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Palladium catalysed queuing processes. Part 2: Termolecular cyclization–anion capture employing carbon monoxide as a relay switch with in situ generated vinylstannanes

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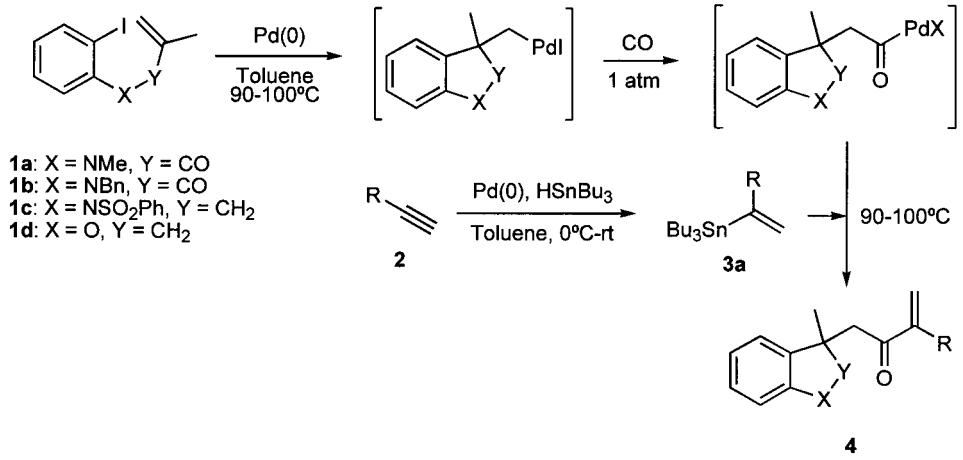
Abstract—The palladium catalysed termolecular queuing processes involving aryl iodides, carbon monoxide (1 atm) and in situ generated vinylstannanes as terminating agents afford a variety of complex heterocyclic α,β-unsaturated ketones in good yield. © 2001 Elsevier Science Ltd. All rights reserved.

In the preceding paper[1] we outlined the general concept of relay switch reactants and their impact on our general palladium catalysed cascade cyclization–anion capture methodology.[2] The new relay switch strategy has enabled a wide variety of ter-, tetra-, penta-, hexa- and octamolecular queuing cascades to be developed[1–3] with CO and allene proving exceptionally versatile relay switch components.

In this paper we report examples of cascade processes involving iodoarenes, CO (1 atm) and in situ generated vinylstannanes (Scheme 1). We have previously demonstrated the versatility of in situ generated vinylstannanes in palladium catalysed cascade reactions[3] and have provided examples involving vinylstannanes derived from carbohydrates, nucleosides, purines, benzodiazepinones, β-lactams, α-amino esters, nitrogen heterocycles and β-aryl/heteroaryl ethylamines.

The methodology outlined in Scheme 1 allows a highly regioselective, temperature controlled cascade to occur, which furnishes enones **4** in good yield (Table 1). We have previously reported ter-, tetra- and pentamolecular queuing cascades in which enones,[4] α,β-unsaturated esters and α,β-unsaturated amides[5] are generated by processes involving the combination of two relay switch reactants (allene and CO). The enone functionality in **4** provides considerable opportunities for further extended cascades by combination with Michael additions, as 2π or 4π



Scheme 1.

Keywords: cascade reactions; palladium catalysis; hydrostannylation; Stille coupling; carbonylation; cyclization; termolecular queuing process.
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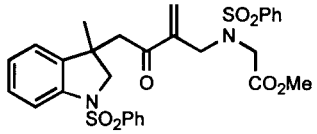
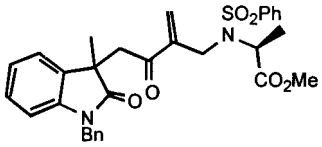
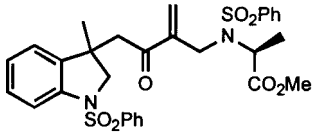
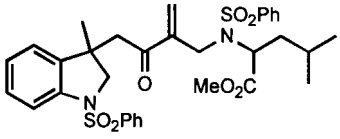
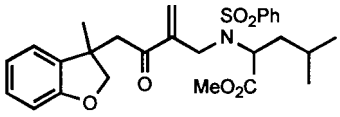
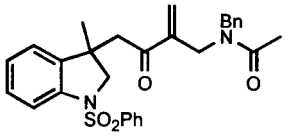
Table 1. Cascade hydrostannylation–cyclization–carbonylation–anion capture for synthesis of **4**

Aryl iodide	Alkyne	$HSnBu_3$(eq):**1**(eq)	**3a**:**3b**[a]	Time (h)	Product	Yield (%)[b]
1c	**2a**	1:2	90:10	6	 **4a**	65
1b	**2b**	1:1	90:10	16	 **4b**	61[c]
1c	**2b**	1:1	90:10	16	 **4c**	60[c]
1c	**2c**	1:1	90:10	18	 **4d**	60[c]
1d	**2c**	1:1	90:10	18	 **4e**	58[c]
1c	**2d**	1:1	85:15	18	 **4f**	63

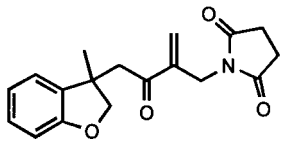
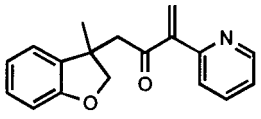
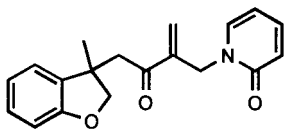
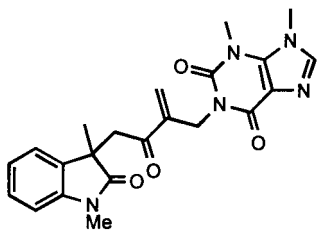
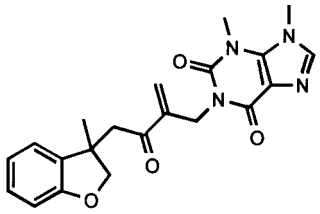
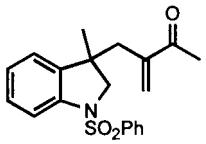
Aryl iodide	Alkyne	$HSnBu_3$(eq):**4**(eq)	**3a**:**3b**[a]	Time (h)	Product	Yield (%)[b]
1d	**2e**	1:1	85:15	1	 **4g**	53
1d	**2f**	1:1	85:15	39	 **4h**	53
1d	**2g**	1:1	85:15	39	 **4i**	45

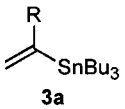
Table 1. (*continued*)

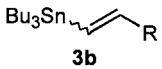
Aryl iodide	Alkyne	$HSnBu_3$(eq):**1**(eq)	**3a**:**3b**[a]	Time (h)	Product	Yield (%)[b]
1a	**2h**	1:1	90:10	1	 **4j**	58
1d	**2h**	1:1	90:10	1	 **4k**	63
1c	**2i**	1:1	85:15	16	 **4l**	56[d]

[a] Calculated by ^{1}H NMR.
[b] Isolated yields after purification by column chromatography (SiO_2).
[c] Obtained as a 1:1 mixture of diastereomers.
[d] Reaction run in absence of carbon monoxide.

components in Diels–Alder reactions, as dipolarophiles in 1,3-dipolar cycloaddition reactions, and in cyclocondensation (e.g. Michael–imine formation) reactions. All these processes have been achieved as part of related work on cascades generating 3-methylene-chroman-4-ones and quinolin-4-ones.[6]

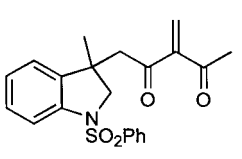
The first step in Scheme 1 involves generation of the vinylstannane **3** from the appropriate alkyne **2** (Chart 1). We selected a range of acyclic **2a–d** and cyclic **2e–h** *N*-propargyl substrates together with acetylenic ketone **2i**. The palladium catalysed hydrostannylation[7] of **2a–i** occurred smoothly in toluene at 0°C over 1 h using Bu_3SnH and a catalytic system comprising 5 mol% Pd_2dba_3 and 20 mol% tri(2-furyl)phosphine.[3,8] A small aliquot of the reaction mixture was removed for ^{1}H NMR analysis of the vinylstannane regioisomeric ratio. The ratio of **3a**:**3b** varied from 85:15 to 90:10 (Table 1) and this selectivity was judged adequate for the proposed cascades. At this point **1a–d** were added and a CO filled balloon attached to the condenser. Raising the temperature to 90–100°C then initiated the cascade as outlined in Scheme 1 affording enones **4a–k** (Table 1) in a well-ordered queuing process.


3a


3b

When **1c** was reacted with alkyne **2i** under these conditions it afforded a complex mixture of products due, presumably, to the sensitivity of the expected 2-methylene-1,3-dicarbonyl product **5** to the reaction conditions. However, product **4l** was obtained in good yield when the same reaction was run in the absence of CO. The products arising from alkynes **2b** and **2c** were 1:1 mixtures of diastereoisomers (^{1}H NMR). A similar ratio was observed in the early stages of the reaction even at lower temperatures.

The very fast reaction observed for the organostannane derived from 3,7-dimethylxanthine is ascribed to a rapid transmetallation step caused by co-ordination between tin and the amide oxygen atom. This chair-like intermediate **6** is also favoured by the highly conjugated mesoionic form containing the endocyclic double bond.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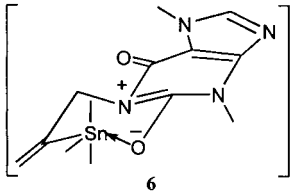
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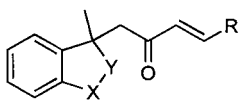
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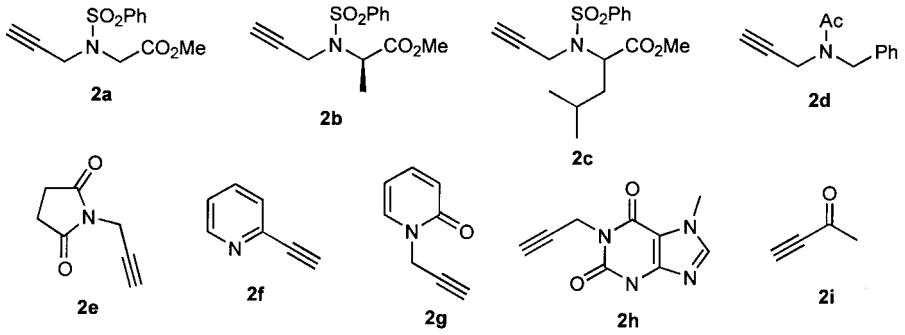
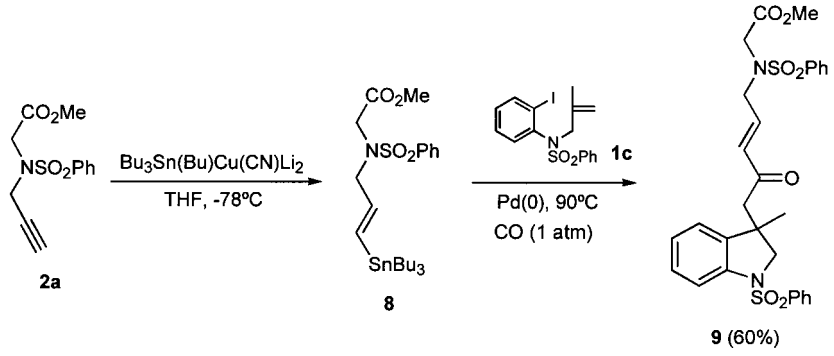


Chart 1.



Scheme 2.

Once again, the coupling reaction of the corresponding β-vinylstannanes **3b** furnished small amounts of products **7**, which were discarded during purification of the desired major compounds **4**. Regioisomeric *E*-enone **9** was prepared, as a unique isomer in good yield (60%), employing different methodology for the generation of organostannane **5**[7b,9] using a lithium cuprate[10] at −78°C (Scheme 2). *E*-Vinylstannane **8** was isolated after quenching the reaction at −78°C with water. The coupling process was completed in 6 h at 90°C under a CO atmosphere employing **1c** as starter affording **9** in 60% yield (Scheme 2). This latter process illustrates the utility of *N*-propargyl substrates, such as **2a–h**, since **9** and its analogues provide additional opportunities for extended cascades as noted previously for **4**.

In conclusion, the above discussion demonstrates that a wide range of *N*-containing enones can be accessed through a simple one pot protocol proceeding via palladium catalysed hydrostannylation followed by cyclization–carbonylation–anion capture, or through a sequential process using a non-palladium catalysed hydrostannylation reaction of a wide variety of alkynes. The unsaturated ketones offer many synthetic possibilities due to their high reactivity which permit the development of new extended cascade processes.

1. Experimental

Melting points were determined on a Koffler hot-stage apparatus and are uncorrected. Mass spectral data were obtained from a VG Autospec mass spectrometer operating at 70 eV. Nuclear magnetic resonance spectra were recorded on Bruker QE300 and AM 400 machines operating at 300 and 400 MHz, respectively. Unless otherwise specified, deuterochloroform was used as solvent with tetramethylsilane as internal standard. Microanalyses were obtained using a Carlo Erba MOD 11016 instrument. Thin layer chromatography was carried out on Whatman PESIL G/UV polyester plates coated with a 0.2 mm layer of silica-gel 60 (Merck 9385). Column chromatography was performed with silica-gel 60 (Merck 9385). Petroleum ether refers to the fraction with bp 40–60°C. Anhydrous DMF was commercially available (Aldrich), THF and toluene were sodium dried under a nitrogen atmosphere and *n*-hexane was distilled prior to use. Compounds **2a**, **2b**, **2g** and **2h** have been previously prepared by us[3] and **2f** and **2i** are commercially available (ACROS).

1.1. Synthesis of propargyl derivatives 2c, 2d and 2e

1.1.1. *N*-Phenylsulphonyl-*N*-propargylleucine methyl ester, 2c. Benzensulphonyl chloride (1.8 g, 10 mmol) was added to a solution of (±)-leucine methyl ester hydrochloride (1.81 g, 10 mmol) and triethylamine (3.5 ml, 25 mmol) in dry dichloromethane (50 ml) cooled at 0°C and the mixture was stirred for 16 h at room temperature. Water was added and the organic layer was separated, dried ($MgSO_4$), filtered and evaporated in vacuo to yield a pale yellow solid. Sodium hydride (95% powder, 177 mg, 7 mmol) was slowly added to a solution of sulphonylated amino ester (2.5 g, 7 mmol) in dry DMF (10 ml). After 2 h at room temperature, propargyl bromide (80% in toluene, 2 g, 14 mmol) was added and stirring was continued for a further 2 h at the same temperature. The mixture was diluted with Et_2O (30 ml) and water (50 ml) was added. The organic

layer was separated, dried ($MgSO_4$), filtered and evaporated in vacuo yielding a thick pale yellow oil, which was purified by column chromatography eluting with 1:1 v/v *n*-hexane–ethyl acetate affording the product (1.8 g, 76%) as a thick yellow oil. (Found: C, 59.2; H, 6.5; N, 4.05; S, 9.7. $C_{16}H_{21}NO_4S$ requires: C, 59.4; H, 6.55, N, 4.3; S, 9.9%); δ 0.89, 0.91 (2d, J=6.5 Hz, 6H, $(CH_3)_2C$), 1.55–1.85 (m, 3H, CH_2CH), 2.22 (t, J=2.5 Hz, 1H, CH≡C), 3.51 (s, 3H, CH_3O), 4.13, 4.31 (2×dd, J=19.0 and 2.5 Hz, 2H, CH_2N), 4.59 (dd, J=10.0 and 4.8 Hz, 1H, CHN) and 7.43–7.90 (m, 5H, ArH); *m/z* (%) 323 (M^+, 8), 266 (25), 265 (45), 264 (100), 208 (17), 182 (43), 141 (35), 125 (18), 122 (20), 80 (15) and 77 (30).

1.1.2. *N*-Acetyl-*N*-propargylbenzylamine, 2d. Sodium hydride (95% powder, 252 mg, 10 mmol) was slowly added to a solution of *N*-acetylbenzylamine (1.5 g, 10 mmol) in dry DMF (10 ml). After 2 h at room temperature propargyl bromide (80% in toluene, 2 g, 14 mmol) was added and stirring was continued for a further 2 h at the same temperature. The mixture was diluted with Et_2O (30 ml) and water (50 ml) was added. The organic layer was separated, dried ($MgSO_4$), filtered and evaporated in vacuo yielding a thick yellow oil, which was purified by column chromatography eluting with 9:1 v/v *n*-hexane–ethyl acetate affording 1.5 g (81%) of **2d** as thick yellow oil. (Found: C, 77.2; H, 6.8; N, 7.4. $C_{12}H_{13}NO$ requires: C, 77.0; H, 6.95, N, 7.5%); δ 2.18 (s, 3H, CH_3), 2.20 (t, J=2.5 Hz, 1H, CH≡C), 4.64–4.71 (m, 4H, 2×CH_2N) and 7.15–7.68 (m, 5H, ArH); *m/z* (%) 187 (M^+, 8), 149 (21), 148 (20), 106 (84), 91 (24), 51 (15), 44 (36) and 43 (100).

1.1.3. *N*-Propargylsuccinimide, 2e. Sodium hydride (95% powder, 177 mg, 7 mmol) was slowly added to a solution of succinimide (0.69 g, 7 mmol) in dry DMF (10 ml). After 2 h at room temperature propargyl bromide (80% in toluene, 2 g, 14 mmol) was added and stirring was continued for a further 2 h at the same temperature. The mixture was diluted with Et_2O (30 ml) and water (50 ml) was added. The organic layer was separated, dried ($MgSO_4$), filtered and evaporated in vacuo yielding a thick yellow oil, which was purified by column chromatography eluting with 1:1 v/v *n*-hexane–ethyl acetate affording 0.84 g (87%) of **2e** as thick yellow oil. (Found: C, 61.25; H, 5.2; N, 10.25. $C_7H_7NO_2$ requires: C, 61.3; H, 5.15; N, 10.2%); δ 2.20 (t, J=2.5 Hz, 1H, CH≡C), 2.78 (s, 4H, 2×CH_2CO), 4.34 and 4.20 (deform. 2×dd, J=19.0 and 2.5 Hz, 2H, CH_2N); *m/z* (%) 137 (M^+, 13), 109 (29), 95 (100), 80 (18), 56 (28), 55 (26), 54 (25), 52 (26) and 39 (36).

1.2. General procedure for 4a–l

Tri-*n*-butyltin hydride (0.150 ml, 0.5 mmol) was added dropwise to a stirred solution of propargylic derivative **2** (0.5 mmol), Pd_2dba_3 (11.2 mg, 0.025 mmol) and tri-(2-furyl)phosphine (11.6 mg, 0.10 mmol) in anhydrous toluene (5 ml) cooled at 0°C. The reaction mixture was stirred at room temperature for 1 h before a solution of **1** (0.5 or 1 mmol, see Table 1) dissolved in toluene (2 ml) was added. The reaction mixture was then saturated with carbon monoxide (1 atm, balloon) and heated at 90–100°C with stirring for the times indicated on Table 1. The reaction mixture was cooled and a saturated aqueous solution of potassium fluoride (10 ml) was added and stirring continued for an additional hour. The suspension was filtered and ethyl acetate added (20 ml). The organic phase was separated, washed with water (10 ml), dried (Na_2SO_4) and concentrated under vacuo. The residue was purified by flash chromatography (SiO_2) eluting with mixtures of petroleum ether–ether. Yields and reaction times are given in Table 1.

1.2.1. Methyl 2-{2-[2-(3-methyl-1-phenylsulphonyl-2,3-dihydro-1*H*-3-indolyl)acetyl]allyl(phenyl)sulphonamido}acetate, 4a. Viscous pale yellow oil. (Found: C, 59.5; H, 5.2; N, 4.55; S, 11.0. $C_{29}H_{30}N_2O_7S_2$ requires: C, 59.75; H, 5.2; N, 4.8; S, 11.0%); δ 1.13 (2×s, 3H, CH_3C), 2.56, 3.03 (2×d, J=17.3 Hz, 2H, CCH_2CO), 3.57 (s, 3H, CH_3O), 3.75, 3.93 (2×d, J=11.0 Hz, 2H, CH_2NAr), 4.02, 4.07 (2×s, 4H, CH_2NCH_2CO), 5.96, 6.03 (2×s, 2H, CH_2=C) and 7.01–7.83 (m, 14H, ArH); *m/z* (%) 582 (M^+, 9), 272 (45), 271 (100), 170 (28), 144 (22), 141 (37), 131 (20), 130 (60), 77 (71) and 51 (16).

1.2.2. Methyl (2*S*)-2-{2-[2-(1-benzyl)-3-methyl-2,3-dihydro-1*H*-3-indolyl)acetyl]allyl(phenyl)sulphonamido}propanoate, 4b. Viscous pale yellow oil. (Found: C, 66.2; H, 5.8; N, 4.7; S, 5.85. $C_{31}H_{32}N_2O_6S$ requires: C, 66.4; H, 5.75, N, 5.0; S, 5.7%); δ (mixed diastereomers) 1.15 and 1.18 (2×d, J=7 Hz, 3H, CH_3), 1.25 and 1.27 (2×s, 3H, CH_3CCO), 3.29 and 3.36 (2×s, 3H, CH_3O), 3.39–3.58 (m, 2H, CH_2CO), 3.81–4.04 (m, 2H, CH_2NAr), 4.53–4.64 (m, 1H, $NCHCO_2$), 4.87, 5.09 (m, 2H, NCHPh), 6.23–6.32 (m, 2H, CH_2=C) and 6.68–7.75 (m, 14H, ArH); *m/z* (%) 560 (M^+, 12), 419 (54), 236 (54), 91 (100) and 77 (49).

1.2.3. Methyl (2*S*)-2-{2-[2-(3-methyl-1-phenylsulphonyl-2,3-dihydro-1*H*-3-indolyl)acetyl]allyl(phenyl)sulphonamido}propanoate, 4c. Viscous pale brown oil. (Found: C, 60.5; H, 5.45; N, 4.6; S, 10.5. $C_{30}H_{32}N_2O_7S_2$ requires: C, 60.4; H, 5.4; N, 4.7; S, 10.7%); δ (mixed diastereomers) 1.16, 1.17 (2×s, 3H, CH_3CCH_2N), 1.29 (d, J=7.3 Hz, 3H, Me), 2.51, 2.65, 3.00 and 3.1 (4×d, J=17.0 Hz, 2H, CCH_2CO), 3.40 (s, 3H, OMe), 3.77–4.20 (m, 4H, C=CCH_2N and CH_2NAr), 4.65 (q, J=7.6 Hz, 1H, $NCHCO_2$), 6.00, 6.03, 6.20 and 6.21 (4×s, 2H, CH_2=C) and 7.00–7.84 (m, 14H, ArH); *m/z* (%) 596 (M^+, 15), 271 (40), 184 (59), 130 (55), 77 (83) and 57 (100).

1.2.4. Methyl 4-methyl-2-{2-[2-(3-methyl-1-phenylsulphonyl-2,3-dihydro-1*H*-3-indolyl)acetyl]allyl(phenyl)sulphonamido}pentanoate, 4d. Viscous pale yellow oil. (Found: C, 61.9; H, 6.1; N, 4.15; S, 10.2. $C_{33}H_{38}N_2O_7S_2$ requires: C, 62.0; H, 6.0; N, 4.4; S, 10.4%); δ (mixed diastereomers) 0.87 and 0.93 (2×d, J=5.2 Hz, 6H, 2×Me), 1.16 (s, 3H, Me), 1.25–1.43 (m, 1H, Me_2CH), 1.54–1.59 (m, 2H, CH_2), 2.51, 2.62, 3.04 and 3.11 (4×d, J=17.5 Hz, 2H, CH_2CO), 3.37 (s, 3H, OMe), 3.82, 3.86, 3.95 and 3.99 (4×d, J=11.2 Hz, 2H, C=CCH_2N), 4.10 (s, 2H, CH_2NAr), 4.53 (t, J=6.0 Hz, 1H, NCH), 6.02, 6.05, 6.20 and 6.21 (4×s, 2H, CH_2=C) and 7.01–7.85 (m, 14H, ArH); *m/z* (%) 639 (M^++1, 23), 272 (100), 131 (52) and 81 (45).

1.2.5. Methyl 4-methyl-2-{2-[2-(3-methyl-2,3-dihydrobenzo[*b*]furan-3-yl)acetyl]allyl(phenyl)sulphonamido}pentanoate, 4e. Viscous pale yellow oil. (Found: C, 65.0; H, 6.65; N, 2.7; S, 6.35. $C_{27}H_{33}NO_6S$ requires: C, 65.0; H,

6.65; N, 2.8; S, 6.4%); δ (mixed diastereomers) 0.85–0.94 (m, 6H, 2×Me), 1.25–1.37 (m, 1H, Me_2CH), 1.41–1.43 (2×s, 3H, Me), 1.53–1.65 (m, 2H, CH_2), 2.93–3.28 (m, 2H, CH_2CO), 3.35 and 3.37 (2×s, 3H, MeCO), 4.14 (s, 2H, CH_2N), 4.46 (s, 2H, CH_2O), 4.50–4.57 (m, 1H, $NCHCO_2Me$), 6.22 and 6.28 (2×s, 2H, C=CH_2) and 6.79–7.86 (m, 9H, ArH); *m/z* (%) 499 (M^+, 11), 440 (80), 358 (55), 226 (64) and 133 (100).

1.2.6. *N*-1-Benzyl-*N*-1-{2-[2-(3-methyl-1-phenylsulphonyl-2,3-dihydro-1*H*-3-indolyl)acetyl]allyl}acetamide, 4f. Viscous pale yellow oil. (Found: C, 69.2; H, 6.3; N, 5.4. $C_{29}H_{30}N_2O_4S$ requires: C, 69.3; H, 6.0; N, 5.2%); δ (rotomers) 1.43 and 1.61 (2×s, 3H, Me), 2.09 and 2.16 (2×s, 3H, Me), 2.09 and 2.16 (2×s, 3H, MeCO), 2.56, 2.65, 2.97 and 3.04 (4×d, *J*=17.0 Hz, 2H, CH_2CO), 3.66 and 3.77 (2×d, 1H of CH_2NCH_2), 3.92–4.15 (m, 3H of CH_2NCH_2), 4.50 (m, 2H, CH_2N), 5.66, 5.77, 5.90 and 5.92 (4×s, 2H, CH_2=C) and 6.99–7.85 (m, 14H, Ar); *m/z* (%) 503 (M^++1, 15), 459 (19), 272 (24), 188 (60), 130 (45), 91 (100) and 77 (60).

1.2.7. 1-{2-[2-(3-Methyl-2,3-dihydrobenzo[*b*]furan-3-yl)-acetyl]allyl}-2,5-pyrrolidine dione, 4g. Colourless prisms 137–140°C (from petroleum ether–ether). (Found: C, 69.0; H, 6.15; N, 4.2. $C_{18}H_{17}O_4N$ requires: C, 69.3; H, 6.0; N, 4.5%); δ 1.42 (s, 3H, Me), 2.76 (s, 4H, CH_2CH_2), 2.96 and 3.28 (4×d, *J*=17.3 Hz, 2H, CH_2CO), 4.34 (s, 2H, CH_2N), 4.45 (s, 2H, CH_2O), 5.60 and 6.04 (2×s, 2H, CH_2=C) and 6.79–7.26 (m, 4H, ArH); *m/z* (%) 313 (M^+, 15), 132 (41), 100 (100), 92 (19), 77 (34) and 56 (67).

1.2.8. 1-(3-Methyl-2,3-dihydrobenzo[*b*]furan-3-yl)-3-(2-pyridyl)-3-buten-2-one, 4h. Viscous pale yellow oil. (Found: C, 77.25; H, 6.2; N, 4.8. $C_{18}H_{17}NO_2$ requires: C, 77.3; H, 6.1; N, 5.0%); δ 1.46 (s, 3H, CH_3), 2.98 and 3.26 (2×d, *J*=17 Hz, 2H, CH_2CO), 4.47 and 4.56 (2×d, *J*=9.0 Hz, 2H, CH_2CO), 6.80–7.75 (m, 7H, ArH and CH_2=C) and 8.56 (d, 1H, ArH); *m/z* (%) 279 (M^+, 12), 132 (34), 103 (31), 92 (14), 91 (10), 78 (16), 77 (23) and 55 (43).

1.2.9. 1-{2-[2-(3-Methyl-2,3-dihydrobenzo[*b*]furan-3-yl)-acetyl]allyl}-1,2-dihydro-2-pyridone, 4i. Colourless oil. (Found: C, 73.85; H, 6.3; N, 4.6. $C_{19}H_{19}NO_3$ requires: C, 73.75; H, 6.2; N, 4.5%); δ 1.38 (s, 3H, CH_3), 2.95 and 3.25 (2×d, *J*=17 Hz, 2H, CH_2O), 4.39 and 4.46 (2×d, *J*=9.0 Hz, 2H, CH_2N), 4.68 and 4.73 (2×d, *J*=15 Hz, 2H, CH_2O), 5.92 (s, 1H, CH=C), 6.12–6.18 (m, 2H, ArH and CH=C), 6.12–6.18 (m, 2H, ArH and CH=C), 6.55 (d, 1H, ArH) and 6.76–7.36 (m, 6H, ArH); *m/z* (%) 310 (M^++1, 100), 214 (83), 177 (65), 134 (97) and 105 (55).

1.2.10. 1-{2-[2-(1,3-Dimethyl-2,3-dihydro-1*H*-3-indolyl)-acetyl}allyl-3,9-dimethyl-2,3,6,9-tetrahydro-1*H*-2,6-purine dione, 4j. Colourless prisms, mp 88°C (from petroleum ether–ether); δ 1.51 (s, 3H, CCH_3), 3.29 (s, 3H, $OCNCH_3$), 3.41, 3.47 (2×d, *J*=17.9 Hz, 2H, C=CCH_2N), 3.35, 3.96 (2×s, 6H, 2×$NCNCH_3$), 4.60, 4.68 (d, *J*=15.4 Hz, 2H, CH_2CO), 5.40, 6.03 (2×s, 2H, C=CH_2), 6.80–7.25 (m, 4H, ArH) and 7.53 (s, 1H, NCHN); *m/z* (%) 421 (M^+, 54), 247 (25), 219 (100). Accurate mass found: 421.1750. $C_{22}H_{23}N_5O_2$ requires: 421.1750.

1.2.11. 3,9-Dimethyl-1-{2-[2-(3-methyl-2,3-dihydrobenzo-[*b*]furan-3-yl)acetyl]allyl}-2,3,6,9-tetrahydro-1*H*-2,6-purine dione, 4k. Colourless prisms, mp 78°C (from petroleum ether–ether); δ 1.43 (s, 3H, CCH_3), 3.00, 3.38 (2×d, *J*=3.0 Hz, 2H, CH_2O), 3.58, 3.98 (2×s, 6H, 2×$NCNCH_3$), 4.48, 4.50 (2×d, *J*=4.5 Hz, 2H, C=CCH_2N), 4.84 (s, 2H, CH_2CO), 5.50, 6.00 (2×s, 2H, C=CH_2), 6.70–7.20 (m, 4H, ArH) and 7.60 (s, 1H, NCHN); *m/z* (%) 394 (M^+, 12), 379 (21), 262 (44) and 219 (100). Accurate mass found: 394.1649. $C_{21}H_{20}N_4O_2$ requires: 394.1641.

1.2.12. 3-[(3-Methyl-1-phenylsulphonyl-2,3-dihydro-1*H*-3-indolylmethyl)-3-buten-2-one, 4l. Colourless prisms, mp 114–117°C (from petroleum ether–ether). (Found; C, 67.55; H, 6.1; N, 3.65; S, 9.0. $C_{20}H_{21}NO_3S$ requires: C, 67.6; H, 6.0; N, 3.9; S, 9.0%); δ 1.15 (s, 3H, Me), 2.21 (s, 3H, OMe), 2.33 and 2.69 (2×d, 2H, *J*=13.1 Hz, CH_2), 3.31 and 3.90 (2×d, 2H, CH_2N), 5.34, 5.85 (2×s, 2H, CH_2=C) and 6.99–7.85 (m, 9H, ArH); *m/z* (%) 355 (M^+, 30), 272 (100), 141 (51), 130 (80) and 84 (77).

1.2.13. Methyl 2-[(*E*)-5-(3-methyl-1-phenylsulphonyl-2,3-dihydro-1*H*-3-indolyl)-4-oxo-2-pentenyl(phenyl)-sulphonamido]acetate, 9. Compound **9** was synthesized using the same procedure as that described for the synthesis of compounds **4** but this time the vinylstannane was prepared previously according to the literature.[10] After 6 h at 90°C extractive work-up and purification (SiO_2) eluting with mixtures v/v 3:1 of petroleum ether–ether, product **9** was obtained as pale yellow oil. (Found: C, 59.7; H, 5.2; N, 4.5; S, 11.0. $C_{29}H_{30}N_2O_7S_2$ requires: C, 59.75; H, 5.2; N, 4.8; S, 11.0%); δ 1.17 (s, 3H, CH_3C), 2.40, 2.79 (2×d, *J*=17.0 Hz, 2H, CCH_2CO), 3.59 (s, 3H, CH_3O), 3.75, 3.96 (2×d, *J*=11.1 Hz, 1H, CH_2NAr), 3.98 (s, 2H, NCH_2CO), 6.48 (d×t, *J*=16.0 and 5.4 Hz, 1H, C*H*=CHCO) and 6.99–7.87 (m, 14H, ArH); *m/z* (%) 582 (M^+, 1), 272 (55), 271 (100), 168 (28), 144 (30), 141 (40), 131 (26), 130 (76), 78 (28), 77 (98) and 51 (42).

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