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Weakly ligated palladium complexes $PdCl_2(RCN)_2$ in piperidine: versatile catalysts for Sonogashira reaction of vinyl chlorides at room temperature

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It is with warmest congratulations and best wishes for continued good health and happiness that this contribution is dedicated to Professor Jean Normant on the occasion of his 65th anniversary

Abstract

Copper iodide and weakly ligated palladium complexes $PdCl_2(RCN)_2$ (R = Ph, Me) catalyzed efficiently the coupling reaction of vinyl chlorides with 1-alkynes in the presence of piperidine to give the corresponding conjugated enynes in good to excellent yields. The reaction takes place rapidly and cleanly at room temperature. Application to the synthesis of terbinafine which exhibits strong antimycotic activity has been realized. © 2001 Elsevier Science B.V. All rights reserved.

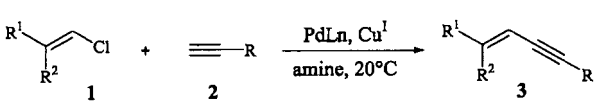
Keywords: Palladium; Copper; Amino vinyl chlorides; Amino enynes; Terbinafine

1. Introduction

The preparation of conjugated enynes [1] has been an area of considerable activity in recent years [2] due primarily to their use as efficient precursors of conjugated dienes [3], as well as their occurence as natural substances [4]. Among various approaches available for conjugated enynes, by far the most convenient and simple method widely used is the palladium–copper catalyzed cross coupling reaction of terminal alkynes with vinyl halides or triflates [5,6]. This procedure, namely *Sonogashira* coupling reaction, is of great interest since the preparation of organometallic acetylide species is not required and allows a huge range of functionalized 1-alkynes to couple chemoselectively under very mild conditions [7].

Usually, the *Sonogashira* coupling reaction is efficiently performed with the more reactive but expensive vinyl iodides, bromides or triflates [7]. However, unlike the case of 1,2-dichloro-ethylenes [7e,8], vinyl chlorides which are considered generally poor reactants have not been used in such coupling. Obviously, extending the scope of this reaction to the chloro analogues is of great interest for synthetic laboratory, industrial chemistry and would be a highly atom-economical approach for the construction of conjugated enynes.

The low reactivity of vinyl chlorides is ascribed to their much lower tendency to undergo oxidative addition to Pd(0) in the catalytic cycle compared with vinyl iodides, bromides or triflates [9]. In our attempts to increase the rate of this step by varying several experimental conditions, we discovered that the weakly ligated palladium complexes $PdCl_2(RCN)_2$ (R = Ph or Me) and CuI in piperidine catalyzed efficiently and rapidly the coupling reaction of 1-alkynes with vinyl chlorides to give conjugated enynes in good to excellent yields. Herein, we wish to detail our results previously reported [10].



a $R^1 = R = n\text{-}C_5H_{11}$ $R^2 = H$

b $R^2 = R = n\text{-}C_4H_9$ $R^1 = H$

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Table 1
Cross coupling reaction of **1a** with **2a**: effects of palladium catalysts and amine

Entry	Amine	PdLn	Time (h)	Isolated yield of **3a** (%)
1	$BuNH_2$	$PdCl_2(PPh_3)_2$	20	24
2	Et_2NH	$PdCl_2(PPh_3)_2$	20	9
3	Et_3N	$PdCl_2(PPh_3)_2$	20	4
4	Pyrrolidine	$PdCl_2(PPh_3)_2$	16	71
5	Piperidine	$PdCl_2(PPh_3)_2$	20	93
6	Piperidine	$PdCl_2$ + 2 PPh_3	20	83
7	Piperidine	$PdCl_2$	16	90
8	Piperidine	$PdCl_2$ + 2 $AsPh_3$	16	75
9	Piperidine	$Pd(OAc)_2$ + 2 PPh_3	16	69
10	Piperidine	$Pd(OAc)_2$ + 2 $AsPh_3$	16	80
11	Piperidine	$Pd(dba)_2$ + 2 $AsPh_3$	16	78
12	Piperidine	$Pd(PPh_3)_4$	20	11
13	Piperidine	$PdCl_2(MeCN)_2$	0.5	90
14	Piperidine	$PdCl_2(PhCN)_2$	0.5	93
15	Morpholine	$PdCl_2(PhCN)_2$	1	89
16	Pyrrolidine	$PdCl_2(PhCN)_2$	0.5	73
17	$PrNH_2$	$PdCl_2(PhCN)_2$	20	2
18	Et_2NH	$PdCl_2(PhCN)_2$	20	9
19	*i*-Pr_2NH	$PdCl_2(PhCN)_2$	20	3
20	Et_3N	$PdCl_2(PhCN)_2$	20	2
21	*N*-Methyl piperidine	$PdCl_2(PhCN)_2$	20	2

2. Results and discussion

At first, we examined the coupling reaction of 1-alkynes with vinyl chlorides under the standard *Sonogashira* conditions [5]. Thus, reaction of vinyl chloride **1a** with 1-heptyne **2a** in Et_2NH as solvent in the presence of $PdCl_2(PPh_3)_2$ (5%) and CuI (10%) at room temperature for 20 h gave very low yield of enyne **3a** (9%, Table 1, entry 2) accompanied with symmetrical diyne arising from the homocoupling of 1-heptyne. Consequently, in order to improve this result, we decided to examine the influence of the nature of the amine and palladium catalysts including the effect of ligands on the course of the reaction. The results are summarized in Table 1.

The coupling reaction of **1a** with **2a** was also unsuccessful when using primary or tertiary amine such as $BuNH_2$ or Et_3N (Table 1, entries 1 and 3). In contrast, the use of cyclic secondary amine allows to improve remarkably the yield of the cross coupling product **3a** (71–93% within 20 h, entries 4 and 5). The best result was obtained when performing the reaction in piperidine in the presence of palladium catalysts coordinated with nitrile ligands rather than triphenyl phosphine. Under these conditions, the use of $PdCl_2(PhCN)_2$ or $PdCl_2(MeCN)_2$ drastically accelerated the rate of the reaction (Scheme 1), thus the coupling reaction proceeds rapidly at room temperature within 0.5 h instead of 20 h and gave **3a** in excellent yield (90–93%, entries 13 and 14). Furthermore, the use of nitrile rather than triphenyl phosphine as ligand in the palladium complex simplified the purification of the product. It is noteworthy that other palladium catalysts can be used successfully (60–90% within 16–20 h, entries 6–11).

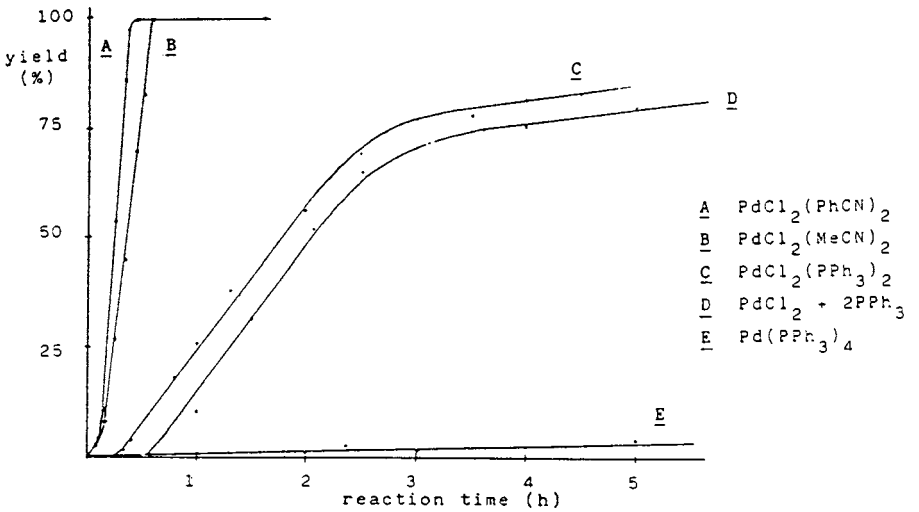
As illustrated in Table 1, the association of $PdCl_2(RCN)_2$-cyclic secondary amine (entries 13–16) was crucial for the success of the coupling reaction since the use of other amines gave low yields of enyne **3a** (entries 17–21).

As exemplified below the reaction is stereospecific and proceeds with retention of the double bond geometry of the vinyl chloride. (*Z*)-1-chloro-hept-1-ene (**1b**) gave (92% yield, stereoisomeric purity $\geq 99.5\%$) (8*Z*)-tetradec-8-en-6-yne (**3b**) in 100 min. The (*Z*)-vinyl chloride was less reactive than the corresponding (*E*)-isomer (Scheme 2).

As shown in Table 2, the coupling reaction of **1a** with **2a** can also be performed in 90–92% yield within 5–6 h by using 20 equivalents of piperidine in THF or NMP as solvent. The use of other solvents gave unsatisfactory yields of the desired enyne **3a** (2–45%, Table 2).

In order to demonstrate the efficiency of this new synthetic approach, a variety of functionalized enynes were thus synthesized in good to excellent yields starting from functionalized vinyl chlorides. As shown in Table 3, the coupling reaction has a large scope of application and tolerates sensitive functional groups on either coupling partner.

An elegant illustration of the efficiency of this procedure is the high yielding synthesis of terbinafine **30** a strong antimycotic agent which is used currently for the



Scheme 1. Reaction of **1a** with 1-heptyne in piperidine in the presence of palladium catalyst (5%) and CuI (10%) at room temperature.

treatment of skin mycoses [11]. Thus, amination of (*E*)-1,3-dichloropropene (**28**) with *N*-methyl-1-naphtalene methanamine (**27**) in dry acetonitrile in the presence of K_2CO_3 and a catalytic amount of KI [12] led regioselectively to the (*E*)-vinyl chloride **29** in 81% yield (Scheme 3). Coupling of (*E*)-amino vinyl chloride (**29**) with *tert*-butyl acetylene in the presence of piperidine and catalytic amounts of $PdCl_2(PhCN)_2$ (5%) and CuI (10%) provided rapidly[1] and stereospecifically terbinafine **30** in 93% isolated yield [14,15][2].

As exemplified below (Scheme 4), the coupling reaction from vinyl iodides, under the same conditions was examined and afforded lower yields of coupled products than vinyl chlorides.

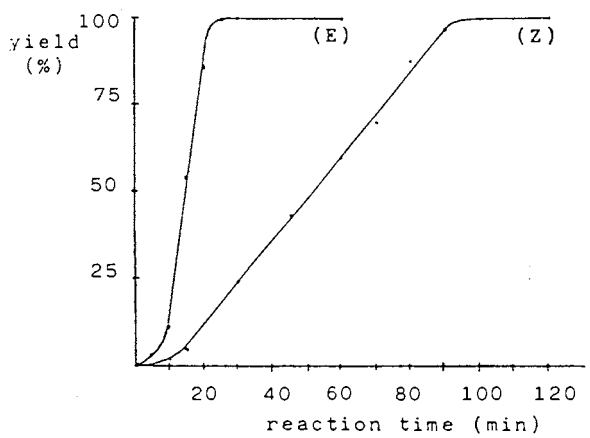
The palladium-catalyzed reaction of several metal acetylides containing Sn, Zn, Si with vinyl iodides [16,17] has been reported; however when heptynyl tributyl stannane was treated with 1(*E*)-chloro-hept-1-ene (**1a**) in the presence of $PdCl_2(PhCN)_2$ in DMF or piperidine for 20 h, no reaction occured. These results show the greater utility, both in term of efficiency and practicability, of copper-catalyzed reactions of terminal acetylenes over the preformed metal acetylides for the synthesis of conjugated enynes.

3. Conclusion

We have shown that vinyl chlorides readily react with terminal alkynes, at room temperature, in piperidine in the presence of CuI and weakly ligated palladium complexes to give the corresponding cross coupling products in high yields. The reaction is stereo- and chemoselective since numerous functional groups are tolerated in both coupling partners.

4. Experimental

All experiments were carried out in flame-dried glassware under an inert atmosphere. All NMR spectra were recorded on a Bruker AC 200, VM 250 or AM 400 MHz spectrometer in deuteriochloroform ($CDCl_3$, δ (ppm), J (Hz)). Mass spectra were determined on a Nermag R 10/10 instrument in the NH_3 chemical ionisation mode. IR spectra were measured on a Perkin–Elmer 599 spectrophotometer (neat, cm^{-1}). Stereoisomeric purity of products was determined by



Scheme 2. Reaction of **1a** (*E*-isomer) and **1b** (*Z*-isomer) with 1-heptyne in piperidine in the presence of $PdCl_2(PhCN)_2$ (5%) and CuI (10%) at room temperature.

[1] The use of $PdCl_2(PhCN)_2$ as catalyst instead of $PdCl_2$ associated with PPh_3 dramatically improved the rate of the coupling reaction (0.5 h instead of 20 h) see Ref. [13].

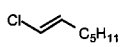
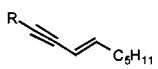
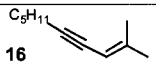
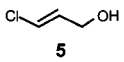
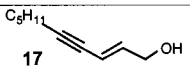
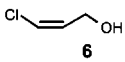
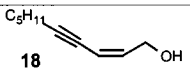
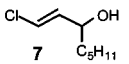
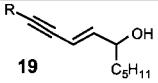
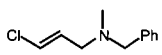
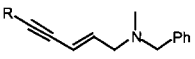
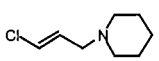
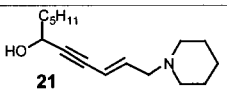
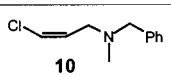
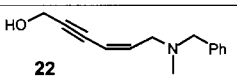
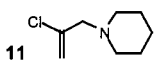
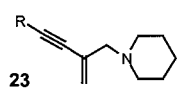
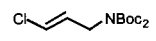
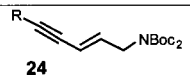
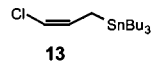
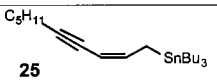
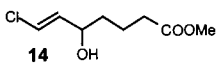
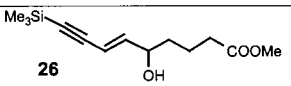
[2] For other syntheses of terbinafine and related compounds see Refs. [11,15].

Table 2
Cross coupling reaction of **1a** with **2a** under $PdCl_2(PhCN)_2$-catalysis: effects of solvents

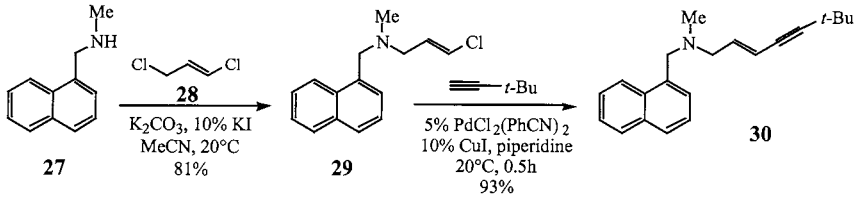
Solvent [a]	C_6H_6	Et_2O	THF	AcOEt	CH_3CN	NMP	DMSO
Yield of **3a** (%) [b]	21	10	92	24	45	90	2

[a] 20 equivalents of piperidine were used.
[b] Isolated yields.

Table 3
Synthesis of functionalized enynes by coupling of vinyl chlorides with terminal alkynes

Entry	Vinyl chloride	Enyne		Yield[a] (%)
22	 **1a**	 **15**	**a:** R = C_6H_5	93
23			**b:** R = $SiMe_3$	90
24			**c:** R = CH_2OH	87
25			**d:** R = $(CH_2)_2OH$	88
26			**e:** $(CH_2)_2COOMe$	74
27	 **4**	 **16**		62
28	 **5**	 **17**		88
29	 **6**	 **18**		85
30	 **7**	 **19**	**a:** R = C_5H_{11}	90
31			**b:** R = CH_2OH	84
32	 **8**	 **20**	**a:** R = C_5H_{11}	86
33			**b:** R = $SiMe_3$	90
34			**c:** R = CH_2OH	73
35			**d:** R = $(CH_2)_2OH$	97
36	 **9**	 **21**		95
37	 **10**	 **22**		64
38	 **11**	 **23**	**a:** R = C_5H_{11}	77
39			**b:** R = $(CH_2)_2OH$	85
40			**c:** R = $CH(OH)C_5H_{11}$	90
41	 **12**	 **24**	**a:** R = C_5H_{11}	90
42			**b:** R = $CH(OH)C_5H_{11}$	71
43	 **13**	 **25**		62
44	 **14**	 **26**		74

[a] Yields of isolated, analytically pure products.



Scheme 3.

gas chromatographic analyses performed on a model Girdel equiped with capillary column (SGE 50 QC 2 / BP5 0.25). Analytical TLC was performed on 0.25 mm precoated silica gel plates (Merck). Products were purified by distillation or by column chromatography (silica gel 60 230–400 mesh ASTM, 0.040–0.063 mm) purchased from E. Merck. Boiling points are uncorrected. $PdCl_2(RCN)_2$ (R = Ph, Me) [18], vinyl chlorides **7** [19] and **13** [20] were prepared following literature procedure.

4.1. (E)-1-Chloro-hept-1-ene (1a)

Compound **1a** was prepared following literature procedure [21]. Copper (I) chloride (11.9 g, 0.12 mol), (1*E*)-1-iodo-hept-1-ene (**31a**) [22] (13.4 g, 0.06 mol) and 60 ml of NMP were stirred 2 h at 130°C. The mixture was cooled, dilued with 5 N HCl and extracted with Et_2O (3 × 30 ml). The organic layer was dried over $MgSO_4$ and the solvent was removed in vacuo. Purification by distillation afforded the vinyl chloride **1a** as a colourless oil (*E* stereoisomeric purity > 99%) in 79% yield (6.2 g); b.p. 140–142°C (760 mmHg); IR (neat) cm^{-1} 1635; ^{1}H-NMR (200 MHz, $CDCl_3$): δ 0.90 (t, $J = 6.7$ Hz, 3H), 1.20–1.50 (m, 6H), 2.00 (q, $J = 6.1$ Hz, 2H), 5.90 (m, 2H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 13.8, 22.3, 28.5, 30.8, 31.1, 116.6, 134.0. Anal. Calc. for $C_7H_{13}Cl$ (132.45): C, 63.42; H, 9.81; Found: C, 63.55; H, 9.98%.

4.2. (Z)-1-Chloro-hex-1-ene (1b)

Compound **1b** was prepared following literature procedure [21]. Copper (I) chloride (9.9 g, 0.10 mol), (1*Z*)-1-iodo-hex-1-ene [23] (10.5 g, 0.05 mol) and 50 ml of NMP were stirred 2 h at 130°C. The mixture was cooled, dilued with 5 N HCl and extracted with Et_2O (3 × 30 ml). The organic layer was dried over $MgSO_4$ and the solvent was removed in vacuo. Purification by distillation afforded the vinyl chloride **1b** as a colourless oil (*E* stereoisomeric purity > 99%) in 65% yield (3.85 g); b.p. 120–122°C (760 mmHg); IR (neat) cm^{-1} 1630; ^{1}H-NMR (200 MHz, $CDCl_3$): δ 0.86 (t, $J = 7.3$ Hz, 3H), 1.20–1.40 (m, 4H), 2.15 (qd, $J = 7.2$ and 1.5 Hz, 2H), 5.68 (q, $J = 7.1$ Hz, 1H), 5.93 (dt, $J = 7.1$ and 1.5 Hz, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 13.7, 22.2, 26.6, 30.5, 117.8, 131.7. Anal. Calc. for $C_6H_{11}Cl$ (118.60): C, 60.99; H, 9.39; Found: C, 61.20; H, 9.57%.

4.3. (E)-3-Chloro-prop-2-en-1-ol (5)

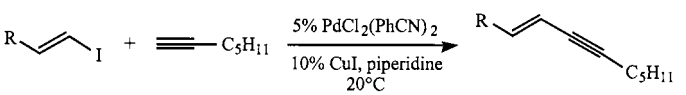
(*E*)-1,3-dichloro-prop-1-ene **28** (3.55 g, 32.2 mmol), K_2CO_3 (4.66 g, 44 mmol) and 40 ml of H_2O were stirred 6 h at 100°C. The mixture was cooled and extracted with Et_2O (3 × 20 ml). The organic layer was dried over $MgSO_4$ and the solvent was removed in vacuo. Purification by distillation afforded pure (*E*)-vinylchloride **5** as a colourless oil in 69% yield (2.06 g); b.p. 77°C (42 mmHg); IR (neat, cm^{-1}) 3350, 3060, 1630, 965; ^{1}H-NMR (200 MHz, $CDCl_3$): δ 1.8 (s, OH), 4.16 (dd, $J = 6.0$ and 1.2 Hz, 2H), 6.10 (dt, $J = 13.3$ and 1.2 Hz, 1H), 6.27 (dt, $J = 13.3$ and 1.2 Hz, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 61.4, 120.5, 132.3.

4.4. (Z)-3-Chloro-prop-2-en-1-ol (6)

(*Z*)-1,3-dichloro-prop-1-ene (3.55 g, 32.2 mmol), K_2CO_3 (4.66 g, 44 mmol) and 40 ml of H_2O were stirred 6 h at 100°C. The mixture was cooled and extracted with Et_2O (3 × 20 ml). The organic layer was dried over $MgSO_4$ and the solvent was removed in vacuo. Purification by distillation afforded pure (*Z*)-vinylchloride **6** as a colourless oil in 63% yield (1.88 g); b.p. 74°C (40 mmHg); IR (neat, cm^{-1}) 3350, 3060, 1630, 965; ^{1}H-NMR (200 MHz, $CDCl_3$): δ 2.07 (s, OH), 4.37 (dd, $J = 6.0$ and 1.8 Hz, 2H), 6.00 (dt, $J = 7.5$ and 6.0 Hz, 1H), 6.14 (dt, $J = 7.5$ and 1.8 Hz, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 58.0, 119.5, 130.7.

4.5. Preparation of amino vinylchlorides: general procedure

To a stirred solution of (*E*) or (*Z*)-1,3-dichloropropene or 1,2-dichloropropene (5.0 g, 45 mmol), K_2CO_3 (8.3 g, 60 mmol) and KI (250 mg, 1.5 mmol) in



31a: R = *n*-C_5H_{11} **3a:** 78%

31b: R = $CH(OH)C_5H_{11}$ **19a:** 76%

Scheme 4.

acetonitrile (80 ml) were added secondary amine (30 mmol). The resulting mixture was heated to reflux. After 6 h, the reaction was hydrolyzed with brine (20 ml) and extracted with Et_2O (3 × 20 ml). The combined organic layers were dried over $MgSO_4$, and concentrated under vacuum. The residue was purified by silica gel column chromatography to give pure amino vinylchloride.

*4.5.1. (E)-N-Benzyl-N-methyl-3-chloro-prop-2-en-1-amine (**8**)*

4.75 g (81%); IR (neat, cm^{-1}) 1635, 1600, 1495, 1455. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 2.20 (s, 3H), 3.05 (d, $J = 6.4$ Hz, 2H), 3.52 (s, 2H), 6.02 (dt, $J = 13.3$ and 6.6 Hz, 1H), 6.15 (d, $J = 13.3$ Hz, 1H), 7.20 (m, 5H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 41.7, 56.8, 61.3, 120.5, 127.2, 128.3, 128.9, 130.4, 138.1. CIMS (NH_3) *m/e* (rel. int.) 198 (41), 196 (100), 122 (18), 120 (19), 108 (14), 106 (18). Anal. Calc. for $C_{11}H_{14}NCl$ (195.69): C, 67.51; H, 7.21; Found: C, 67.62; H, 7.30%.

*4.5.2. (E)-1-(3-Chloro-prop-2-enyl)-piperidine (**9**)*

4.10 g (87%); IR (neat, cm^{-1}) 1635. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 1.45 (m, 2H), 1.6 (m, 4H), 2.4 (m, 4H), 2.95 (d, $J = 6.6$ Hz, 2H), 6.01 (dt, $J = 14.7$ and 6.6 Hz, 1H), 6.12 (d, $J = 14.7$ Hz, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 25.9, 54.4, 55.4, 120.1, 128.8. Anal. Calc. for $C_8H_{14}NCl$ (159.66): C, 60.18; H, 8.84; Found: C, 60.31; H, 8.98%.

*4.5.3. (Z)-N-Benzyl-N-methyl-3-chloro-prop-2-en-1-amine (**10**)*

4.57 g (78%); IR (neat, cm^{-1}) 1635, 1600, 1495, 1460. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 2.15 (s, 3H), 3.17 (dd, $J = 6.4$ and 1.6 Hz, 2H), 3.44 (s, 2H), 5.86 (dt, $J = 7.2$ and 6.4 Hz, 1H), 6.10 (dt, $J = 7.2$ and 1.7 Hz, 1H), 7.24 (m, 5H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 42.2, 53.5, 61.8, 120.1, 127.1, 128.2, 129.0, 129.1, 138.6. Anal. Calc. for $C_{11}H_{14}NCl$ (195.69): C, 67.51; H, 7.21; Found: C, 67.69; H, 7.32%.

*4.5.4. 1-(2-Chloro-prop-2-enyl)-piperidine (**11**)*

3.69 g (77%); IR (neat, cm^{-1}) 1635. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 1.31 (m, 2H), 1.51 (quint., $J = 5.6$ Hz, 4H), 2.32 (m, 4H), 2.95 (s, 2H), 5.15 (s, 1H), 5.29 (s, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 24.3, 26.0, 54.2, 65.4, 113.7, 139.4. Anal. Calc. for $C_8H_{14}NCl$ (159.66): C, 60.18; H, 8.84; Found: C, 60.31; H, 9.06%.

*4.5.5. N,N-di-t-Butoxycarbonyl-3-chloro-prop-2-en-1-amine (**12**)*

7.7 g (88%); IR (neat, cm^{-1}) 1750, 1700, 1630, 1372, 1150, 1110. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 1.45 (s, 18H), 4.12 (dd, $J = 6.7$ and 0.9 Hz, 2H), 5.95 (dt, $J = 13.3$ and 6.8 Hz, 1H), 6.17 (d, $J = 13.3$ Hz, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 27.8, 45.5, 82.4, 121.3, 128.5, 151.7. Anal. Calc. for $C_{13}H_{22}NO_4Cl$ (291.78): C, 53.52; H, 7.60; Found: C, 53.21; H, 7.83%.

*4.5.6. Methyl (E)-5-hydroxy-7-chloro-hept-6-enoate (**14**)*

To a solution of methyl (*E*)-7-chloro-5-oxo-hept-6-enoate [24] (1.64 g, 8 mmol) and $CeCl_3$; $7H_2O$ (3.29 g, 8.8 mmol) in MeOH (20 ml) was added slowly $NaBH_4$ (342 mg, 9.05 mmol) at room temperature (r.t.). After complete addition, the reaction was stirred for 15 min. and was hydrolyzed with brine (20 ml). The aqueous layer was extracted with AcOEt (3 × 10 ml) and Et_2O (3 × 10 ml). The combined organic layers were washed with water (15 ml), dried over $MgSO_4$ and concentrated under vacuum. Purification by silica gel column chromatography gave hydroxy vinyl chloride **14** in 91% yield (1.5 g). IR (neat, cm^{-1}) 3420, 1730, 1605, 1020; ^{1}H-NMR (200 MHz, $CDCl_3$): δ 1.53 (m, 2H), 1.65 (m, 2H), 2.30 (t, 2H, $J = 7.2$Hz), 3.60 (s, 3H), 4.08 (q, $J = 7.0$ Hz, 1H), 5.90 (dd, $J = 16.0$ and 7.0 Hz, 1H), 6.15 (dd, $J = 16.0$ and 1.5 Hz, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 174.1, 135.9, 119.7, 70.5, 51.6, 36.2, 33.6, 20.5. Anal. Calc. for $C_8H_{13}O_3Cl$ (192.64): C, 49.88; H, 6.80; Found: C, 49.98; H, 6.96%.

4.6. Coupling of vinyl chlorides with terminal alkynes: general procedure

To a suspension of $PdCl_2(PhCN)_2$ (19 mg, 0.05 mmol), vinyl chloride (1 mmol), CuI (19 mg, 0.1 mmol) in piperidine (3 ml) was added alkyne (2 mmol). The reaction was stirred at r.t. and monitored by TLC analysis until complete consumption of the vinyl chloride. After 0.5–3 h, the reaction mixture was treated with saturated solution of NH_4Cl (30 ml). The aqueous layer was extracted with ether (3 × 20 ml). The combined organic layers were washed successively with aqueous HCl (0.2 M, 15 ml), $NaHCO_3$ (10 ml) and water (2 × 30 ml), dried over $MgSO_4$ and concentrated under vacuum. Purification by silica gel column chromatography afforded the corresponding pure enyne.

*4.6.1. (E)-Tetradec-8-en-6-yne (**3a**)*

179 mg (91%); IR (neat, cm^{-1}) 2115, 1610. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 0.88 (t, $J = 6.9$ Hz, 3H), 0.90 (t, $J = 6.6$ Hz, 3H), 1.20–1.60 (m, 12H), 2.08 (q, $J = 6.7$ Hz, 2H), 2.28 (td, $J = 7.1$ and 2.0 Hz, 2H), 5.45 (dt, $J = 15.8$ and 1.8 Hz, 1H), 6.06 (dt, $J = 15.7$ and 7.2 Hz, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 13.9, 14.0, 19.3, 22.2, 22.5, 28.5, 28.6, 31.0, 31.2, 32.9, 79.1, 88.6, 109.7, 143.3. Anal. Calc. for $C_{14}H_{24}$ (192.35): C, 87.42; H, 12.58; Found: C, 87.95; H, 12.85%.

*4.6.2. (Z)-Tridec-5-en-7-yne (**3b**)*

177 mg (91%); IR (neat, cm^{-1}) 2120, 1600. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 0.85 (2t, $J = 6.5$ Hz, 2 × 3H),

1.20–1.60 (m, 10H), 2.27 (m, 4H), 5.40 (m, 1H), 5.77 (td, $J = 10.6$ and 7.3 Hz, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 13.8, 13.9, 19.5, 22.2, 22.3, 28.6, 29.7, 31.0, 77.4, 94.3, 109.4, 142.4. Anal. Calc. for $C_{13}H_{22}$ (178.22): C, 87.53; H, 12.34; Found: C, 87.62; H, 12.51%.

4.6.3. (E)-1-Phenyl-non-3-en-1-yne (**15a**)

184 mg (93%); IR (neat, cm^{-1}) 2190, 1590, 1485, 1440, 1300. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 0.92 (t, $J = 6.8$ Hz, 3H), 1.27–1.51 (m, 6H), 2.18 (qd, $J = 7.2$ and 1.0 Hz, 2H), 5.71 (dt, $J = 15.8$ and 1.3 Hz, 1H), 6.27 (dt, $J = 15.8$ and 7.2 Hz, 1H), 7.27–7.46 (m, 5H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 14.0, 22.5, 28.4, 31.3, 33.2, 88.4, 87.8, 109.5, 123.6, 127.8, 128.2, 131.4, 145.3. CIMS (NH_3) *m/e* (rel. int.) 216, 199, 198 (100). Anal. Calc. for $C_{15}H_{18}$ (198.31): C, 90.85; H, 9.15; Found: C, 91.16; H, 9.42%.

4.6.4. (E)-1-Trimethylsilyl-non-3-en-1-yne (**15b**)

175 mg (90%); IR (neat, cm^{-1}) 2120, 1625, 1470, 960. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 0.16 (s, 9H), 0.86 (t, $J = 6.7$ Hz, 3H), 1.19–1.42 (m, 6H), 2.07 (qd, $J = 7.2$ and 1.2 Hz, 2H), 5.47 (dt, $J = 15.9$ and 1.5 Hz, 1H), 6.19 (dt, $J = 15.9$ and 7.0 Hz, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 0.03, 13.9, 22.4, 28.2, 31.2, 32.9, 92.3, 104.1, 109.5, 144.2. CIMS (NH_3) *m/e* (rel. int.) 212 (5), 195 (60), 175 (40), 90 (100). Anal. Calc. for $C_{12}H_{22}Si$ (194.39): C, 74.14; H, 11.41; Found: C, 74.43; H, 11.65%.

4.6.5. (E)-Dec-4-en-2-yn-1-ol (**15c**)

132 mg (87%); IR (neat, cm^{-1}) 3420, 2180, 1600, 1010, 940. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 0.86 (t, $J = 6.6$ Hz, 3H), 1.26–1.40 (m, 6H), 1.64 (s, OH), 2.08 (q, $J = 6.7$ Hz, 2H), 4.35 (d, $J = 1.8$ Hz, 2H), 5.47 (dt, $J = 15.9$ and 1.7 Hz, 1H), 6.18 (dt, $J = 15.8$ and 7.1 Hz, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 13.9, 22.4, 28.2, 31.1, 32.9, 51.5, 84.5, 85.5, 108.7, 145.7. CIMS (NH_3) *m/e* (rel. int.) 170 (72), 152 (51), 137 (100). Anal. Calc. for $C_{10}H_{16}O$ (152.24): C, 78.90; H, 10.59; Found: C, 79.12; H, 10.82%.

4.6.6. (E)-Undec-5-en-3-yn-1-ol (**15d**)

146 mg (88%); IR (neat, cm^{-1}) 3400, 2220, 1610, 1470, 1080, 960. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 0.85 (t, $J = 6.6$ Hz, 3H), 1.21–1.38 (m, 6H), 1.73 (s, OH), 2.06 (q, $J = 6.6$ Hz, 2H), 2.55 (td, $J = 6.2$ and 2.0 Hz, 2H), 3.70 (t, $J = 6.2$ Hz, 2H), 5.42 (dt, $J = 15.8$ and 1.8 Hz, 1H), 6.08 (dt, $J = 15.8$ and 7.3 Hz, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 13.9, 22.4, 23.6, 28.4, 31.2, 32.9, 61.1, 81.0, 84.6, 109.3, 144.3. Anal. Calc. for $C_{11}H_{18}O$ (166.27): C, 79.46; H, 10.91; Found: C, 79.60; H, 10.98%.

4.6.7. Methyl (E)-dodec-6-en-4-ynoate (**15e**)

154 mg (74%); IR (neat, cm^{-1}) 1740, 1600, 1440, 1170, 960. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 0.85 (t, $J = 6.7$ Hz, 3H), 1.23–1.40 (m, 6H), 2.04 (q, $J = 6.8$ Hz, 2H), 2.48–2.60 (m, 4H), 3.68 (s, 3H), 5.40 (dt, $J = 15.9$ and 1.7 Hz, 1H), 6.04 (dt, $J = 15.9$ and 7.1 Hz, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 13.9, 15.2, 22.4, 28.4, 31.2, 32.8, 33.4, 51.6, 79.8, 86.1, 109.4, 144.0, 172.3. CIMS (NH_3) *m/e* (rel. int.) 226 (72), 209 (100). Anal. Calc. for $C_{13}H_{20}O_2$ (208.30): C, 74.96; H, 9.68; Found: C, 75.03; H, 9.79%.

4.6.8. Methyl-2-dec-2-en-4-yne (**16**)

93 mg (62%); IR (neat, cm^{-1}) 2200, 1600. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 0.85 (t, $J = 7.0$ Hz, 3H), 1.20–1.50 (m, 6H), 1.70 (s, 3H), 1.80 (s, 3H), 2.27 (td, $J = 7.0$ and 2.0 Hz, 2H), 5.20 (m, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 13.9, 19.5, 20.6, 22.2, 24.4, 28.8, 31.1, 78.3, 92.0, 105.5, 146.2. Anal. Calc. for $C_{11}H_{18}$ (150.27): C, 87.93; H, 12.07; Found: C, 88.50; H, 12.42%.

4.6.9. (E)-Dec-2-en-4-yn-1-ol (**17**)

134 mg (88%); IR (neat, cm^{-1}) 3350, 2180, 1610, 1015, 950. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 0.90 (t, $J = 7.0$ Hz, 3H), 1.20–1.60 (m, 6H), 1.80 (s, OH), 2.30 (td, $J = 7.0$ and 2.0 Hz, 2H), 4.40 (dd, $J = 5.4$ and 1.7 Hz, 2H), 5.70 (dquint., $J = 15.9$ and 2.0 Hz, 1H), 6.15 (dt, $J = 15.9$ and 5.4 Hz, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 13.9, 19.3, 22.1, 26.3, 31.0, 63.0, 78.3, 91.4, 111.2, 140.1. Anal. Calc. for $C_{10}H_{16}O$ (152.24): C, 78.90; H, 10.59; Found: C, 79.45; H, 10.92%.

4.6.10. (Z)-Dec-2-en-4-yn-1-ol (**18**)

129 mg (85%); IR (neat, cm^{-1}) 3400, 2185, 1610, 1010, 950. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 0.90 (t, $J = 7.0$ Hz, 3H), 1.31 (m, 4H), 1.55 (m, 2H), 1.70 (s, OH), 2.34 (td, $J = 7.0$ and 2.1 Hz, 2H), 4.40 (d, $J = 6.2$ Hz, 2H), 5.59 (dt, $J = 10.8$ and 2.0 Hz, 1H), 6.01 (dt, $J = 11.0$ and 6.2 Hz, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 14.8, 20.5, 23.2, 29.5, 32.0, 61.6, 77.8, 92.2, 11.3, 140.1. Anal. Calc. for $C_{10}H_{16}O$ (152.24): C, 78.90; H, 10.59; Found: C, 79.38; H, 10.76%.

4.6.11. (E)-Pentadec-7-en-9-yn-6-ol (**19a**)

200 mg (90%); IR (neat, cm^{-1}) 3420, 2220, 1470, 1080. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 0.85 (t, $J = 7.0$ Hz, 3H), 0.83 (t, $J = 7.0$ Hz, 3H), 1.10–1.55 (m, 14H and OH), 2.25 (td, $J = 7.0$ and 2.0 Hz, 2H), 4.06 (q, $J = 6.2$ Hz, 1H), 5.65 (dq, $J = 16.0$ and 2.0 Hz, 1H), 5.97 (dd, $J = 16.0$ and 6.5 Hz, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 13.9, 14.0, 19.3, 22.2, 22.5, 24.9, 28.4, 31.0, 31.7, 36.9, 72.3, 78.4, 91.1, 110.4, 144.2. Anal. Calc. for $C_{15}H_{26}O$ (222.37): C, 81.02; H, 11.79; Found: C, 81.31; H, 12.02%.

4.6.12. (E)-Undec-4-en-2-yn-1,6-diol (**19b**)

153 mg (84%); IR (neat, cm^{-1}) 3400, 2260, 1470, 1180, 1030, 970. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 0.85 (t, $J = 6.5$ Hz, 3H), 1.10–1.55 (m, 8H and OH), 2.25 (sbr,

2H), 4.10 (q, $J = 6.2$ Hz, 1H), 4.34 (d, $J = 2.0$ Hz, 1H), 5.70 (dq, $J = 16.0$ and 2.0 Hz, 1H), 6.15 (dd, $J = 16.0$ and 6.2 Hz, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 13.8, 22.3, 24.8, 31.5, 36.5, 50.6, 71.8, 83.2, 87.8, 108.9, 145.9. Anal. Calc. for $C_{11}H_{18}O_2$ (182.26): C, 72.49; H, 9.95; Found: C, 72.75; H, 10.22%.

4.6.13. (E)-N-Benzyl-N-methyl-dec-2-en-4-yn-1-amine (**20a**)

220 mg (86%); IR (neat, cm^{-1}) 2220, 1600, 1495, 1365, 1135, 1075, 1025. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 0.90 (t, $J = 7.2$ Hz, 3H), 1.40 (m, 6H), 2.20 (s, 3H), 2.28 (dt, $J = 7.0$ and 1.6 Hz, 2H), 3.00 (d, $J = 6.6$ Hz, 2H), 3.50 (s, 2H), 5.64 (dt, $J = 15.8$ and 1.6 Hz, 1H), 6.11 (dt, $J = 15.8$ and 6.6 Hz, 1H), 7.30 (m, 5H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 14.0, 19.4, 22.2, 28.5, 31.1, 42.0, 59.4, 61.5, 78.6, 90.5, 113.0, 127.0, 128.1, 128.9, 138.6, 139.1. CIMS (NH_3) *m/e* (rel. int.) 256 (69), 136 (15), 123 (13), 122 (100), 120 (31), 106 (21). Anal. Calc. for $C_{18}H_{25}N$ (255.41): C, 84.65; H, 9.87; Found: C, 84.92; H, 10.02%.

4.6.14. (E)-N-Benzyl-N-methyl-5-trimethylsilyl-pent-2-en-4-yn-1-amine (**20b**)

231 mg (90%); IR (neat, cm^{-1}) 2220, 1610, 1500, 1360, 1080. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 1.20 (s, 9H), 2.30 (s, 3H), 3.27 (dd, $J = 6.4$ and 1.5 Hz, 2H), 3.60 (s, 2H), 5.85 (dt, $J = 16.0$ and 1.3 Hz, 1H), 6.40 (dt, $J = 16.0$ and 6.4 Hz, 1H), 7.40 (m, 5H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 42.2, 51.5, 56.1, 61.7, 81.6, 93.0, 111.0, 127.0, 128.2, 129.2, 138.4, 140.7. Anal. Calc. for $C_{16}H_{23}NSi$ (257.45): C, 74.65; H, 9.00; Found: C, 74.92; H, 9.29%.

4.6.15. (E)-N-Benzyl-N-methyl-hex-2-en-4-yn-6-ol-1-amine (**20c**)

157 mg (73%); IR (neat, cm^{-1}) 3400, 1630, 1600, 1490, 1450, 1160, 1020. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 2.20 (s, 3H), 3.30 (dd, $J = 6.6$ and 1.0 Hz, 2H), 3.50 (s, 2H), 4.37 (d, $J = 1.8$ Hz, 2H), 5.70 (dt, $J = 15.9$ and 1.7 Hz, 1H), 6.28 (dt, $J = 15.9$ and 6.5 Hz, 1H), 7.35 (m, 5H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 41.5, 51.2, 58.5, 61.1, 83.2, 88.3, 113.2, 127.7, 128.5, 129.5, 136.5, 139.4. CIMS (NH_3) *m/e* (rel. int.) 217 (20), 216 (100), 214 (8), 198 (8), 122 (15). Anal. Calc. for $C_{14}H_{17}NO$ (215.30): C, 78.10; H, 7.96; Found: C, 78.56; H, 8.28%.

4.6.16. (E)-N-Benzyl-N-methyl-hept-2-en-4-yn-7-ol-1-amine (**20d**)

222 mg (97%); IR (neat, cm^{-1}) 3415, 1630, 1600, 1495, 1450, 1050, 965. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 2.09 (s, 3H), 2.45 (dt, $J = 6.4$ and 1.5 Hz, 2H), 2.97 (dd, $J = 6.6$ and 1.5 Hz, 2H), 3.41 (s, 2H), 3.60 (t, $J = 6.4$ Hz, 2H), 5.54 (dquint, $J = 15.9$ and 1.5 Hz, 1H), 6.05 (dt, $J = 15.9$ and 6.6 Hz, 1H), 7.10–7.30 (m, 5H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 23.7, 41.8, 58.9, 60.9, 61.4, 80.2, 86.8, 112.8, 127.1, 128.2, 129.1, 137.9, 139.6. CIMS (NH_3) *m/e* (rel. int.) 230 (88), 136 (35), 122 (100), 120 (54), 108 (22), 106 (43). Anal. Calc. for $C_{15}H_{19}NO$ (229.32): C, 78.56; H, 8.35; Found: C, 78.86; H, 8.58%.

4.6.17. (E)-1-(Piperidin-1-yl)-undec-2-en-4-yn-6-ol (**21**)

237 mg (95%); IR (neat, cm^{-1}) 3400, 1625, 1600, 1165, 1015. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 0.85 (t, $J = 6.8$ Hz, 3H), 1.15–1.75 (m, 14H and OH), 2.35 (m, 4H), 2.95 (dd, $J = 6.8$ and 1.3 Hz, 2H), 4.40 (td, $J = 6.2$ and 1.3 Hz, 1H), 5.60 (dd, $J = 15.9$ and 1.3 Hz, 1H), 6.20 (dt, $J = 15.9$ and 6.8 Hz, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 13.8, 22.3, 23.8, 24.8, 25.2, 31.2, 37.7, 54.1, 61.2, 61.6, 81.8, 91.1, 112.1, 140.0. Anal. Calc. for $C_{16}H_{27}NO$ (249.40): C, 77.06; H, 10.91; Found: C, 77.55; H, 11.36%.

4.6.18. (Z)-N-benzyl-N-methyl-hex-2-en-4-yn-6-ol-1-amine (**22**)

138 mg (64%); IR (neat, cm^{-1}) 3430, 1630, 1600, 1490, 1450, 1160 ^{1}H-NMR (200 MHz, $CDCl_3$): δ 2.15 (s, 3H), 2.40 (s, OH), 3.20 (d, $J = 6.8$ Hz, 2H), 3.50 (s, 2H), 4.32 (d, $J = 1.9$ Hz, 2H), 5.60 (dt, $J = 11.1$ and 1.6 Hz, 1H), 6.02 (dt, $J = 10.9$ and 6.8 Hz, 1H), 7.23 (m, 5H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 42.2, 51.5, 56.1, 61.7, 81.6, 93.0, 111.0, 127.0, 128.2, 129.2, 138.4, 140.7. Anal. Calc. for $C_{14}H_{17}NO$ (215.30): C, 78.10; H, 7.96; Found: C, 78.42; H, 8.11%.

4.6.19. 1-(2-Methylene-non-3-ynyl)-piperidine (**23a**)

169 mg (77%); IR (neat, cm^{-1}) 1630, 1605, 1450. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 0.85 (t, $J = 7.3$ Hz, 3H), 1.40 (m, 12H), 2.26 (t, $J = 7.1$ Hz, 2H), 2.38 (t, $J = 4.8$ Hz, 4H), 2.92 (t, $J = 1.2$ Hz, 2H), 5.23 (s, 1H), 5.28 (t, $J = 1.2$ Hz, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 14.0, 19.3, 22.2, 24.3, 26.0, 28.4, 31.0, 54.2, 64.2, 80.6, 90.4, 121.5, 128.8. Anal. Calc. for $C_{15}H_{25}N$ (219.37): C, 82.13; H, 11.49; Found: C, 82.56; H, 11.92%.

4.6.20. 5-(Piperidinomethyl)-hex-5-en-3-yn-1-ol (**23b**)

164 mg (85%); IR (neat, cm^{-1}) 3430, 1630, 1605, 1450, 1160, 1025. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 1.50 (m, 2H), 1.52 (m, 4H), 2.30 (m, 4H), 2.48 (t, $J = 5.6$ Hz, 2H), 2.92 (t, $J = 1.1$ Hz, 2H), 3.62 (t, $J = 5.7$ Hz, 2H), 5.22 (t, $J = 1.6$ Hz, 1H), 5.26 (s, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 23.7, 24.0, 25.3, 54.1, 60.5, 66.3, 82.6, 88.7, 121.4, 128.5. Anal. Calc. for $C_{12}H_{19}NO$ (193.29): C, 74.57; H, 9.91; Found: C, 74.92; H, 10.22%.

4.6.21. 2-(Piperidinomethyl)-dec-1-en-3-yn-5-ol (**23c**)

224 mg (90%); IR (neat, cm^{-1}) 3430, 1630. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 0.80 (t, $J = 7.3$ Hz, 3H), 1.10–1.70 (m, 6H), 2.23 (s, OH), 2.32 (m, 4H), 2.91 (s, 2H), 4.42 (t, $J = 6.4$ Hz, 1H), 5.35 (s, 1H), 5.38 (s, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 13.8, 22.3, 24.0, 24.8, 25.3, 31.3, 37.35, 54.0, 61.6, 63.7, 84.0, 91.3, 123.0,

127.7. Anal. Calc. for $C_{16}H_{27}NO$ (249.40): C, 77.06; H, 10.91; Found: C, 77.88; H, 11.55%.

*4.6.22. (E)-N,N-di-t-Butoxycarbonyl-dec-2-en-4-yn-1-amine (**24a**)*

292 mg (90%); IR (neat, cm^{-1}) 2120, 1745, 1700, 1630, 1150. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 0.90 (t, $J = 7.2$ Hz, 3H), 1.35 (m, 4H), 1.48 (s, 18H), 2.40 (m, 2H), 4.30 (dd, $J = 6.2$ and 1.4 Hz, 2H), 5.60 (dt, $J = 15.7$ and 1.7 Hz, 1H), 5.97 (dt, $J = 15.7$ and 6.4 Hz, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 13.8, 19.3, 22.1, 28.0, 28.3, 31.0, 47.5, 78.3, 82.4, 91.1, 112.7, 136.6, 152.0. Anal. Calc. for $C_{20}H_{33}NO_4$ (351.49): C, 68.34; H, 9.46; Found: C, 68.85; H, 9.85%.

*4.6.23. (E)-N,N-di-t-Butoxycarbonyl-undec-2-en-4-yn-6-ol-1-amine (**24b**)*

271 mg (71%); IR (neat, cm^{-1}) 3400, 2130, 1750, 1620, 1120. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 0.90 (t, $J = 7.2$ Hz, 3H), 1.35 (m, 4H), 1.50 (s, 18H), 1.70 (m, 4H), 2.40 (m, 2H), 4.28 (dd, $J = 6.2$ and 1.3 Hz, 2H), 4.55 (m, 1H), 5.70 (dt, $J = 15.8$ and 1.6 Hz, 1H), 5.97 (dt, $J = 15.9$ and 6.1 Hz, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 13.7, 22.3, 24.6, 27.6, 31.1, 37.5, 47.3, 62.7, 82.5, 82.4, 90.6, 111.2, 138.5, 151.8. Anal. Calc. for $C_{21}H_{35}NO_5$ (381.52): C, 66.11; H, 9.25; Found: C, 66.21; H, 9.26%.

*4.6.24. (Z)-1-Tributyltin-dec-2-en-4-yne (**25**)*

264 mg (62%); IR (neat, cm^{-1}) 2120, 1620. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 0.92 (m, 18H), 1.2–1.65 (m, 18H), 2.17 (d, $J = 6.9$ and 2.0 Hz, 2H), 2.36 (td, $J = 6.9$ and 2.0 Hz, 2H), 5.12 (dq, $J = 9.5$ and 2.0 Hz, 1H), 6.05 (q, $J = 9.5$ Hz, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 9.8, 13.6, 13.9, 14.8, 19.7, 22.2, 27.3, 28.8, 29.1, 31.2, 78.2, 95.1, 102.8, 142.2. Anal. Calc. for $C_{22}H_{42}Sn$ (425.27): C, 62.14; H, 9.95; Found: C, 62.68; H, 10.65%.

*4.6.25. Methyl (E)-5-Hydroxy-9-trimethylsilyl-non-6-en-8-ynoate (**26**)*

188 mg (74%); IR (neat, cm^{-1}) 3410, 2130, 1730, 1250. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 0.01 (s, 9H), 1.38 (q, $J = 7.1$ Hz, 2H), 1.55 (quint., $J = 7.1$ Hz, 2H), 2.10 (s, OH), 2.16 (t, $J = 7.2$ Hz, 2H), 3.90 (qd, $J = 6.0$ and 1.1 Hz, 1H), 5.55 (dd, $J = 16.0$ and 1.4 Hz, 1H), 6.00 (dd, $J = 15.9$ and 6.0 Hz, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ -0.5, 20.3, 33.4, 35.7, 51.3, 71.1, 94.8, 102.9, 109.6, 146.3, 173.9. CIMS (NH_3) m/e (rel. int.) 237 (100). Anal. Calc. for $C_{13}H_{22}O_3Si$ (254.40): C, 61.38; H, 8.72; Found: C, 61.75; H, 9.03%.

*4.6.26. (E)-N-Methyl N-naphtyl methylene-3-chloro-prop-2-en-1-amine (**29**)*

206 mg (81%); IR (neat, cm^{-1}) 1635, 1600, 1500, 1460, 1365, 1135, 1025. ^{1}H-NMR (200 MHz, $CDCl_3$): δ 2.25 (s, 3H), 3.12 (d, $J = 6.2$ Hz, 2H), 3.90 (s, 2H), 6.08 (dt, $J = 13.5$ and 6.0 Hz, 1H), 6.18 (d, $J = 13.5$ Hz, 1H), 7.60 (m, 4H), 7.82 (m, 2H), 8.32 (d, $J = 8.7$ Hz, 1H). ^{13}C-NMR (50 MHz, $CDCl_3$): δ 42.0, 57.2, 59.6, 120.1, 124.5, 125.1, 125.6, 125.7, 127.3, 128.0, 128.4, 130.6, 132.4, 133.6, 134.4. Anal. Calc. for $C_{15}H_{16}NCl$ (245.75): C, 73.31; H, 6.56; Found: C, 73.65; H, 6.82%.

*4.6.27. Terbinafine (**30**)*

271 mg (93%); ^{1}H-NMR (200 MHz, $CDCl_3$): δ 1.34 (s, 9H), 2.31 (s, 3H), 3.22 (dd, $J = 6.6$ and 1.4 Hz, 2H), 3.95 (s, 2H), 5.78 (dt, $J = 15.8$ and 1.4 Hz, 1H), 6.26 (dt, $J = 15.8$ and 6.6 Hz, 1H), 7.55 (m, 4H), 7.90 (m, 2H), 8.36 (m, 1H). The spectral properties of terbinafine **30** were in good agreement with those reported in the literature [15].

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