (entry 7), although again attempted addition to methyl phenylpropiolate and to dibenzoylacetylene was unsatisfactory. The use of the 5-methoxycarbonyltetrazole (**1d**) offered some advantages over the 5-unsubstituted derivative (**1b**), in that conjugate addition to methyl propiolate proceeded in higher yield (entry 8); this is attractive since selective removal, in high yield, of the 2-ethoxycarbonyl group of an imidazole 2,4-diester has recently been reported.[9] However, other conjugate additions of the tetrazole (**1d**) were less satisfactory (entries 9 and 10).

In summary, the conjugate addition of tributylstannyltetrazoles to activated alkynes provides a one-step synthesis of alkenyl tetrazoles bearing electron-withdrawing groups. Although the reaction does not work well in every case, the yields of the required 1-alkenyltetrazoles can be in the range 40—80%. The use of *N*-tributylstannyl heterocycles in conjugated addition reactions appears to be new, and probably merits further attention in that it offers some advantages over the use of the corresponding *N*–H compounds, as follows. The *N*-stannyl derivatives are more reactive and, because the intermediate vinylstannanes are stable, addition of a second molecule of heterocycle does not occur. Addition to a second molecule of the Michael acceptor is equally precluded; in contrast, the reaction of 5-methyltetrazole with DMAD in refluxing benzene in the presence of a catalytic amount of triethylamine gave the 1:2-adduct (**10**) as the major product (71%).



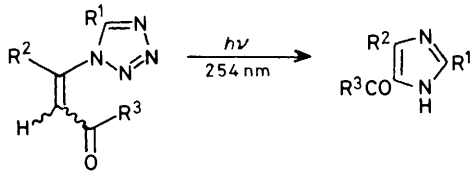
(10) (11)



(12)

Photolysis of 1-Alkenyltetrazoles.—Irradiation of the 1-alkenyltetrazoles at 254 nm gave the expected imidazoles in moderate yield (Table 2), presumably *via* cyclisation of the intermediate *N*-vinylimidoylnitrene (**11**). When a pure geometric isomer of the 1-alkenyltetrazole was irradiated, *E*/*Z* isomerism of the double bond occurred during the photolysis. The yield of the 2-unsubstituted imidazole was low, in accord with our previous findings on the decomposition of 1-alkenyl-5-unsubstituted tetrazoles.[1] Photocyclisation involving the 1-alkenyl and 5-phenyl groups is a possible side-reaction,[1] but this was not observed here except with the tetrazoles (**4b**)/(**5b**) which gave a small amount of the photocyclised product (**12**).

Table 2. Photolysis of 1-alkenyltetrazoles to give imidazoles



Starting tetrazole	R^1	R^2	R^3	Solvent	% Yield
(4a)	Ph	H	OMe	Petroleum[a]	61
(5a)	Ph	H	OMe	Petroleum	52
(4b)/(5b)[b]	Ph	CO_2Me	OMe	Petroleum	24
(4c)/(5c)[b]	Ph	H	Me	CH_2Cl_2	40[c]
(5d)	Ph	H	Pr	Cyclohexane	57
(4e)	H	H	OMe	EtOH	10[d]
(5g)	Me	H	OMe	MeOH	63[e]
(5h)	CO_2Me	H	OMe	MeOH	63

[a] Light petroleum, b.p. 60—80 °C. [b] An *E*/*Z* mixture was photolysed. [c] At 84% conversion. [d] N.m.r. yield. [e] At 92% conversion.

Conclusions

This route to imidazoles complements that previously described (Scheme 1)[1] in that it involves similar 1-alkenyltetrazoles, but leads to imidazoles bearing a carbonyl substituent at C-4(5). Although the yields, which have not been optimised, are not good in every case, the route is short, the imidazoles being prepared in two steps from readily available alkynes.

Experimental

For general points see ref. 1. ^{13}C N.m.r. spectra were recorded for $CDCl_3$ solutions on a Bruker WM 250 spectrometer.

Conjugate Addition of 2-(Tri-n-butystannyl)tetrazoles to Activated Alkynes.—General procedure. A mixture of the tetrazole (**1**) (1.0 equiv.) and the alkyne (1.5 equiv.) in dry benzene (2 ml per mmol) was heated under reflux under nitrogen until t.l.c. indicated no further change. The solvent was evaporated off and the resulting oil was treated with a saturated solution of hydrogen chloride in ether. After 3 h the solvent was removed, and the residue was chromatographed on silica gel with petroleum containing an increasing proportion of ether as eluant.

Reaction of tetrazole (**1a**) *with methyl propiolate.* A mixture of the tetrazole (**1a**) (3.04 g, 7.15 mmol) and methyl propiolate (0.95 ml, 10.7 mmol) was refluxed in benzene (10 ml) for 30 h. Work-up and chromatography gave (i) *methyl* (E)-3-(5-*phenyltetrazol-2-yl)propenoate* (**7a**) (222 mg, 14%), m.p. 144.5—145.5 °C (Found: C, 57.1; H, 4.3; N, 24.2. $C_{11}H_{10}N_4O_2$ requires C, 57.4; H, 4.4; N, 24.3%); $\nu_{max.}$ 1 712 and 1 644 cm^{-1}; δ (90 MHz; $CDCl_3$) 3.88 (3 H, s), 6.94 (1 H, d, *J* 14 Hz), 7.44—7.64 (3 H, m), 8.08—8.30 (2 H, m), and 8.40 (1 H, d, *J* 14 Hz); *m*/*z* 202 ($M^+ - 28$), 171, and 104; (ii) *methyl* (Z)-3-(5-*phenyltetrazol-2-yl)propenoate* (**6a**) (195 mg, 12%), m.p. 73—75 °C (Found: C, 57.4; H, 4.3; N. 24.3%); $\nu_{max.}$ 1 727 and 1 668 cm^{-1}; δ (90 MHz; $CDCl_3$) 3.88 (3 H, s), 6.12 (1 H, d, *J* 12 Hz), 7.42—7.65 (4 H, m), and 8.07—8.30 (2 H, m); *m*/*z* 230 (M^+), 202, 171, 104, and 103; (iii) *methyl* (E)-3-(5-*phenyltetrazol*-1-*yl)propenoate* (**5a**) (577 mg, 35%), m.p. 94.5—96 °C (Found: C, 57.2; H, 4.3; N, 24.2%); $\nu_{max.}$ 1 706 and 1 661 cm^{-1}; $\lambda_{max.}$(EtOH) 218 (log ε 4.13) and 253 nm (4.22); δ (90 MHz; $CDCl_3$) 3.87 (3 H, s), 7.01 (1 H, d, *J* 13 Hz), 7.55—7.85 (5 H, m), and 7.99 (1 H, d, *J* 13 Hz); *m*/*z* 230 (M^+), 201, 171 (base), 144, 133, 104, 103, and 77; and (iv) *methyl* (Z)-3-(5-*phenyltetrazol*-1-*yl)propenoate* (**4a**) (593 mg, 36%) as an oil (Found: M^+, 230.0807. $C_{11}H_{10}N_4O_2$ requires *M*, 230.0804); $\nu_{max.}$ 1 725 and 1 662 cm^{-1}; $\lambda_{max.}$(EtOH) 223 (log ε 4.15) and 239 nm (4.16); δ (90 MHz; $CDCl_3$) 3.66 (3 H, s), 6.32 (1 H, *J* 9 Hz), 7.27 (1 H, d, *J* 9 Hz), and 7.40—8.0 (5 H, m); *m*/*z* 230 (M^+), 201, 171, 144, 104, 103, and 77 (base).

Reaction of tetrazole (**1a**) *with dimethyl acetylenedicarboxylate.* A mixture of the tetrazole (**1a**) (4.25 g, 10 mmol) and DMAD (1.85 g, 13 mmol) in benzene (30 ml) was heated under reflux for 38 h. Work-up and chromatography gave (i) *dimethyl* (Z)-2-(5-*phenyltetrazol-2-yl)butenedioate* (**6b**) (281 mg, 12%), m.p. 92—94 °C (Found: C, 54.5; H, 4.2; N, 19.6. $C_{13}H_{12}N_4O_4$ requires C, 54.2; H, 4.2; N, 19.4%); $\nu_{max.}$ 1 749, 1 717, and 1 650 cm^{-1}; δ (90 MHz; $CDCl_3$) 3.88 (3 H, s), 4.12 (3 H, s), 7.04 (1 H, s), 7.45—7.63 (3 H, m), and 8.1—8.35 (2 H, m); *m*/*z* 288 (M^+), 260 (base), 229, 197, 172, 129, 118, 103, and 82; (ii) dimethyl (*E*)-2-(5-phenyltetrazol-2-yl)butenedioate (**7b**) (193 mg, 8%); δ (90 MHz; $CDCl_3$) 3.67 (3 H, s), 3.92 (3 H, s), 7.36 (1 H, s), 7.4—7.64 (3 H, m), and 8.1—8.35 (2 H, m) which could not be completely purified; and (iii) *dimethyl* (E/Z)-2-(5-*phenyltetrazol*-1-*yl)butenedioate* (**4b**)/(**5b**) (1.919 g, 79%) (Found: M^+, 288.0850. $C_{13}H_{12}N_4O_4$ requires *M*, 288.0859); $\nu_{max.}$ 1 736 and 1 655 cm^{-1}; $\lambda_{max.}$(EtOH) 231 nm; δ (90 MHz; $CDCl_3$) for *Z*-isomer 3.57 (3 H, s), 3.91 (3 H, s), 6.92 (1 H, s), and 7.45—7.85 (5 H, m); and for *E*-isomer 3.66 (3 H, s), 3.78 (3 H, s), 7.37 (1 H, s), and 7.45—7.85 (5 H, m); *m*/*z* 288 (M^+), 260, 259, 229, 202, 201, 145, 134 (base), 133, 104, and 103.

Reaction of Tetrazole (**1a**) *with but-3-yn-2-one.* A mixture of the tetrazole (**1a**) (2.08 g, 4.9 mmol) and but-3-yn-2-one (0.50 g, 7.3 mmol) in benzene (15 ml) was stirred at 25 °C for 65 h and heated under reflux for 3 h. Work-up and chromatography gave (i) (E)-4-(5-*phenyltetrazol-2-yl)but-3-en-2-one* (**7c**) (15 mg, 2%), m.p. 109—110 °C (Found: C, 62.0; H, 4.7; N, 26.1. $C_{11}H_{10}N_4O$ requires C, 61.7; H, 4.7; N, 26.2%); $\nu_{max.}$ 3 070, 1 665, 1 650, 1 640, 1 250, 1 210, 980, and 730 cm^{-1}; δ (250 MHz; $CDCl_3$) 2.48 (3 H, s), 7.21 (1 H, d, *J* 14.5 Hz), 7.53 (3 H, m), 8.21 (2 H, m) and 8.29 (1 H, d, *J* 14.5 Hz); *m*/*z* 214 (M^+), 186, 171,158, 144, 116, 104, 83, 68 and 43 (base); (ii) (Z)-4-(5-*phenyltetrazol-2-yl)but-3-en-2-one* (**6c**) (92 mg, 9%) oil, $\nu_{max.}$ 1 710 and 1 645 cm^{-1}; δ (90 MHz; $CDCl_3$) 2.47 (3 H, s), 6.03 (1 H, d, *J* 10 Hz), 7.33 (1 H, d, *J* 10 Hz), 7.30—7.45 (3 H, m), and 7.95—8.08 (2 H, m); *m*/*z* 186 ($M^+ -$ 28), 179, 171, 164, 147, 122, 112, 104, 83, 77, 68, and 43 (base); (iii) (E)-4-(5-*phenyltetrazol*-1-*yl)but-3-en-2-one* (**5c**) (366 mg, 35%), m.p. 100—102 °C (Found: C, 61.6; H, 4.7; N, 26.1%); $\nu_{max.}$ 1 700, 1 625, and 1 605 cm^{-1}; $\lambda_{max.}$(MeOH) 257 nm; δ (60 MHz; $CDCl_3$) 2.39 (3 H, s), 7.12 (1 H, d, *J* 14 Hz), 7.62 (5 H, m), and 7.83 (1 H, d, *J* 14 Hz); *m*/*z* 214 (M^+), 204, 189, 172, 171 (base), 104, 77, 68, 51,

and 43; and (iv) (*Z*)-4-(5-phenyltetrazol-1-yl)but-3-en-2-one (**4c**) (212 mg, 20%), oil, $\nu_{max.}$ 1 710, and 1 630 cm^{-1}; δ (60 MHz; $CDCl_3$) 2.19 (3 H, s), 6.43 (1 H, d, *J* 9 Hz), 7.11 (1 H, d, *J* 9 Hz), and 7.39—7.89 (5 H, m); *m/z* 214 (M^+), 212, 186, 185, 172, 171 (base), 144, 105, 104, 103, 83, 77, and 43.

Reaction of Tetrazole (**1a**) *with hex-1-yn-3-one.* A mixture of the tetrazole (**1a**) (1.52 g, 3.6 mmol) and hex-1-yn-3-one (0.515 g, 5.4 mmol) in benzene (10 ml) was heated under reflux for 15 h. Chromatography gave (i) (E)-1-(5-*phenyltetrazol*-2-*yl*)*hex*-1-*en*-3-*one* (**7d**) (148 mg, 17%), m.p. 84—85 °C (Found: C, 64.5; H, 5.9; N, 23.2. $C_{13}H_{14}N_4O$ requires C, 64.45; H, 5.8; N, 23.1%); $\nu_{max.}$ 1 660 and 1 630 cm^{-1}; δ (90 MHz; $CDCl_3$) 1.00 (3 H, t, *J* 7 Hz), 1.76 (2 H, m), 2.69 (2 H, t, *J* 7 Hz), 7.18 (1 H, d, *J* 15.5 Hz), 7.48 (3 H, m), 8.14 (2 H, m), and 8.24 (1 H, d, *J* 15.5 Hz); *m/z* 242 (M^+), 214, 186, 171, 144 (base), 104, 77, and 68; and (ii) (E)-1-(5-*phenyltetrazol*-1-*yl*)*hex*-1-*en*-3-*one* (**5d**) (552 mg, 63%), m.p. 98—99 °C (Found: C, 64.2; H, 5.7; N, 23.1%); $\nu_{max.}$ 1 700, 1 625, and 1 605 cm^{-1}; $\lambda_{max.}$(MeOH) 257 nm (log ε 4.16); δ (250 MHz; $CDCl_3$) 0.93 (3 H, t, *J* 7 Hz), 1.70 (2 H, m), 2.63 (2 H, t, *J* 7 Hz), 7.24 (1 H, d, *J* 13.5 Hz), 7.59 (5 H, m) and 7.81 (1 H, d, *J* 13.5 Hz); *m/z* 242 (M^+), 214, 199, 185, 171 (base), 144, 119, 118, 116, 103, and 77.

Reaction of tetrazole (**1b**) *with methyl propiolate.* A solution of the tetrazole (**1b**) (2.56 g, 7.14 mmol) and methyl propiolate (0.95 ml, 10.71 mmol) was heated under reflux in benzene (10 ml) for 23 h. Work-up and chromatography gave (i) *methyl* (E)-3-(*tetrazol*-2-*yl*)*propenoate* (**7e**) (223 mg, 20%), m.p. 111.5—112.5 °C (Found: C, 39.0; H, 3.9; N, 36.4. $C_5H_6N_4O_2$ requires C, 39.0; H, 3.9; N, 36.35%); $\nu_{max.}$ 1 720 and 1 666 cm^{-1}; δ (90 MHz; $CDCl_3$) 3.81 (3 H, s), 6.89 (1 H, d, *J* 14 Hz), 8.36 (1 H, d, *J* 14 Hz), and 8.60 (1 H, s); *m/z* 154 (M^+) 125, 99, 95, and 68 (base); (ii) *methyl* (Z)-3-(*tetrazol*-2-*yl*)*propenoate* (**6e**) (227 mg, 21%), m.p. 45—46 °C (Found: C, 38.95; H, 3.9; N, 36.4%); $\nu_{max.}$ 1 727 and 1 672 cm^{-1}; δ (90 MHz; $CDCl_3$) 3.87 (3 H, s), 6.24 (1 H, d, *J* 10 Hz), 7.63 (1 H, d, *J* 10 Hz), and 8.67 (1 H, s); *m/z* 155 (M^+ + 1), 126, 123, 99, 95, and 68 (base); and (iii) *methyl* (Z)-3-(*tetrazol*-1-*yl*)*propenoate* (**4e**) (184 mg, 17%), m.p. 35—37 °C (Found: C, 39.1; H, 3.9; N, 35.9%); $\lambda_{max.}$ (EtOH) 237 nm (log ε 3.95); δ (90 MHz; $CDCl_3$) 3.88 (3 H, s), 6.16 (1 H, d, *J* 11 Hz), 7.75 (1 H, d, *J* 11 Hz), and 10.12 (1 H, s); *m/z* 155 (M^+ + 1), 123, 95 (base), 94, 68, 67, 59, 53, and 40.

Reaction of tetrazole (**1c**) *with methyl propiolate.* A mixture of the tetrazole (**1c**) (5.60 g, 15.0 mmol) and methyl propiolate (1.89 g, 22.5 mmol) in benzene (50 ml) was heated under reflux for 22 h. Work-up and chromatography gave (i) *methyl* (E)-3-(5-*methyltetrazol*-2-*yl*)*propenoate* (**7g**) (280 mg, 11%), m.p. 83—84 °C (Found: C, 42.8; H, 4.5; N, 33.5. $C_6H_8N_4O_2$ requires C, 42.9; H, 4.8; N, 33.3%) $\nu_{max.}$ 1 720 and 1 660 cm^{-1}; $\lambda_{max.}$(EtOH) 261 nm (log ε 4.22); δ (90 MHz; $CDCl_3$) 2.57 (3 H, s), 3.80 (3 H, s), 6.74 (1 H, d, *J* 14 Hz), and 8.21 (1 H, d, *J* 14 Hz); δ_C 10.8, 52.1, 113.0, 135.1, 164.0, and 165.0 p.p.m.; *m/z* 140 (M^+ − 28), 109, 99, 82, 71, 68, 59, 44, 42 (base), and 40; (ii) *methyl* (Z)-3-(5-*methyltetrazol*-2-*yl*)*propenoate* (**6g**) (270 mg, 11%), oil (Found; C, 42.9; H, 4.9; N, 33.3%); $\nu_{max.}$ 1 735 and 1 670 cm^{-1}; δ (90 MHz; $CDCl_3$) 2.53 (3 H, s), 3.76 (3 H, s), 5.98 (1 H, d, *J* 10 Hz), and 7.36 (1 H, d, *J* 10 Hz); *m/z* 169 (M^+ + H), 140, 109, 99, 71, 68, 59, and 42 (base); (iii) *methyl* (E)-3-(5-*methyltetrazol*-1-*yl*)*propenoate* (**5g**) (747 mg, 30%), m.p. 61 °C (Found: C, 43.0; H, 4.7; N, 33.1%); $\nu_{max.}$ 1 715 and 1 665 cm^{-1}; δ (60 MHz; $CDCl_3$) 2.70 (3 H, s), 3.82 (3 H, s), 6.76 (1 H, d, *J* 14 Hz), and 7.93 (1 H, d, *J* 14 Hz); *m/z* 168 (M^+), 139, 137, 125, 109 (base), 99, 82, 81, 68, 59, 54, 42, and 40; and (iv) *methyl* (Z)-3-(5-*methyltetrazol*-1-*yl*)*propenoate* (**4g**) (393 mg, 16%), oil (Found: C, 43.2; H, 5.2; N, 33.4%); $\nu_{max.}$ 1 730 and 1 670 cm^{-1}; δ (90 MHz; $CDCl_3$) 2.54 (3 H, s), 3.78 (3 H, s), 5.96 (1 H, d, *J* 10 Hz), and 7.33 (1 H, d, *J* 10 Hz); *m/z* 169 (M^+ + 1), 137, 125, 109 (base), 99, 82, 68, 55, and 42.

Reaction of tetrazole (**1d**) *with methyl propiolate.* A mixture of the tetrazole (**1d**) (4.17 g, 10 mmol) and methyl propiolate (1.26 g, 15 mmol) in benzene (20 ml) was heated under reflux for 25 h. Work-up and chromatography gave (i) *methyl* (E)-3-(5-*methoxycarbonyltetrazol*-2-*yl*)*propenoate* (**7h**) (400 mg, 19%), m.p. 129—131 °C (Found: C, 39.5; H, 3.7; N,26.5. $C_7H_8N_4O_4$ requires C, 39.6; H, 3.8; N, 26.4%); $\nu_{max.}$ 1 745, 1 715, and 1 660 cm^{-1}; δ (60 MHz; $CDCl_3$) 3.83 (3 H, s), 4.04 (3 H, s), 7.07 (1 H, d, *J* 14 Hz), and 8.40 (1 H, d, *J* 14 Hz); *m/z* 212 (M^+), 154, 128, 100, 57 (base), and 41; (ii) methyl (*Z*)-3-(5-methoxycarbonyltetrazol-2-yl)propenoate (**6h**) (188 mg, 9%); δ (60 MHz: $CDCl_3$) 3.83 (3 H, s), 4.08 (3 H, s), 6.32 (1 H, d, *J* 9 Hz), and 7.58 (1 H, d, *J* 9 Hz); (iii) *methyl* (E)-3-(5-*methoxycarbonyltetrazol*-1-*yl*)*propenoate* (**5h**) (418 mg, 20%), m.p. 99—102 °C (Found: C, 39.9; H, 3.8; N, 26.0%); $\nu_{max.}$ 1 740 and 1 655 cm^{-1}; δ (60 MHz; $CDCl_3$) 3.88 (3 H, s), 4.14 (3 H, s), 7.00 (1 H, d, *J* 13 Hz), and 8.68 (1 H, d, *J* 13 Hz); *m/z* 213 (M^+ + 1), 210, 184, 181, 157, 153, 142, 125, 114, 109, 95, 81, 69, and 59 (base); and (iv) *methyl* (Z)-3-(5-*methoxycarbonyltetrazol*-1-*yl*)*propenoate* (**4h**) (431 mg, 20%), oil (Found: C, 39.7; H, 4.0; N, 26.6%); $\nu_{max.}$ 1 740br and 1 670 cm^{-1}; δ (60 MHz; $CDCl_3$) 3.72 (3 H, s), 4.10 (3 H, s), 6.33 (1 H, d, *J* 9 Hz), and 7.60 (1 H, d, *J* 9 Hz); *m/z* 213 (M^+ + 1), 181, 157, 153, 139, 125, 109, 100, 95, 81, 68, and 59 (base).

Reaction of tetrazole (**1d**) *with dimethyl acetylenedicarboxylate.* A mixture of the tetrazole (**1d**) (4.17 g, 10 mmol) and DMAD (2.13 g, 15 mmol) in benzene (20 ml) was heated under reflux for 25 h. Work-up and chromatography gave (i) dimethyl (*Z*)-2-(5-methoxycarbonyltetrazol-2-yl)butenedioate (**6i**) (22 mg, 1%), oil, $\nu_{max.}$ 1 730br and 1 640 cm^{-1}; δ (60 MHz; $CDCl_3$) 3.78 (3 H, s), 3.87 (3 H, s), 3.96 (3 H, s), and 6.20 (1 H, s); (ii) dimethyl (*E*)-2-(5-methoxycarbonyltetrazol-1-yl)butenedioate (**5i**) (115 mg, 4%), oil, $\nu_{max.}$ 1 750, 1 720, and 1 630 cm^{-1}; δ (250 MHz; $CDCl_3$) 3.71 (3 H, s), 3.75 (3 H, s), 3.90 (3 H, s), and 5.21 (1 H, s); and (iii) dimethyl (*Z*)-2-(5-methoxycarbonyltetrazol-1-yl)butenedioate (**4i**) (206 mg, 8%), oil, $\nu_{max.}$ 1 750br and 1 655 cm^{-1}; δ (250 MHz; $CDCl_3$) 3.90 (3 H, s), 4.09 (3 H, s), 4.11 (3 H, s), and 7.13 (1 H, s).

Reaction of tetrazole (**1d**) *with hex-1-yn-3-one.* A mixture of the tetrazole (**1d**) (2.95 g, 7.06 mmol) and hex-1-yn-3-one (1.02 g, 10.6 mmol) in benzene (25 ml) was stirred at 25 °C for 45 h and then heated under reflux for 3.5 h. Work-up and chromatography gave (i) (E)-1-(5-*methoxycarbonyltetrazol*-2-*yl*)*hex*-1-*en*-3-*one* (**7j**) (139 mg, 9%), m.p. 43—45 °C (Found: C, 47.8; H, 5.6; N, 25.0. $C_9H_{12}N_4O_3$ requires C, 48.2; H, 5.4; N, 25.0%); $\nu_{max.}$ 1 750, 1 660, and 1 640 cm^{-1}; δ (60 MHz; $CDCl_3$) 1.00 (3 H, t, *J* 7 Hz), 1.70 (2 H, m), 2.75 (2 H, t, *J* 7 Hz), 4.12 (3 H, s), 7.36 (1 H, d, *J* 14 Hz), and 8.34 (1 H, d, *J* 14 Hz); and (ii) (*E*)-1-(5-*methoxycarbonyltetrazol*-1-*yl*)*hex*-1-*en*-3-*one* (**5j**) (392 mg, 25%), m.p. 36—38 °C [Found: (M^+ − N_2), 196.0845. $C_9H_{12}N_2O_3$ requires *m/z*, 196.0847]; $\nu_{max.}$ 1 740, 1 700, and 1 625 cm^{-1}; δ (60 MHz; $CDCl_3$) 0.99 (3 H, t, *J* 7 Hz), 1.73 (2 H, m), 2.73 (2 H, t, *J* 7 Hz), 4.18 (3 H, s), 7.24 (1 H, d, *J* 14 Hz), and 8.56 (1 H, d, *J* 14 Hz); *m/z* 196 (M^+ − 28), 165, 137, 109, 96, 81, 71, 59 (base), and 43.

Reaction of tetrazole (**1a**) *with ethyl phenylpropiolate.* A solution of the tetrazole (**1a**) (5.10 g, 12 mmol) and ethyl phenylpropiolate (3.14 g, 18 mmol) in xylene (15 ml) was heated under reflux under nitrogen for 3 days. Work-up and chromatography gave ethyl 3,5-diphenylpyrazole-4-carboxylate (**8**) (1.35 g, 39%), m.p. 139—141 °C (lit.,[10] 141—142 °C).

Hydrolysis and Decomposition of Pyrazole (**8**).—A solution of the pyrazole (**8**) (150 mg) in sulphuric acid (80%; 0.5 ml) was heated at 110 °C for 6 h. Having cooled, it was diluted with water (10 ml) and extracted with chloroform. The combined extracts were dried ($MgSO_4$) and evaporated to give 3,5-diphenylpyrazole (100 mg, 90%), m.p. 198—202 °C (lit.,[10] 199—200 °C).

Thermolysis of Methyl (E)-3-(5-*Phenyltetrazol*-2-*yl*)*propenoate* (**7a**).—A solution of the tetrazole (**7a**) (56 mg) in xylene (1 ml)

was heated under reflux for 1.5 h. The solvent was evaporated off and the residue was chromatographed to give methyl 3-phenylpyrazole-4-carboxylate (19.4 mg, 39%), m.p. 113—115 °C (lit.,[11] 111.5—112.5 °C).

Reaction of 5-Methyltetrazole with Dimethyl Acetylenedicarboxylate.—Triethylamine (2 drops) was added to a mixture of 5-methyltetrazole (168 mg, 2.0 mmol) and DMAD (312 mg, 2.2 mmol) in benzene (10 ml) which was then stirred at 25 °C for 70 h and heated under reflux for 2 h. Chromatography gave the 1:2 *adduct* (**10**) (289 mg, 71%) m.p. 114—118 °C (Found: C, 45.8; H, 4.3; N, 15.45. $C_{14}H_{16}N_4O_8$ requires C, 45.7; H, 4.4; N, 15.2%); $\nu_{max.}$ 3 015, 2 960, 1 750—1 710, 1 660, 1 520, 1 435, 1 290—1 220, 1 020, and 780 cm^{-1}; δ (250 MHz; $CDCl_3$) 2.59 (3 H, s), 3.60 (3 H, s), 3.74 (3 H, s), 3.79 (3 H, s), 3.91 (3 H, s), and 7.07 (1 H, s).

Photolysis of 1-Alkenyltetrazoles.—General procedure. A solution of the tetrazole in the solvent specified was irradiated at 254 nm in a quartz vessel under a stream of nitrogen. The irradiation was continued until no tetrazole remained (t.l.c.), and the products were isolated by chromatography.

Methyl (Z)-3-(5-*phenyltetrazol*-1-*yl*)*propenoate* (**4a**). A solution of the tetrazole (**4a**) (98.5 mg) in petroleum (150 ml) was irradiated for 20 h. Chromatography gave methyl 2-phenylimidazole-5-carboxylate (52.5 mg, 61%), m.p. 218—220 °C (lit.,[12] 219—221 °C).

Methyl (E)-3-(5-*phenyltetrazol*-1-*yl*)*propenoate* (**5a**). A solution of the tetrazole (**5a**) (172 mg) in petroleum (100 ml) was irradiated for 36 h. Chromatography gave methyl 2-phenylimidazole-5-carboxylate (79 mg, 52%), m.p. 218—220 °C.

Dimethyl (E/Z)-2-(5-*phenyltetrazol*-1-*yl*)*butenedioate* (**4b**)/(**5b**). A solution of the *E*/*Z* mixture of tetrazoles (**4b**)/(**5b**) (193.5 mg) in petroleum (600 ml) was irradiated for 7 h. Chromatography gave (i) *dimethyl* 5,6-*dihydrotetrazolo*[5,1-a]*isoquinoline*-5,6-*dicarboxylate* (**12**) (10 mg, 5%), m.p. 168—170 °C (from chloroform–petroleum) (Found: C, 53.95; H, 4.1; N, 19.3. $C_{13}H_{12}N_4O_4$ requires C, 54.2; H, 4.2; 19.4%); $\nu_{max.}$ 1 736 and 1 616 cm^{-1}; δ (250 MHz; $CDCl_3$) 3.66 (3 H, s), 3.68 (3 H, s), 4.67 (1 H, d, *J* 1 Hz), 6.19 (1 H, d, *J* 1 Hz), 7.55—7.60 (3 H, m), and 8.18—8.26 (2 H, m); *m*/*z* 288 (M^+), 229 (base), 173, 169, 142, 128, 115, and 59; and (ii) dimethyl 2-phenylimidazole-4,5-dicarboxylate (42 mg, 24%), m.p. 157—160 °C (lit.,[13] 157 °C).

(E/Z)-4-(5-*Phenyltetrazol*-1-*yl*)*but*-3-*en*-2-*one* (**4c**)/(**5c**). A solution of the *E*/*Z* mixture of tetrazoles (**4c**)/(**5c**) (76 mg) in methylene dichloride (80 ml) was irradiated for 12 h. Chromatography gave (i) the *E*/*Z* mixture of starting material (12 mg, 16%) and (ii) 5-acetyl-2-phenylimidazole (22.5 mg, 34%) (lit.,[14] 156.5—157.5 °C), m.p. 153—156 °C (Found: C, 70.9; H, 5.4; N, 15.3. Calc. for $C_{11}H_{10}N_2O$: C, 70.95; H, 5.4; N, 15.0%); $\nu_{max.}$ 1 660 and 1 530 cm^{-1}; δ (90 MHz; $CDCl_3$) 2.53 (3 H, s), 7.31—7.49 (3 H, m), 7.78 (1 H, s), and 7.90—8.05 (2 H, m); *m*/*z* 187, 186 (M^+), 171 (base), 143, 116, 104, 89, 77, 63, 51, and 43.

(E)-1-(5-*Phenyltetrazol*-1-*yl*)*hex*-1-*en*-3-*one* (**5d**). A solution of the tetrazole (**5d**) (30 mg) in cyclohexane (50 ml) was irradiated for 2.5 h. Chromatography gave 1-(2-*phenylimidazol*-4-*yl*)*butan*-1-*one* (15.2 mg, 57%), m.p. 212—214 °C (Found: C, 73.05; H, 6.6; N, 12.8. $C_{13}H_{14}N_2O$ requires C, 73.0; H, 6.6; 13.0%); $\nu_{max.}$ 3 450, 3 280, 3 070, 2 970, 1 640, 1 515, 1 460, 1 400, and 690 cm^{-1}; δ (250 MHz; $CDCl_3$) 1.01 (3 H, t, *J* 7 Hz), 1.81 (2 H, m), 2.83 (2 H, t, *J* 7 Hz), 7.46 (3 H, m), 7.82 (1 H, s), 7.98 (2 H, m), and 10.70 (1 H, br s); *m*/*z* 214 (M^+), 186, 171 (base), 144, 126, 104, 89, and 77.

Methyl (Z)-3-(*tetrazol*-1-*yl*)*propenoate* (**4e**). A solution of the tetrazole (**4e**) (54 mg) in ethanol (25 ml) was irradiated for 2.5 h. The solvent was evaporated off and the residue was examined by n.m.r. spectroscopy. It contained methyl imidazole-5-carboxylate (*ca.* 10%).

Methyl (E)-3-(5-*methyltetrazol*-1-*yl*)*propenoate* (**5g**). A solution of the tetrazole (**5g**) (89.2 mg) in methanol (100 ml) was irradiated for 40 min. Chromatography gave (i) starting material (7.0 mg, 8%); and (ii) *methyl* 2-*methylimidazole*-5-*carboxylate* (43.2 mg, 58%), m.p. 155—158 °C (Found: C, 51.6; H, 5.8; N, 19.85. $C_6H_8N_2O_2$ requires C, 51.4; H, 5.75; N, 20.0%); $\nu_{max.}$ 1 725 and 1 540 cm^{-1}; δ (60 MHz; $CDCl_3$) 2.50 (3 H, s), 3.88 (3 H, s), 7.75 (1 H, s), and 10.71 (1 H, br s); *m*/*z* 140 (M^+), 109 (base), 81, 54, 42, 40, and 32.

Methyl(E)-3-(5-*methoxycarbonyltetrazol*-1-*yl*)*propenoate* (**5h**). A solution of the tetrazole (**5h**) (100 mg) in methanol (100 ml) was irradiated for 3.25 h. Chromatography gave *dimethyl imidazole*-2,5-*dicarboxylate* (55.0 mg, 63%), m.p. 196—198 °C (Found: C, 45.6; H, 4.2; N, 15.1. $C_7H_8N_2O_4$ requires C, 45.7; H, 4.4; N, 15.2%); $\nu_{max.}$ 1 725, 1 700—1 680, and 1 530 cm^{-1}; δ [250 MHz; $(CD_3)_2SO$] 3.93 (3 H, s), 3.99 (3 H, s), 7.89 (1 H, s), and 10.65 (1 H, br s); *m*/*z* 184 (M^+), 154, 153, 126, 121, and 94.

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