Journal of Sulfur Chemistry
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gsrp20

Regioselective S-allylation of thiols with cyclic Baylis-Hillman acetates

Imen Erray[ab], Julie Oble[b], Giovanni Poli[b] & Farhat Rezgui[a]

[a] Laboratoire de Chimie Organique Structurale et Macromoléculaire, Faculté des Sciences Campus Universitaire, Université de Tunis El Manar, 2092 Tunis, Tunisie

[b] UMR 7201 - CNRS, Institut Parisien de Chimie Moléculaire, Université Pierre et Marie Curie, Case 229 Bât F. 2e étage 4, Place Jussieu, 75252 Paris Cedex 05, France

Published online: 10 Jul 2013.

To cite this article: Imen Erray, Julie Oble, Giovanni Poli & Farhat Rezgui (2014) Regioselective S-allylation of thiols with cyclic Baylis-Hillman acetates, Journal of Sulfur Chemistry, 35:2, 128-136, DOI: 10.1080/17415993.2013.809453

To link to this article: http://dx.doi.org/10.1080/17415993.2013.809453

Journal of Sulfur Chemistry, 2014
Vol. 35, No. 2, 128–136, http://dx.doi.org/10.1080/17415993.2013.809453

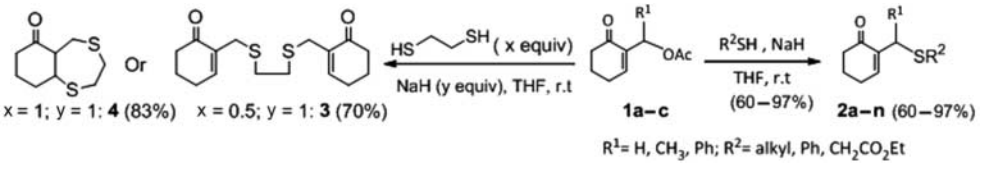
Regioselective *S*-allylation of thiols with cyclic Baylis–Hillman acetates

Imen Erray[a,b], Julie Oble[b], Giovanni Poli[b] and Farhat Rezgui[a]*

[a]*Laboratoire de Chimie Organique Structurale et Macromoléculaire, Faculté des Sciences Campus Universitaire, Université de Tunis El Manar, 2092 Tunis, Tunisie;* [b]*UMR 7201 – CNRS, Institut Parisien de Chimie Moléculaire, Université Pierre et Marie Curie, Case 229 Bât F. 2e étage 4, Place Jussieu, 75252 Paris Cedex 05, France*

(*Received 2 April 2013; final version received 23 May 2013*)

An efficient and mild *S*-allylation of thiols with cyclic Baylis–Hillman acetates with no need of a transition-metal-catalyst or an expensive additive is described. Allyl sulfides are prepared in good to excellent yields (60–97%) and a single regioisomer was observed in all cases.



Keywords: Baylis–Hillman; nucleophilic substitution; conjugate addition; allyl sulfides; regioselectivity

1. Introduction

Nucleophilic allylic substitutions are useful transformations in organic chemistry that are often utilized as powerful tools for the construction of carbon–carbon and carbon-heteroatom bonds in the synthesis of complex organic molecules.[1] Highly reactive allylic substrates smoothly react with a large variety of nucleophiles with no need for catalysts[2] while less reactive ones first require activation toward substitution reactions using transition metal catalysts such as palladium ([3] and references therein) and ruthenium.[4–6] In this context, a large number of synthetic methods involving carbon, nitrogen, and oxygen nucleophiles have been previously reported.[7–15] However, synthetic approaches, using transition metal-free or transition-metal-catalyzed *S*-allylation of thiols, are not yet well-developed,[16] presumably due to the poisoning of metal catalysts by coordinating-sulfur[17–19] and the low selectivity of such procedures.[20, 21]

Therefore, a clean and economical *S*-allylation is still a very attractive goal for the construction of carbon–sulfur bonds, especially in functionalized allylic compounds such as Baylis–Hillman (BH) adducts. As it so happens, reactions of acyclic BH acetates with thiols,[22, 23] sulfonylhydrazides,[24] and thiolacetic acid,[25] under basic conditions, afforded

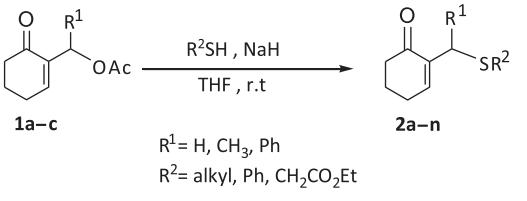
*Corresponding author. Email: rez_far@yahoo.fr

the corresponding S_N2' products whereas treatment of acyclic BH alcohols [22, 26] or their corresponding tert-butyldimethylsilyl ethers [22] with thiols resulted in the formation of Michael adducts.

In the course of our study on the chemistry of cyclic BH adducts, we have previously reported the *S*-allylation of alkyl alcohols and thiols with 2-(hydroxymethyl)cyclohex-2-en-1-one in the presence of p-TsOH [27] as well as the *C*-allylation of β-dicarbonyl compounds with either cyclic BH acetates[28] or even with their corresponding alcohols,[29] *through* a Tsuji-Trost-type reaction. To the best of our knowledge, the *S*-allylation of thiols with cyclic BH acetates has not been extensively studied in the presence of a transition metal-catalyst or under catalyst-free conditions. Hence, we wish to report in this paper an efficient highly regioselective transition metal-free *S*-allylation of a variety of thiols with BH acetates **1a–c** under mild reaction conditions (THF at room temperature).

2. Results and discussions

In our preliminary attempt, a mixture of thiophenol and the BH acetate **1a** in THF was carried out without any additive, first at room temperature, then at reflux for 8 h. In this case, we have observed that the starting materials were recovered, presumably because the thiophenol is not sufficiently nucleophilic to convert the acetate **1a** into the corresponding allylic sulfur compound **2a**. Therefore, we investigated, in THF at room temperature, the behavior of the acetate **1a** toward sodium thiophenolate which would be more nucleophilic than the corresponding thiophenol. Under these conditions, we have actually observed a catalyst-free total conversion of the acetate **1a** into the S_N2-type product **2a** (For previous reports on α-(alkylthioalkyl)cyclic enones, see [30–33]) in 72% yield (Table 1, Entry 1) (Scheme 1).



Scheme 1. S-allylation of thiols with BH acetates **1a–c.**

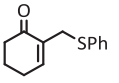
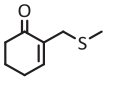
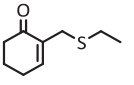
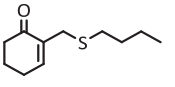
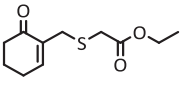
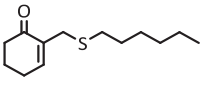
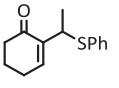
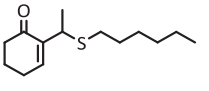
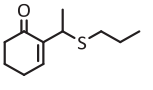
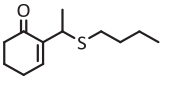
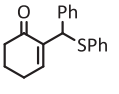
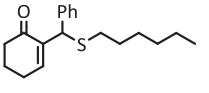
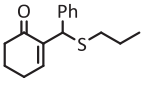
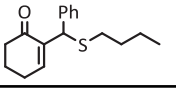
According to our previous work[28, 29] and previous papers[31, 32, 34–36] on the allylic nucleophilic substitutions of cyclic BH adducts, we believe that the reaction starts with a β-conjugate addition of sodium thiolate to Michael acceptor **1a**, followed by the elimination of acetate ion, to afford the intermediate **I**. Subsequent β′-conjugate addition of sodium thiolate to **I** and elimination of the thiolate ion, provides the thermodynamically stable product **2a**, which is then the result of two consecutive S_N2' reactions through a *one pot* addition-elimination sequence.

Another alternative reaction mechanism could be proposed for the reaction of allylic acetates with thiols, suggesting an anchimeric assistance of the acetoxy moiety.[37]

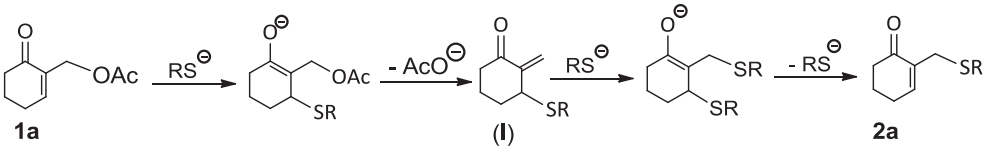
In order to demonstrate the scope and the limitation of this interesting synthetic methodology, we investigated, under the above reaction conditions (THF at room temperature) the reactivity of a variety of sodium thiolates toward the acetate **1a** (Table 1, Entries 2–6) as well as with differentially α-substituted BH acetates **1b–c** (Table 1, Entries 7–14). Our results, listed in Table 1, showed the total conversion of all acetates **1a–c** into the corresponding allyl sulfides **2b–n** in 60–97% yields.

Encouraged by these successful results on the allylation of thiols with BH acetates **1a–c**, under these mild conditions, we attempted to extend this simple synthetic methodology to ethane

Table 1. *S*-allylation of thiols with BH acetates **1a–c**.

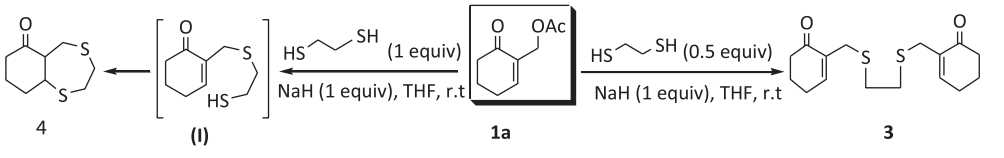
Entry	R^1	Thiol	Product **2**	Yield (%)
1	H(**1a**)	PhSH	**2a**: 	72
2	H(**1a**)	MeSH	**2b**: 	83
3	H(**1a**)	EtSH	**2c**: 	61
4	H(**1a**)	*n*-BuSH	**2d**: 	63
5	H(**1a**)	EtO_2CCH_2SH	**2e**: 	73
6	H(**1a**)	$CH_3(CH_2)_4CH_2SH$	**2f**: 	84
7	CH_3(**1b**)	PhSH	**2g**: 	60
8	CH_3(**1b**)	$CH_3(CH_2)_4CH_2SH$	**2h**: 	80
9	CH_3(**1b**)	$CH_3CH_2CH_2SH$	**2i**: 	81
10	CH_3(**1b**)	*n*-BuSH	**2j**: 	60
11	Ph(**1c**)	PhSH	**2k**: 	75
12	Ph(**1c**)	$CH_3(CH_2)_4CH_2SH$	**2l**: 	97
13	Ph(**1c**)	$CH_3CH_2CH_2SH$	**2m**: 	85
14	Ph(**1c**)	*n*-BuSH	**2n**: 	92

1,2-dithiol in a suspension of NaH in THF. In this case, 0.5 equiv of sodium ethane 1,2-bis(thiolate), *in situ* generated from 0.5 equiv of ethane dithiol and 1 equiv of NaH at 0°C, reacted with 1 equiv of acetate **1a**, at room temperature, in the same way as observed for the sodium thiolates, to give the bis-S_N2 type product **3** in 70% yield (Scheme 2).[32]



Scheme 2. Proposed mechanism for the conversion of **1a** to **2a.**

On the other hand, when 1 equiv of ethane 1,2-dithiol was left to react, under the previous conditions, but with 1 equiv of NaH, the monosodium salt of ethane 1,2-dithiol was obtained; its thiolate moiety further reacted, similarly to the above thiolates, with the acetate **1a**, to give the allyl sulfur adduct **I**. The latter, bearing a thiol moiety as a soft nucleophile, subsequently reacted in an intramolecular 1,4-addition on the cyclic enone subunit, to finally afford the bicyclic 1,4-dithiane derivative **4** in 83% overall yield (Scheme 3).[32]



Scheme 3. Reactions of acetate **1a** with ethane 1,2-dithiol.

3. Conclusions

We have developed a mild and highly regioselective catalyst-free *S*-allylation of thiols with BH acetates in moderate to excellent yields. Moreover, the behavior of ethane 1,2-dithiol/NaH toward the acetate **1a** was investigated and we have disclosed that the sodium ethane 1,2-bis(thiolate) gave the bis allylation compound **3** while the monosodium salt of ethane 1,2-dithiol afforded the 1,4-dithiane derivative **4**.

4. Experimental section

4.1. *General*

IR spectra were recorded on a Bruker (IFS 66v/S) spectrometer. ^{1}H NMR and ^{13}C NMR spectra were recorded on a Bruker AC-300 spectrometer (300 MHz for ^{1}H and 75 MHz for ^{13}C) in $CDCl_3$, using TMS as an internal standard (chemical shift in δ values, J in Hz). High resolution mass spectra (HRMS) were recorded as ESI-HRMS on an Auto Spec Ultima/micromass mass spectrometer.

Analytical thin layer chromatography was performed using Fluka Kieselgel 60 F_{254} precoated silica gel plates. Visualization was achieved by UV light (254 nm). Flash chromatography was performed using Merck silica gel 60 and a gradient solvent system (pet-ether/ether as eluent).

4.2. *Typical procedure for the preparation of sulfur compounds 2a–n*

To a suspension of NaH (8 mmol, 192 mg), in dry THF (20 mL) at 0°C, was added a solution of thiol (8 mmol) in THF (2 mL). The reaction mixture was then stirred at room temperature for 30 min. the allyl acetate **1a** (6 mmol, 1.008 g) in dry THF (10 mL) was added dropwise at 0°C. The resulting mixture was stirred at room temperature for a further 1 h. The reaction mixture was partitioned between water (20 mL) and ether (30 mL). The aqueous phase was extracted with ether (3×20 mL). The ether extracts were washed with brine, dried over $MgSO_4$, and concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (ether/petroleum ether: 1/4).

4.2.1. *2-(Phenylthiomethyl)cyclohex-2-en-1-one (**2a**)*

Yield = 72%; yellow oil; IR ($CHCl_3$): 1680, 1590, 1480, 1440 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): 7.33–7.00 (m, 5H), 6.67 (t, $J = 4.0$ Hz,1H), 3.67–3.53 (m, 2H), 2.50–1.67 (m, 6H); ^{13}C NMR (75 MHz, $CDCl_3$): 197.6, 147.3, 135.8, 134.6, 129.8, 128.4, 126.0, 37.9, 32.2, 25.6, 22.5; MS (EI): m/z (%) 53(46), 79(55.4), 81(98), 110(54.5), 185(36.6), 218($C_{13}H_{14}OS$, M^+, 100).

4.2.2. *2-(Methylthiomethyl)cyclohex-2-en-1-one (**2b**)*

Yield = 83%; yellow oil; IR ($CHCl_3$): 1670 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): 6.91 (t, $J =$ 4.0 Hz, 1H), 3.25 (s, 2H), 2.48–2.42 (m, 4H), 2.03 (s, 3H), 2.06–1.98 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): 197.5, 146.2, 135.1, 37.8, 31.6, 25.4, 22.4, 15.0; MS (EI): m/z (%) 53(41), 79(46), 141(38), 156 ($C_8H_{12}OS$, M^+, 100).

4.2.3. *2-(Ethylthiomethyl)cyclohex-2-en-1-one (**2c**)*

Yield = 61%; yellow oil; IR ($CHCl_3$): 1660 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): 6.90 (t, $J =$ 4.0 Hz, 1H), 3.30 (s, 2H), 2.50 (m, 6H), 2.00 (m, 2H), 1.26 (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 198.0, 146.5, 136.1, 38.1, 29.3, 25.8, 25.83, 22.8, 14.2; MS (EI): m/z (%) 53(52), 82(97), 110(91), 141(100), 170($C_9H_{14}OS$, M^+, 90).

4.2.4. *2-(Butylthiomethyl)cyclohex-2-en-1-one (**2d**)*

Yield = 63%; yellow oil; IR ($CHCl_3$): 1662 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): 6.90 (t, $J =$ 4.0 Hz, 1H), 3.33 (s, 2H), 2.66–2.33 (m, 6H), 2.10–1.80 (m, 2H), 1.60–1.00 (m, 4H), 0.9 (t, $J = 4.0$ Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 197.9, 146.4, 136.1, 38.1, 31.6, 31.1, 29.8, 25.7, 22.7, 21.7, 13.4; MS (EI): m/z (%) 53(63), 82(97), 110(100), 141(60), 198($C_{11}H_{18}OS$, M^+, 33).

4.2.5. *2-(Ethoxycarbonylmethylthiomethyl)cyclohex-2-en-1-one (**2e**)*

Yield = 73%; yellow oil; IR ($CHCl_3$): 1740, 1725, 1670 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): 6.93 (t, $J = 4.1$ Hz, 1H), 4.17 (q, $J = 7.0$ Hz, 2H), 3.40 (s, 2H), 3.15 (s, 2H), 2.67–1.80 (m, 6H), 1.27 (t, $J = 7.1$ Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 197.8, 170.2, 147.4, 135.1, 61.1, 38.1, 33.0, 30.2, 25.8, 22.7, 14.0; MS (EI): m/z (%) 53(36.0), 79(72.7), 141(100), 182(45.7), 228($C_{11}H_{16}O_3S$, M^+, 20.53).

4.2.6. *2-(Hexylthiomethyl)cyclohex-2-en-1-one (**2f**)*

Yield = 84%; yellow oil; IR: 1673 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): 6.91 (t, $J = 4.2$ Hz, 1H), 3.29 (d, $J = 3$ Hz, 2H), 2.48–2.41 (m, 6H), 2.07–1.97 (m, 2H), 1.61–1.52 (m, 2H), 1.39–1.25 (m, 6H), 0.88 (t, $J = 7.5$ Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 198.1, 146.6, 136.5, 38.4, 32.3, 31.5, 30.3, 29.7, 28.6, 26.1, 23.0, 22.8, 14.0; HRMS (ESI): calcd for $C_{13}H_{22}OSNa$ $[M + Na]^+$ 249.1289, found 249.1284.

4.2.7. *2-(1-(Phenylthio)ethyl)cyclohex-2-en-1-one (**2g**)*

Yield = 60%; yellow oil; IR: 1670 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): 7.34–7.19 (m, 5H), 6.85 (t, $J = 3$ Hz, 1H), 4.46 (q, $J = 7.1$ Hz, 1H), 2.42 (t, $J = 7.5$ Hz, 2H), 2.35–2.29 (m, 2H), 1.97–1.9 (m, 2H), 1.34 (d, $J = 7.1$ Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 197.3, 145.7, 140.4, 135.0, 135.52, 128.6, 126.9, 39.0, 38.4, 25.9, 22.6, 20.8; HRMS (ESI): calcd for $C_{14}H_{16}OSNa$ $[M + Na]^+$ 255.0819, found 255.0814.

4.2.8. *2-(1-(Hexylthio)ethyl)cyclohex-2-en-1-one (**2h**)*

Yield = 80%; yellow oil; IR: 1674 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): 7.03 (t, $J = 4.2$ Hz, 1H), 4.05 (q, $J = 7.1$ Hz, 1H), 2.48–2.41 (m, 6H), 2.04–1.95 (m, 2H), 1.59–1.49 (m, 2H), 1.37–1.24 (m, 6H), 1.33 (d, $J = 7.0$ Hz, 3H), 0.88 (t, $J = 7.5$ Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 197.5, 144.9, 142.0, 38.6, 36.0, 31.7, 31.5, 29.6, 28.67, 26.1, 22.9, 22.5, 21.5, 14.0; HRMS (ESI): calcd for $C_{14}H_{24}OSNa$ $[M + Na]^+$ 263.1445, found 263.1440.

4.2.9. *2-(1-(Propylthio)ethyl)cyclohex-2-en-1-one (**2i**)*

Yield = 81%; yellow oil; IR: 1670 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): 7.07 (t, $J = 4.2$ Hz, 1H), 4.02 (q, $J = 7$Hz, 1H), 2.49–2.39 (m, 6H), 2.04–1.95 (m, 2H), 1.61–1.51 (m, 2H), 1.35 (d, $J = 7$ Hz, 3H), 0.96 (t, $J = 7.5$ Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 197.7, 145.1, 141.8, 38.6, 35.8, 33.64, 26.1, 22.9, 22.82, 21.4, 13.58; HRMS (ESI): calcd for $C_{11}H_{18}OSNa$ $[M + Na]^+$ 221.0976, found 221.0971.

4.2.10. *2-(1-(Butylthio)ethyl)cyclohex-2-en-1-one (**2j**)*

Yield = 60%; yellow oil; IR: 1672.02 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): 7.03 (t, $J = 4.2$ Hz, 1H), 4.04 (q, $J = 7.0$ Hz, 1H), 2.49–2.42 (m, 6H), 2.04–1.97 (m, 2H), 1.56–1.51 (m, 2H), 1.43–1.39 (m, 2H), 1.34 (d, $J = 7.0$ Hz, 3H), 0.89 (t, $J = 7.5$ Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 197.8, 145.2, 141.8, 38.9, 35.8, 31.6, 31.2, 26.1, 22.8, 22.1, 21.7, 13.7; HRMS (ESI): calcd for $C_{12}H_{20}OSNa$ $[M + Na]^+$ 235.1133, found 235.1127.

4.2.11. *2-((Phenylthio)benzyl)cyclohex-2-en-1-one (**2k**)*

Yield = 75%; yellow oil; IR: 1671.04 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): 7.38–7.08 (m, 11H), 5.69 (s, 1H), 2.40–2.29 (m, 4H), 1.91–1.82 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): 197.0, 148.1, 139.9, 138.9, 134.7, 132.7, 129.9, 129.5, 128.8, 128.5, 126.4, 48.6, 38.2, 26.0, 22.0; HRMS (ESI): calcd for $C_{19}H_{18}OSNa$ $[M + Na]^+$ 317.0976, found 317.0971.

4.2.12. *2-((Hexylthio)benzyl)cyclohex-2-en-1-one (**2l**)*

Yield = 97%; yellow oil; IR: 1674.91 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): 7.39–7.16 (m, 5H), 7.11 (t, $J = 4.0$ Hz, 1H), 5.22 (s, 1H), 2.40–2.32 (m, 6H), 1.95–1.89 (m, 2H), 1.54–1.47 (m, 2H), 1.33–1.20 (m, 6H), 0.85 (t, $J = 6.0$ Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 197.0, 147.2, 142.7, 141.0, 128.4, 128.3, 126.9, 45.5, 38.3, 32.4, 31.3, 29.4, 29.2, 26.1, 22.6, 22.5, 13.6; HRMS (ESI): calcd for $C_{19}H_{26}OSNa$ $[M + Na]^+$ 325.1602, found 325.1597.

4.2.13. *2-((Propylthio)benzyl)cyclohex-2-en-1-one (**2m**)*

Yield = 85%; yellow oil; IR: 1672.02 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): 7.40–7.18 (m, 5H), 7.12 (t, $J = 4.0$ Hz, 1H), 5.22 (s, 1H), 2.44–2.31 (m, 6H), 1.99–1.89 (m, 2H), 1.58–1.49 (m, 2H), 0.92 (t, $J = 7.5$ Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 197.1, 147.3, 142.7, 139.9, 128.3, 128.2, 127.9, 45.4, 38.4, 32.1, 26.1, 22.9, 22.8, 13.5; HRMS (ESI): calcd for $C_{16}H_{20}OSNa$ $[M + Na]^+$ 283.1133, found 283.1127.

4.2.14. *2-((Butylthio)benzyl)cyclohex-2-en-1-one (**2n**)*

Yield = 92%; yellow oil; IR: 1673.58 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): 7.40–7.19 (m, 5H), 7.12 (t, $J = 4.2$ Hz, 1H), 5.22 (s, 1H), 2.43–2.33 (m, 6H), 2.00–1.88 (m, 2H), 1.54–1.46 (m, 2H), 1.37–1.30 (m, 2H), 0.85 (t, $J = 7.5$ Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): 197.2, 147.3, 143.0, 140.0, 128.3, 128.2, 127.9, 45.5, 38.4, 32.0, 31.1, 26.1, 22.6, 21.9, 13.6; HRMS (ESI): calcd for $C_{17}H_{22}OSNa$ $[M + Na]^+$ 297.1289, found 297.1284.

4.2.15. *2,2′-((Ethane-1,2-diyl(disulfanyl)dimethyl)dicyclohex-2-en-1-one (**3**)*

To a suspension of NaH (6 mmol, 144 mg) in dry THF (15 mL), was added, under nitrogen, ethane 1,2-dithiol (3 mmol, 282 mg) dropwise at 0°C. The reaction mixture was stirred at room temperature for 30 min. 2-(Acetoxymethyl)cyclohex-2-en-1-one **1a** (6 mmol, 1.008 g) in dry THF (10 mL) was then added dropwise at 0°C. The reaction mixture was stirred at room temperature for a night and then partitioned between water (20 mL) and dichloromethane (40 mL). The aqueous phase was extracted with dichloromethane (3 × 20 mL). The combined organic phase was washed with brine, dried over $MgSO_4$ and concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (ether/light petroleum ether: 2/1). Yield = 70%; yellow oil; IR ($CHCl_3$): 1710, 1670, 1420 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): 6.94 (t, $J = 4.2$ Hz, 2H), 3.32 (d, $J = 3.0$ Hz, 4H), 2.67 (s, 4H), 2.49–2.42 (m, 8H), 2.04–1.99 (m, 4H); ^{13}C NMR (75 MHz, $CDCl_3$): 198.0, 147.3, 136.0, 38.3, 31.9, 30.0, 26.0, 22.9; HRMS (ESI): calcd for $C_{16}H_{22}O_2S_2Na$ $[M + Na]^+$ 333.0959, found 333.0953.

4.2.16. *2,5-Dithia-bicyclo[5.4.0]undecan-8-one (**4**)*

To a suspension of NaH (6 mmol, 144 mg) in dry THF (15 mL), was added, under nitrogen, ethane 1,2-dithiol (6 mmol, 564 mg) dropwise at 0°C. The reaction mixture was stirred at room temperature for 30 min. 2-(Acetoxymethyl)cyclohex-2-en-1-one **1a** (6 mmol, 1.008 g) in dry THF (10 mL) was then added dropwise at 0°C. The reaction mixture was stirred at room temperature for a night and then partitioned between water (20 mL) and dichloromethane (40 mL). The aqueous phase was extracted with dichloromethane (3 × 20 mL). The combined organic phase was washed with brine, dried over $MgSO_4$ and concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (ether/light petroleum ether: 2/1). Yield = 83%;

mp = 150–152°C; IR ($CHCl_3$): 1710, 1410 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): 4.26–2.74 (m, 8H), 2.43–2.23 (m, 6H); ^{13}C NMR (75 MHz, $CDCl_3$): 208.9, 60.1, 55.1, 49.8, 41.7, 40.4, 39.2, 39.1, 36.8, 33.1, 32.8, 22.8; MS (EI) *m/s*: 97 (22.3), 110 (54.1), 174 (16.9), 202 ($C_9H_{14}OS_2$, M^+, 100).

Acknowledgements

We gratefully acknowledge financial support of this work by the Ministry of Higher Education of Tunisia.

References

[1] Trost BM, Crawley ML. Asymmetric transition-metal-catalyzed allylic alkylations: applications in total synthesis. Chem Rev. 2003;103:2921–2943.
[2] Han X, Zhang Y, Wu J. Mild two-step process for the transition-metal-free synthesis of carbon-carbon bonds from allylic alcohols/ethers and Grignard reagents. J Am Chem Soc. 2010;132:4104–4106.
[3] Sato Y, Yoshino T, Mori, M. Pd-catalyzed allylic substitution using nucleophilic *N*-heterocyclic carbene as a ligand. Org Lett. 2003;5:31–33.
[4] Kondo T, Morisaki Y, Uenoyama S-Y, Wada K, Mitsudo T-A. First ruthenium-catalyzed allylation of thiols enables the general synthesis of allylic sulfides. J Am Chem Soc. 1999;121:8657–8658.
[5] Bayer A, Kazmaier U. Highly regioselective ruthenium-catalyzed allylic alkylations of chelated enolates. Org Lett. 2010;12:4960–4963.
[6] Kawatsura M, Sato M, Tsuji H, Ata F, Itoh T. Retention of regiochemistry and chirality in the ruthenium catalyzed allylic alkylation of disubstituted allylic esters. J Org Chem. 2011;76:5485–5488.
[7] Evans PA, Nelson JD. Conservation of absolute configuration in the acyclic rhodium-catalyzed allylic alkylation reaction: evidence for an enyl ($\sigma + \pi$) organorhodium intermediate. J Am Chem Soc. 1998;120:5581–5582.
[8] Companyo X, Valero G, Ceban V, Calvet T, Font-Bardia M, Moyano A, Rios R. Enantioselective organocatalytic asymmetric allylic alkylation. Bis(phenylsulfonyl)methane addition to MBH carbonates. Org Biomol Chem. 2011;9:7986–7989.
[9] Benfatti F, Cardillo G, Gentilucci L, Mosconi E, Tolomelli A. Synthesis of dehydro-β-amino esters *via* highly regioselective amination of allylic carbonates. Org Lett. 2008;10:2425–2428.
[10] Liu Y-L, Liu L, Wang D, Chen Y-J. A highly α-regioselective $In(OTf)_3$-catalyzed *N*-nucleophilic substitution of cyclic Baylis–Hillman adducts with aromatic amines. Tetrahedron. 2009;65:3473–3479.
[11] Huang J-R, Cui H-L, Lei J, Sun X-H, Chen Y-C. Organocatalytic chemoselective asymmetric *N*-allylic alkylation of enamides. Chem Commun. 2011;47:4784–4786.
[12] Garzon C, Attolini M, Maffei M. Synthesis of β-aminovinylphosphonates by organocatalytic nucleophilic displacement of acetate with amines. Tetrahedron Lett. 2010;51:3772–3774.
[13] Kim H, Lee C. A Mild and efficient method for the stereoselective formation of C−O Bonds: palladium-catalyzed allylic etherification using Zinc(II) alkoxides. Org Lett. 2002;4:4369–4371.
[14] Saha A, Leazer J, Varma RS. *O*-Allylation of phenols with allylic acetates in aqueous media using a magnetically separable catalytic system. Green Chem. 2012;14:67–71.
[15] Basavaiah D, Reddy BS, Badsara SS. Recent contributions from the Baylis-Hillman reaction to organic chemistry. Chem Rev. 2010;110:5447–5674.
[16] Saha A, Ranu BC. Transition metal-free activation of allylic acetates toward regioselective S-allylation of thiols. Tetrahedron Lett. 2010;51:1902–1905.
[17] Goux C, Lhoste P, Sinou, D. Palladium(0)-catalyzed alkylation of thiols. Tetrahedron. 1994;50:10321–10330.
[18] Komine N, Sako A, Hirahara S-Y, Hirano M, Komiya S. Selective allylation of arenethiols using water-soluble palladium complex catalyst in recyclable water/hexane biphasic media. Chem Lett. 2005;34:246–247.
[19] Kondo T, Morisaki Y, Uenoyama S-Y, Wada K, Mitsudo T-A. First ruthenium-catalyzed allylation of thiols enables the general synthesis of allylic sulfides. J Am Chem Soc. 1999;121:8657–8658.
[20] Tamura S, Shiomi A, Kaneko M, Ye Y, Yoshida M, Yoshikawa M, Kimura T, Kobayashi M, Murakami N. New rev-export inhibitor from *Alpinia galanga* and structure–activity relationship. Bioorg Med Chem Lett. 2009;19:2555–2557.
[21] Gao N, Zheng S, Yang W, Zhao X. Carbon-sulfur bond formation *via* iridium-catalyzed asymmetric allylation of aliphatic thiols. Org Lett. 2011;13:1514–1516.
[22] Kamimura A, Morita R, Matsuura K, Mitsudera H, Shirai M. A convenient stereoselective synthesis of β-lactams from β-hydroxy-α-thioalkylesters prepared from Michael/aldol tandem reaction or stereoselective addition of thiols to the Baylis–Hillman adducts. Tetrahedron. 2003;59:9931–9938.
[23] Das B, Chowdhury N, Damodar K, Banerjee J. A mild and efficient stereoselective synthesis of (*Z*)- and (*E*)-allyl sulfides and potent antifungal agent, (*Z*)-3-(4-methoxybenzylidene)thiochroman-4-one from Morita–Baylis–Hillman acetates. Chem Pharm Bull. 2007;55:1274–1276.
[24] Li X, Xu X, Tang Y. Tetrabutylammonium iodide catalyzed allylic sulfonylation of Baylis–Hillman acetates with sulfonylhydrazides in water. Org Biomol Chem. 2013;11:1739–1742.

[25] Cha MJ, Song YS, Lee K-J. Synthesis of symmetric diallyl disulfides from Baylis-Hillman acetates. Bull Korean Chem Soc. 2006;27:1900–1902.
[26] Ramesh C, Lei P-M, Kavala V, Kuo C-W, Yao C-F. A convenient one-pot preparation of 2-methyl-3-(phenylthiomethyl)quinolines from Morita-Baylis-Hillman adducts and their oxidation to the corresponding sulfones. Molecules. 2012;17:5081–5094.
[27] Gatri R, Rezgui F, El Gaied MM. Regioselective reaction of a cyclic Baylis-Hillman adduct with alcohols and thiols. J Chem Res. 2002;8:366–367.
[28] Rezgui F, El Gaied MM. Réaction régiospécifique des carbanions stabilisés avec la 2-(acétoxyméthyl)cyclohex-2-én-1-one: Synthèse de diénones bicycliques. Tetrahedron. 1997;53:15711–15716.
[29] Mhasni O, Rezgui F. The first DMAP-mediated palladium-free Tsuji-Trost-type reaction of cyclic and acyclic Baylis–Hillman alcohols with active methylene compounds. Tetrahedron Lett. 2010;51:586–587.
[30] Cohen T, Kosarych Z, Suzuki K, Yu L-C. [2,3]-Sigmatropic rearrangement of an *in situ* prepared ylide and a thioether to thio ester conversion as key steps in short syntheses of sarkomycin and its phenylthio ester. J Org Chem. 1985;50:2965–2968.
[31] Tamura R, Tamai S, Suzuki H. New substitution reaction of allylic nitro compounds. Regioselective replacement of nitro group in cyclic α-(nitroalkyl)enones by nucleophiles. Tetrahedron Lett. 1989;30:2413–2416.
[32] Tamura R, Katayama H, Watabe K, Suzuki H. Regioselective replacement of nitro or sulfonyl group in cyclic α-(nitroalkyl)- or α-(phenylsulfonylalkyl)enones by nucleophiles. Tetrahedron. 1990;46:7557–7568.
[33] Baraldi PG, Achille B, Simoneta B, Piero PG, Vinicio Z. 2,3a,5,6,7,7a-Hexahydro-3h,4h-benzothiophene-3,4-dione and cyclopenta [b]-tetrahydrothiophene-3,4-dione enolate anions as synthetic equivalents to cyclohex-2-enone and cyclopent-2-enone c-2-carbanions. Tetrahedron Lett. 1984;25:4291–4294.
[34] Tamura R, Tamai S, Katayama H, Suzuki H. Me_3SiCl promoted conjugate addition of organocuprates to base-sensitive cyclic α-(nitroalkyl)enones. Tetrahedron Lett. 1989;30:3685–3688.
[35] Okamoto S, Kobayashi Y, Kato H, Hori K, Takahashi T, Tsuji J, Sato F. Prostaglandin synthesis via two-component coupling. Highly efficient synthesis of chiral prostaglandin intermediates 4-alkoxy-2-alkyl-2-cyclopenten-1-one and 4-alkoxy-3-alkenyl-2-methylenecyclopentan-1-one. J Org Chem. 1988;53:5590–5592.
[36] Takahashi T, Hori K, Tsuji J. Regiospecific carbon-carbon bond formation at α and β positions in cyclic ketones *via* double Michael addition to α-methylene-β-alkoxy cyclic ketone. Tetrahedron Lett. 1981;22:119–122.
[37] Nayak SK, Thijs L, Zwanenburg B. Baylis-Hillman reaction of *N*-trityl aziridine-2-(S)-carboxaldehyde. Tetrahedron Lett. 1999;40:981–984.