Catalysis Science & Technology

Accepted Manuscript

ROYAL SOCIETY OF CHEMISTRY

www.rsc.org/catalysis

Journal Name

ARTICLE

Organoselenium-Catalyzed Selectivity-Switchable Oxidation of *β-Ionone*†

Received 00th January 20xx,
Accepted 00th January 20xx

DOI: 10.1039/x0xx00000x

www.rsc.org/

Lei Yu,*[ab] Zengbing Bai,[a] Xu Zhang[ab] Xiaohong Zhang,[a] Yuanhua Ding[a] and Qing Xu[ab]

Catalyzed by the organoselenium compounds, β-*Ionone* was easy to be oxidized by H_2O_2 under mild and clean conditions. We were very surprised to find that the reaction selectivity was switchable by the catalyst. To the best of our knowledge, this should be the first example for the selectivity regulation using organoselenium catalysts in the field, indicating the great potential of the organoselenium catalysis in synthetic organic chemistry in future.

Introduction

Organoselenium compounds have attracted much attention owning to their wide applications in organic synthesis, biochemistry, medicinal chemistry and material science.[1-2] Recently, the green side of organoselenium chemistry is gradually realized by chemists[3] and organoselenium-catalysis should be its most significant application in green chemistry.[4] Compared with transition metal catalysts, the organoselenium catalysts have many advantages. Selenium is a necessary trace element for animals that can be metabolized in organism, and thus does not accumulate in body and is safe to environment.[5] Selenium is cheaper (*ca*. $54/kg)[6] than noble metals and the organoselenium catalysts are always employed free of ligands or additives. The organoselenium-catalyzed reactions are performed under mild conditions with green procedures,[7-8] and may provide more opportunities to discover novel reactions and enrich the toolbox for organic synthesis.[9] During the past decade, organoselenium catalysts have been widely employed in many useful transformations.[7-10] As a part of our continuous investigations on green synthetic methodologies,[8,11] we focused much on this topic and have reported a series of organoselenium-catalyzed reactions, such as the dehydrations of aldoximes to nitriles,[8a] the Baeyer-Villiger (BV) oxidations of α,β-unsaturated ketones to vinyl esters[8b-8c] and the dihydroxylation of cyclohexene to *trans*-1,2-cyclohexanediol.[8d-8e] All of the previous works of ours and the other groups' show that organoselenium compounds are practical catalysts because of their stability and recyclability. Thus, we continue the investigations in this area and begin to develop the organoselenium-catalyzed green oxidations of the useful natural products for potential industrial applications.[8f]

On the other hand, *β-Ionone* is also an abundantly accessible natural product that widely exists in many plants. The oxidation of *β-Ionone* is a topic with good application value because the products are important intermediates in perfume industry, agricultural chemistry, medicinal chemistry and even natural product synthesis.[12] However, currently reported methods employ the chemical oxidants and thus inevitably produce large amount of solid waste, which is harmful to environment and prevents the large-scale production.[13] In addition, the multiple reaction sites of *β-Ionone* impose a tremendous challenge to develop the highly selective oxidation methodologies (Fig. 1). Recently, we investigated the organoselenium-catalyzed oxidation of *β-Ionone* with H_2O_2 and were very surprised to find that the reaction selectivity was controllable using different organoselenium catalysts. Herein, we wish to report our findings.

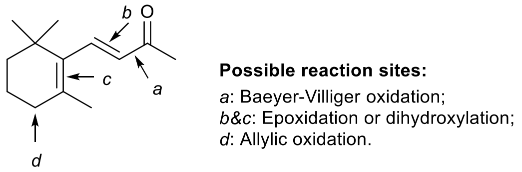


Fig. 1 Possible reaction sites of *β-Ionone*.

Results and discussion

Initially, we tested the blank reactions without catalyst. Stirring *β-Ionone* **1** with H_2O_2 in MeCN for 24 hours only led to the epoxide **2** in very low yield, while most starting material **1** remained unreacted and could be recovered in 80% yield (Table 1, entry 1). Adding inorganic catalyst SeO_2 could slightly promote the reaction, but the products **2** and **3** were generated simultaneously in low yields with poor selectivity (entry 2). The organoselenium catalysts were then employed but it was found that neither selenides nor simple diaryldiselenides could optimize the reaction to get satisfied results (entries 3-4).

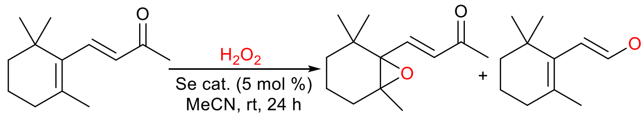
---

[a] Jiangsu Co-innovation Center for Prevention and Control of Important Animal Infectious Diseases and Zoonoses, School of Chemistry and Chemical Engineering, Yangzhou University, Yangzhou, Jiangsu 225002, China; Email: yulei@yzu.edu.cn.
[b] Zhejiang Key Laboratory of Carbon Materials, College of Chemistry and Materials Engineering, Wenzhou University, Wenzhou, Zhejiang 325035, China.

†Electronic Supplementary Information (ESI) available: Detailed conditional optimization tables and product NMR Spectra See DOI: 10.1039/x0xx00000x

Interestingly, the CF_3-substituted diaryldiselenides obviously improved the reaction selectivity to generate the epoxide **2** as the major product (entries 5-6) and $[3,5\text{-}(CF_3)_2C_6H_3Se]_2$ was finally screened out to be the specific catalyst for epoxidation (entry 6). The catalytic activities of dialkyl diselenides were also tested. Using $(c\text{-}C_6H_{11}Se)_2$ gave both **2** and **3** with very low selectivity (entry 7), but in the reaction catalyzed by $(n\text{-}C_4H_9Se)_2$, a linear organoselenium catalyst with lower steric hindrance, the vinyl ester **3** was obtained as the major product (entry 8). Further screenings demonstrated that dibenzyldiselenides favoured the Baeyer-Villiger (BV) oxidations to generate **3** and $(PhCH_2Se)_2$, the simplest and cheapest dibenzyl diselenide, was found to be the best one among them (entry 9 *vs.* 10).

Table 1 Screening of the organoselenium catalysts[a,14]



1 **2** **3**

Entry	Se *cat.*	**2** / %[b]	**3** / %[b]
1[c]	-	8	0
2[c]	SeO_2[d]	21	24
3[c]	PhSeR[d,e]	11-26	10-40
4[c]	$(ArSe)_2$[f]	16-40	15-41
5	$(CF_3ArSe)_2$[g]	40-41	7-8
6	**$[3,5\text{-}(CF_3)_2C_6H_3Se]_2$**	**70**	**0**
7[c]	$(c\text{-}C_6H_{11}Se)_2$	36	45
8	$(n\text{-}C_4H_9Se)_2$	15	67
9	**$(PhCH_2Se)_2$**	**10**	**77**
10	$(ArCH_2Se)_2$[h]	12-25	56-72

[a] *β-Ionone* **1** (1 mmol), Se cat. (0.05 mmol, 5 mol%) and H_2O_2 (4 mmol, 400 %) in commercial MeCN (1 mL) was stirred at room temperature (ca. 25 °C) under air and monitored by TLC. [b] Isolated yields based on **1**. [c] Reaction not completed. [d] 0.1 mmol (10 mol%) catalyst was employed. [e] R = Et, $c\text{-}C_6H_{11}$ or Ph. [f] Ar = Ph, $3\text{-}MeC_6H_4$, $3\text{-}MeOC_6H_4$, $4\text{-}MeOC_6H_4$, $4\text{-}ClC_6H_4$, $2\text{-}FC_6H_4$, $3\text{-}FC_6H_4$ or $1\text{-}C_{10}H_7$. [g] CF_3Ar = $2\text{-}CF_3C_6H_4$, $3\text{-}CF_3C_6H_4$ or $4\text{-}CF_3C_6H_4$. [h] Ar = $2\text{-}FC_6H_4$, $3\text{-}FC_6H_4$, $4\text{-}FC_6H_4$, $2\text{-}ClC_6H_4$, $3\text{-}ClC_6H_4$, $4\text{-}ClC_6H_4$, $2,6\text{-}Cl_2C_6H_3$ or $2,4\text{-}Cl_2C_6H_3$, $4\text{-}MeOC_6H_4$, $2\text{-}MeOC_6H_4$, $3\text{-}MeC_6H_4$ or $4\text{-}MeC_6H_4$.

As shown above, the selectivity of the reaction was switchable by catalyst: $[3,5\text{-}(CF_3)_2C_6H_3Se]_2$ was propitious to the epoxidation while $(PhCH_2Se)_2$ favoured the BV oxidation (Table 1, entry 6 *vs.* 9). Since both of the products **2** and **3** are useful chemicals,[12] it is of practical application value to further optimize the reaction conditions. Table 2 gave the conditional optimizations to prepare **2**. Solvents, such as MeCN, CH_2Cl_2, EtOH, H_2O, acetone, DMF and THF were first tested and MeCN and CH_2Cl_2 were found to be the best ones among the above candidates, giving **2** in approximate yields (Table 2, entry 1, 2 *vs.* 3). But considering the environmental factors, the chloro-free MeCN should be the better solvent and the catalyst loading effects in it were then studied. It was found that the best catalyst loading was 1 mol % (entries 4, 5 *vs.* 6, 7). Although there were always traces of the starting material observed in TLC, the product yield did not increase with extended reaction time (entries 5 *vs.* 4). Excess H_2O_2 was necessary and 400 % equivalent should be the best dosage (entries 4 *vs.* 8-9). Various starting material concentrations were also tested, but 1 mol / L, as we initially employed, was found to be the best condition (entries 4 *vs.* 10-11). In summary, using 1 mol % of the catalyst $[3,5\text{-}(CF_3)_2C_6H_3Se]_2$, 400 mol % of the oxidant H_2O_2 and performing with the starting material concentration 1 mol / L in MeCN should be the best reaction conditions to synthesize **2** (entry 4). A magnified experiment in 40 mmol scale was also performed and provided **2** in 70 % yield (entry 12).

Table 2 Conditional optimizations for the synthesis of **2**[a,14]

$$\mathbf{1} \xrightarrow[\text{cat. }[3,5\text{-}(CF_3)_2C_6H_3Se]_2\text{, rt, 24 h}]{H_2O_2} \mathbf{2} + \mathbf{3}$$

Entry	Solvent (v / mL)[b]	*cat.* / %[c]	H_2O_2 / %[d]	**2** (**3**) / %[e]
1	**MeCN (1)**	**5**	**400**	**70 (0)**
2	CH_2Cl_2 (1)	5	400	71 (0)
3[f]	*oth. solvt.* (1)[g]	5	400	20-36 (23-50)
4[f]	**MeCN (1)**	**1**	**400**	**72 (9)**
5[f,h]	MeCN (1)	1	400	72 (8)
6[f]	MeCN (1)	0.5, 2-3	400	40-71 (6-15)
7	MeCN (1)	10	400	63(0)
8[f]	MeCN (1)	1	100-300	40-61 (8-10)
9	MeCN (1)	1	500	70 (0)
10[f]	MeCN (0.5)	1	400	65 (10)
11[f]	MeCN (2-4)	1	400	48-60 (8)
12[i]	MeCN (40)	1	400	70 (8)

[a] *β-Ionone* **1** (1 mmol), $[3,5\text{-}(CF_3)_2C_6H_3Se]_2$ and H_2O_2 in solvent was stirred at room temperature (*ca.* 25 °C) under air and monitored by TLC. [b] Volume of solvent (mL). [c] Molar ratio of the catalyst loading based on **1**. [d] Molar ratio of the H_2O_2 dosage based on **1**. [e] Isolated yields of **2** outside the parentheses; isolated yields of **3** inside the parentheses. [f] Reaction not completed. [g] Other solvents: EtOH, H_2O, acetone, DMF and THF were tested. [h] Reaction time delayed to 48 h. [i] Reaction performed in 40 mmol scale.

The conditions of the BV oxidation were also optimized (Table 3). Solvent screenings demonstrated that the reaction proceeded smoothly in MeCN, EtOH or THF (entries 1-3 *vs.* 4) and gave the highest yield of **3** in THF (86%, entry 3). Different from the epoxidation, the BV oxidations required more catalyst and the product yield was elevated to 91 % when 10 mol % of $(PhCH_2Se)_2$ was employed (entries 6 *vs.* 3, 5, 7). The best H_2O_2 dosage and starting material concentration were 400 mol % and 1 mol / L respectively, as initially employed (entries 6 *vs.* 8-11). The reaction was also scalable and the product yield remained at the high level (87 %) in a 40 mmol scale magnified reaction (entry 12), showing that these methodologies were very practical and have potential applications in industrial production.

Table 3 Conditional optimizations for the synthesis of **3**[a,14]

$$\mathbf{1} \xrightarrow[\text{cat.(PhCH}_2\text{Se)}_2\text{, rt, 24 h}]{H_2O_2} \mathbf{3} + \mathbf{2}$$

Entry	Solvent (v / mL)[b]	*cat.* / %[c]	H_2O_2 / %[d]	**3** (**2**) / %[e]
1	MeCN (1)	5	400	77 (10)
2	EtOH (1)	5	400	80 (12)
3	**THF (1)**	**5**	**400**	**86 (8)**
4[f]	*oth. solvt.* (1)[g]	5	400	16-73 (9-20)
5[f]	THF (1)	0.5-3	400	38-65 (5-9)
6	**THF (1)**	**10**	**400**	**91 (5)**
7	THF (1)	20	400	85 (6)
8[f]	THF (1)	10	100-300	34-82 (5-8)
9	THF (1)	10	500	90 (5)
10	THF (0.5)	10	400	86 (10)
11[f]	THF (2-4)	10	400	76-80 (0-5)
12[h]	THF (40)	10	400	87 (6)

[a] *β-Ionone* **1** (1 mmol), $(PhCH_2Se)_2$ and H_2O_2 in commercial solvent was stirred at room temperature (ca. 25 °C) under air and monitored by TLC and/or GC. [b] Volume of solvent (mL). [c] Catalyst loading based on **1**. [d] H_2O_2 dosage based on **1**. [e] Isolated yields of **3** outside the parentheses; isolated yields of **2** inside the parentheses. [f] Reaction not completed. [g] Other solvents: H_2O, acetone, DMF and CH_2Cl_2 were tested. [h] Reaction performed in 40 mmol scale.

In addition, the organoselenium catalyst in the BV oxidation of *β-Ionone* was recyclable. After extraction (*vide infra*, experimental section), the aqueous layer containing the organoselenium catalytic species was recycled and reused after the evaporation of water under vacuum. Table 4 showed that the catalyst could be reused for at least 3 times without much product yield decreasing. But for the 4th cycle, the yield of 3 was reduced to 60 %, probably due to the accumulated loss of catalyst in extraction.

Table 4 Catalyst recycle and reuse[a]

$$\mathbf{1} + H_2O_2 \xrightarrow[\text{rt, 24 h}]{(PhCH_2Se)_2\ (10\ \text{mol}\ \%)} \mathbf{3}$$

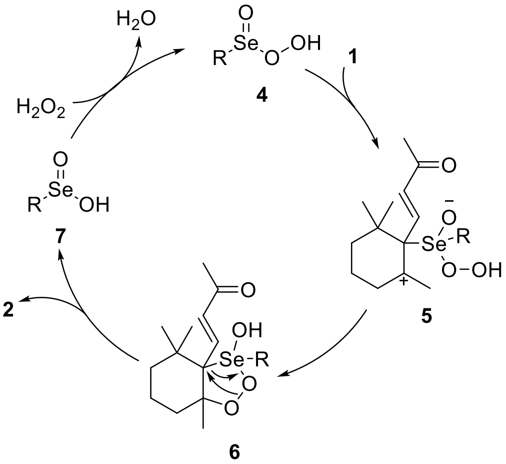
Cycle NO.	0[b]	1	2	3	4
3 / %[c]	89	81	77	71	60

[a] The reactions were performed in 40 mmol scale using the optimized conditions in Table 3, entry 12. [b] First use. [c] Isolated yields of **3**.

As it was the first time for us to observe the selectivity regulation by organoselenium catalysts for complex compound oxidation, the mechanisms of these interesting reactions were also what we concerned. Based on the reported works as well as the experimental results in Table 1, the possible mechanisms were supposed.[7-10] Our previous studies with ^{77}Se NMR analysis have disclosed that in the organoselenium-catalyzed oxidations with H_2O_2, the catalyst diselenides $(RSe)_2$ were first oxidized and hydrolyzed to the selenic peroxide acid RSe(O)OOH **4**, which was the real catalytic species in the reaction (eqn (1)).[8b]

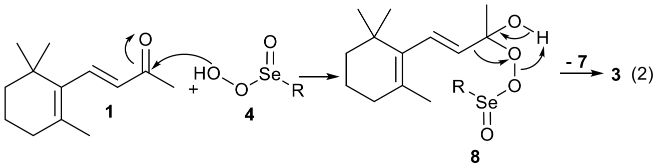
$$(RSe)_2 \xrightarrow{H_2O_2} PhSe(O)OOH \quad (1)$$

In the epoxidation reaction[7d] of *β-Ionone*, the electrophilic addition of the γ,δ-C=C bond with the Se^+ centre of RSe(O)OOH **4** initially afforded the intermediate **5**, which soon led to the intermediate **6**. The intramolecular rearrangement of **6** generated the epoxide **2** and the selenic acid **7**, which was re-oxidized by H_2O_2 to the catalytic species **4** (Scheme 1). In this mechanism, the electrophilic addition of the alkene with **4** should be the key step. The electron-withdrawing CF_3-substituted diaryldiselenides, especially $[3,5\text{-}(CF_3)_2C_6H_3Se]_2$, could generate the corresponding selenic peroxide acid **4** with stronger Se^+ electrophilic centre than simple diselenides and thus were preferable catalysts for epoxidation.[7d]



Scheme 1 Possible mechanisms for the epoxidation.

For BV reactions, the nucleophilic attack of RSe(O)OOH **4** to the C^+ centre of the carbonyl of *β-Ionone* was the key step that led to the intermediate **8**.[8b-8c, 8f] The intramolecular rearrangement of **8** gave the BV oxidation product **3** and released the selenic acid **7**, which could be re-oxidized to **4** and participate the next turn of reaction (eqn (2)). Thus, it was not difficult to understand the phenomenon that dibenzyl diselenide was the preferable catalyst for BV oxidation because it was less bulky so that it received less hindrance than the 2° carbon substituted selenides in the nucleophilic attack step and because it was an electron-enriched compound that led to the corresponding selenic peroxide acid **4** with good nucleophilic activity.[8c]



Conclusions

In conclusion, we reported the organoselenium-catalyzed selectivity-switchable oxidations of *β-Ionone* with H_2O_2. The $[3,5\text{-}(CF_3)_2C_6H_3Se]_2$-catalyzed reaction led to (*E*)-5,6-epoxy-*β-Ionone* **2**, while the dibenzyl diselenide-catalyzed reaction afforded (*E*)-2-(2,6,6-trimethylcyclohex-1-en-1-yl)vinyl acetate **3** as the overwhelming major product. Both of them are useful chemicals with broad application scopes.[12] To the best of our knowledge, this should be the first example for the selectivity regulation using organoselenium catalysts. The findings indicated that the organoselenium catalysts were not only simple oxygen-transfer reagents but also the catalysts that could switch the reaction selectivity, depending on their molecular structures. Thus, organoselenium catalysis might have broader application scopes than what we recognized before and thus deserve further in-depth studies. More investigations on the relationships of the structures of the organoselenium compounds with their catalytic activities are on the way in our laboratory.

Experimental

General methods

β-Ionone was purchased from reagent merchant with the purity more than 98% and was directly used as received. Organoselenium-catalysts were commercially available or prepared according to literature.[8d] Solvents were analytical pure (AR) and directly used without any special treatment. All reactions were carried out in open air and monitored by TLC. IR spectra were measured on Bruker Tensor 27 Infrared spectrometer. ^1H and ^{13}C NMR spectra were recorded on a Bruker Avance 400 instrument (400 MHz for ^1H and 100 MHz for ^{13}C NMR spectroscopy) using $CDCl_3$ as the solvent and Me_4Si as the internal standard. Chemical shifts for ^1H and ^{13}C NMR were referred to internal Me_4Si (0 ppm) and *J*-values were shown in Hz. Mass spectra were measured on a Shimadzu GCMS-QP2010 Ultra spectrometer (EI).

Typical procedure for the synthesis of 2

To a reaction tube, 5.8 mg of $[3,5\text{-}(CF_3)_2C_6H_3Se]_2$ (0.01 mmol) was added. The solutions of 1 mmol of *β-Ionone* in 0.5 mL of MeCN and 4 mmol of 30% H_2O_2 in 0.5 mL of MeCN were then injected subsequently. The mixture was stirred at rt (*ca*. 25 ^oC) for 24 h. The solvent was then evaporated under vacuum and the residue was isolated by flash column chromatography (eluent: petroleum/EtOAc 20:1), affording 149.9 mg of **2** in 72 % yield. In a large scale preparation (40 mmol), 0.5 g of MnO_2 was added into the reaction mixture and stirred for 2 h after the reaction to decompose the excess H_2O_2. The MnO_2 was then removed by filtration before further processes.

Typical procedure for the synthesis of 3

To a reaction tube, 34.0 mg of $(PhCH_2Se)_2$ (0.1 mmol) was added. The solutions of 1 mmol of *β-Ionone* in 0.5 mL of THF and 4 mmol of 30% H_2O_2 in 0.5 mL of THF were then injected subsequently. The mixture was stirred at rt (*ca*. 25 ^oC) for 24 h. The solvent was then evaporated under vacuum and the residue was isolated by flash column chromatography (eluent: petroleum/EtOAc 20:1), affording 189.6 mg of **3** in 91 % yield. To recycle the organoselenium catalyst, the terminated reaction liquid (40 mmol scale) was added into 60 mL of EtOAc and extracted with water (30 mL × 3). The combined aqueous layer was evaporated under vacuum and the residue was reused as catalyst in the next turn of reaction.

Characterization of the products

(*E*)-5,6-Epoxy-*β-Ionone* 2. 149.9 mg, 72 %; Oil; IR (film): 2937, 1753, 1677, 1627, 1461, 1432, 1362, 1300, 1255, 1173, 1046, 985, 941, 909, 834, 788cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$, TMS): δ 7.03 (d, J = 15.6 Hz, 1H), 6.29 (d, J = 15.6 Hz, 1H), 2.29 (s, 3H), 1.95-1.87 (m, 1H), 1.80-1.74 (m, 1H), 1.48-1.42 (m, 3H), 1.15 (s, 6H), 1.11-1.07 (m, 1H), 0.94 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 197.4, 142.6, 132,4, 70.5, 65.8, 35.4, 33.5, 29.7, 28.2, 25.8 (d), 20.8, 16.8 ppm; MS (EI, 70 eV): *m/z* (%) 208 (10) [M^+], 123 (100), 43 (22); *Known compound*.[15]

(*E*)-2-(2,6,6-Trimethylcyclohex-1-en-1-yl)vinyl acetate 3. 189.6 mg, 91 %; Oil**.** IR (film): 3674, 3649, 3086, 2961, 2930, 2866, 1759, 1653, 1558, 1541, 1457, 1371, 1293, 1220, 1087, 933, 804 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$, TMS): δ 7.01 (d, J = 12.8 Hz, 1H), 5.88 (d, J = 12.8 Hz, 1H), 2.15 (s, 3H), 1.98 (t, J = 6.0 Hz, 2H), 1.70 (s, 3H), 1.60-1.59 (m, 2H), 1.47-1.44 (m, 2H), 0.98 (s, 6H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 168.2, 137.8, 132.2, 130.5, 112.3, 39.2, 34.0, 32.7, 28.5, 21.5, 20.8, 19.2 ppm; MS (EI, 70 eV): *m/z* (%) 208 (32) [M^+], 151 (100), 162 (98); *Known compound*.[8c]

Acknowledgements

This work was financially supported by NNSFC (21202141, 21173182), Priority Academic Program Development (PAPD) of Jiangsu Higher Education Institutions, Yangzhou Nature Science Foundation (YZ2014040), the Opening Foundation of the Key Laboratory of Environmental Materials and Engineering of Jiangsu Province (K14010) and the State Key Laboratory of Heavy Oil Processing. We thank Prof. Xingfa Gao for suggestions and Miss Xuejiao Gao, Mr.Yubin Wu and the analysis centre of Yangzhou University for assistances.

Notes and references

1 Selected reviews or monographs, see: (*a*) T. Wirth, *Organoselenium Chemistry;* Springer: Berlin, 2000; Vol. 208; (*b*) A. Ogawa, In *Main Group Metals in Organic Synthesis*; H. Yamamoto and K. Oshima, Eds.; Wiley-VCH: Weinheim, 2004; Vol. 2, p 813; (*c*) C. W. Nogueira, G. Zeni and J. B. T. Rocha, *Chem. Rev.*, 2004, **104**, 6255; (*d*) T. Wirth, *Organoselenium Chemistry: Synthesis and Reactions;* Wiley-VCH: Weinheim, 2011; (*e*) B. Godoi, R. F. Schumacher and G. Zeni, *Chem. Rev.*, 2011, **111**, 2937; (*f*) A. Nomoto, Y. Higuchi, Y. Kobiki and A. Ogawa, *Mini-Rev. Med. Chem.*, 2013, **13**, 814; (*g*) S. T. Manjare, Y. Kim and D. G. Churchill, *Acc. Chem. Res.*, 2014, **47**, 2985.

2 Selected articles, see: (*a*) A. A. Vieira, J. B. Azeredo, M. Godoi, C. Santi, E. N. da Silva J. and A. L. Braga, *J. Org. Chem*., 2015, **80**, 2120; (*b*) K. K. Casola, D. F. Back and G. Zeni, *J. Org. Chem*., 2015, **80**, 7702; (*c*) V. Nascimento, N. L. Ferreira, R. F. S. Canto, K. L. Schott, E. P. Waczuk, L. Sancineto, C. Santi, J. B. T. Rocha and A. L. Braga, *Eur. J. Med. Chem*., 2014, **87**, 131; (*d*) A. C. Mantovani, T. A. C. Goulart, D. F. Back, P. H. Menezes and G. Zeni, *J. Org. Chem*., 2014, **79**, 10526; (*e*) B. Hou, D. Benito-Alifonso, R. Webster, D. Cherns, M. C. Galan and D. J. Fermin, *J. Mater. Chem. A*, 2014, **2**, 6879; (*f*) L. Yu, Y.-L. Wu, T. Chen, Y. Pan and Q. Xu, *Org. Lett*., 2013, **15**, 144.

3 (*a*) S. Santoro, J. B. Azeredo, V. Nascimento, L. Sancineto, A. L. Braga and C. Santi, *RSC Adv*., 2014, **4**, 31521; (*b*) C. Santi and C. Tidei, *Electrophilic selenium/tellurium reagents: reactivity and their contribution to Green Chemistry*, in: *The Chemistry of Organic Selenium and Tellurium Compounds;* Z. Rappoport, Ed.; John Wiley & Sons, Chichester, 2013; Vol. 4, pp 569–655.

4 For reviews, see: (*a*) D. M. Freudendahl, S. Santoro, S. A. Shahzad, C. Santi and T. Wirth, *Angew. Chem. Int. Ed*., 2009, **48**, 8409; (*b*) C. Santi, S. Santoro and B. Battistelli, *Curr. Org. Chem*., 2010, **14**, 2442; (*c*) A. Breder and S. Ortgies, *Tetrahedron Lett*., 2015, **56**, 2843; (*d*) J. Młochowski and H. Wójtowicz-Młochowska, *Molecules*, 2015, **20**, 10205.

5 The organoselenium compounds are obviously less toxic than inorganic selenium compounds such as SeO_2, H_2SeO_3 *et. al.* Moreover, compared with transitional metals, selenium could be metabolized by creatures and is thus much safer to environment. An adequate englobement of selenium is even good for health. For details, see: M. P. Rayman, *Lancet*, 2012, **379**, 1256.

6 The price in China in August, 2015.

7 For selected articles, see: (*a*) L. Sancineto, C. Tidei, L. Bagnoli, F. Marini, E. J. Lenardao and C. Santi, *Molecules*, 2015, **20**, 10496; (*b*) C. Santi, R. Di Lorenzo, C. Tidei, L. Bagnoli and T. Wirth, *Tetrahedron*, 2012, **68**, 10530; (*c*) S. Santoro, C. Santi, M. Sabatini, L. Testaferri and M. Tiecco, *Adv. Synth. Catal*., 2008, **350**, 2881; (*d*) G.-J. ten Brink, B. C. M. Fernandes, M. C. A. van Vliet, I. W. C. E. Arends and R. A. Sheldon, *J. Chem. Soc., Perkin Trans. 1*, **2001**, 224.

8 (*a*) L. Yu, H.-Y. Li, X. Zhang, J.-Q. Ye, J.-P. Liu, Q. Xu and M. Lautens, *Org. Lett*., 2014, **16**, 1346; (*b*) L. Yu, Y.-L. Wu, H.-E. Cao, X. Zhang, X.-K. Shi, J. Luan, T. Chen, Y. Pan and Q. Xu, *Green Chem*., 2014, **16**, 287; (*c*) X. Zhang, J.-Q. Ye, L. Yu, X.-K. Shi, M. Zhang, Q. Xu and M. Lautens, *Adv. Synth. Catal*., 2015, **357**, 955; (*d*) L. Yu, J. Wang, T. Chen, Y.-G. Wang and Q. Xu, *Appl. Organometal. Chem*., 2014, **28**, 652; (*e*) L. Yu, J. Wang, T. Chen, K.-H. Ding and Y. Pan, *Chin. J. Org. Chem*., 2013, **33**, 1096; (*f*) L. Yu, J.-Q. Ye, X. Zhang, Y.-H. Ding and Q. Xu, *Catal. Sci. Technol*., 2015, **5**, 4830.

9 A. J. Cresswell, S. T.-C. Eey and S. E. Denmark, *Nat. Chem*., 2015, **7**, 146.

10 Selected articles: (*a*) X.-L. Zhang, R.-Z. Guo and X.-D. Zhao, *Org. Chem. Front*., 2015, **2**, 1334; (*b*) Z.-M. Deng, J.-L. Wei, L.-H. Liao, H.-Y. Huang and X.-D. Zhao, *Org. Lett*., 2015, **17**, 1834; (*c*) F. Chen, C. K. Tan and Y.-Y. Yeung, *J. Am. Chem. Soc*., 2013, **135**, 1232; (*d*) J. Trenner, C. Depken, T. Weber and A. Breder, *Angew. Chem. Int. Ed*., 2013, **52**, 8952; (*e*) D. W. Tay, I. T. Tsoi, J. C. Er, G. Y. C. Leung and Y.-Y. Yeung, *Org. Lett*., 2013, **15**, 1310; (*f*) F. V. Singh and T. Wirth, *Org. Lett*., 2011, **13**, 6504.

11 Selected articles: (*a*) L. Yu, Y.-P. Huang, Z. Wei, Y.-H. Ding, C.-L. Su and Q. Xu, *J. Org. Chem*., 2015, **80**, 8677; (*b*) Q. Xu, H.-M. Xie, P.-L. Chen, L. Yu, J.-H. Chen and X.-G. Hu, *Green Chem*., 2015, **17**, 2774; (*c*) L. Xu, J.-J. Huang, Y.-B. Liu, Y.-N. Wang, B.-L. Xu, K.-H. Ding, Y.-H. Ding, Q. Xu, L. Yu and Y.-N. Fan, *RSC Adv*., 2015, **5**, 42178; (*d*) Y.-G. Wang, B.-C. Zhu, Q. Xu, Q. Zhu and L. Yu, *RSC Adv*., 2014, **4**, 49170; (*e*) L. Yu, J. Wang, X. Zhang, H.-E. Cao, G.-L. Wang, K.-H. Ding, Q. Xu and M. Lautens, *RSC Adv*., 2014, **4**, 19122; (*f*) L. Fan, R. Yi, L. Yu, Y.-L. Wu, T. Chen and R. Guo, *Catal. Sci. Technol*., 2012, **2**, 1136.

12 Selected articles: (*a*) M. Jiang, C. Kulsing, Y. Nolvachai and P. J. Marriott, *Anal. Chem*., 2015, **87**, 5753; (*b*) R. Joshi, A. Rana and A. Gulati, *Food Chem*., 2015, **176**, 357; (*c*) M. Bellotti, A. Salis, A. Grozio, G. Damonte, T. Vigliarolo, A. Galatini, E. Zocchi, U. Benatti and E. Millo, *Bioorg. Med. Chem*., 2015, **23**, 22; (*d*) G. W. Burton, J. Daroszewski, J. G. Nickerson, J. B. Johnston, T. J. Mogg and G. B. Nikiforov, *Can. J. Chem*., 2014, **92**, 305; (*e*) W.-G. Liu, J.-M. Zhou, G.-Y. Geng, R.-T. Lin and J.-H. Wu, *Invest. New Drug*., 2014, **32**, 227; (*f*) Q.-S. Shao, Y.-Q. Huang, A.-C. Zhou, H.-P. Guo, A.-L. Zhang and Y. Wang, *J. Sci. Food Agr*., 2014, **94**, 1430; (*g*) T. A. Engler, U. Sampath, S. Naganathan, D. Vander Velde, F. Takusagawa and D. Yohannes, *J. Org. Chem*., 1989, **54**, 5712.

13 (*a*) A. Srikrishna, G. Satyanarayana and K. R. Prasad, *Synth. Commun*., 2007, **37**, 1511; (*b*) A. Srikrishna, L. Shaktikumar and G. Satyanarayana, *ARKIVOC*, **2003**, 69; (*c*) A. Bosser, E. Paplorey and J.-M. Belin, *Biotechnol. Prog*., 1995, **11**, 689; (*d*) D. A. Hartman, M. E. Pontones, V. F. Kloss, R. W. Curley Jr. and L. W. Robertson, *J. Nat. Prod*., 1988, **51**, 947.

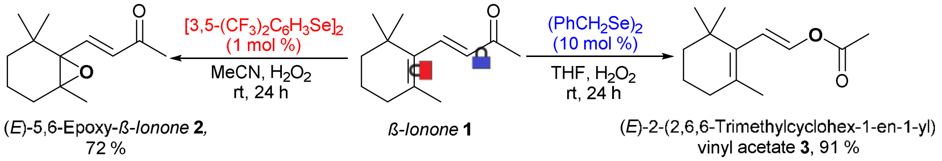
14 For detailed conditional optimizations, see ESI.

15 G. Englert, *Helv. Chim. Acta*, 1975, **58**, 2367.

Table of Contents

Organoselenium-Catalyzed Selectivity-Switchable Oxidation of ***β-Ionone***

Lei Yu,* Zengbing Bai, Xu Zhang Xiaohong Zhang, Yuanhua Ding and Qing Xu



Scalable at least to 40 mmol

The selectivities of the oxidations of *β-Ionone* **1** were switchable by the organoselenium catalysts. $[3,5\text{-}(CF_3)_2C_6H_3Se]_2$ as the catalyst led to (*E*)-5,6-epoxy-*β-Ionone* **2** in 72 % yield as the major product, while $(PhCH_2Se)_2$ was the preferable catalyst for Baeyer-Villiger oxidation, giving product **3** in the excellent 91 % yield. These interesting findings indicated the great potential of the organoselenium catalysis.