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Convenient synthesis of *Z*-monoacetates of 2-alkylidene-1,3-propanediols

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Dedicated to Professor E. J. Corey on the occasion of his 80th birthday.

ABSTRACT

Various kinds of 3-substituted (*Z*)-hydroxymethyl-2-propenyl acetates were conveniently obtained in excellent yields by highly regioselective hydrolysis of 2-alkylidene-1,3-propylene diacetates in the presence of 100 w/w % of porcine pancreas lipase (PPL) Type II.

1. Introduction

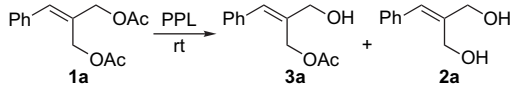
Regioselective protection of allylic diols by acetyl group is not much known except Takabe's method.[1] The corresponding *Z*-monoacetates were afforded only in moderate yields (24–52%) because the corresponding diols and *E*-monoacetates were obtained as by-products in all cases. We have reported preparation of 3-substituted (*E*)-hydroxymethyl-2-propenyl acetates by regiospecific acetylation of 2-alkylidene-1,3-propanediols containing substituted benzene ring,[2a] polycyclic or heterocyclic aromatic ring[2b] with vinyl acetate using porcine pancreas lipase (PPL) Type II.[3] Furthermore, we have developed preparation of 3-substituted (*Z*)-hydroxymethyl-2-propenyl acetates[4] by highly regioselective hydrolysis of 2-alkylidene-1,3-propylene diacetates using PPL Type II. Herein, we describe the detail for preparation of *Z*-monoacetates by highly regioselective hydrolysis of 2-alkylidene-1,3-propylene diacetates **1** using 100 w/w % of PPL Type II.

2. Results and discussion

2-Alkylidene-1,3-propylene diacetates **1** were easily prepared from 2-alkylidene-1,3-propanediols **2**[2] and acetic anhydride in pyridine in 82% to quantitative yields. In a preliminary investigation, the reaction of 2-benzylidene-1,3-propylene diacetate (**1a**) in the presence of 100 w/w % of PPL in a 1:1 mixture of DMSO (dimethyl sulfoxide)–PB (1/15 M phosphate buffer, pH 7.0) afforded the corresponding *Z*-isomer **3a** in 98% yield as indicated in entry 6 of Table 1. In the case of using methanol as a solvent, no reaction was observed (see entry 1). Ethanol and 2-propanol work as a solvent for solvolysis of **1a** to afford poorer yields as shown in entries 2 and 3, respectively. Hydrolysis of **1a** proceeded in PB to give 59% yield of the corresponding *Z*-acetate with 19% yield of 2-benzylidenepropane-1,3-diol (**2a**) (see entry 4). It is suggested that DMSO effectively controls the activity of PPL and solubility of the starting material. The *E*-isomer was not detected from ^{1}H NMR analysis of the crude products as shown in all entries of Table 1, which presents the solvent effect.

Next, the amount of PPL was optimized at rt for 25 h in the reaction of **1a** and the results are summarized in Table 2. Increasing the amount of PPL from 10 w/w % to 100 w/w % in the hydrolysis of **1a** afforded higher yield of the *Z*-isomer **3a** and either the *E*-isomer or the diol **2a** was not observed in any cases. The use of 100 w/w % of PPL afforded an enough result on both of the yield and regioselectivity as shown in entry 4.

Table 1
Solvent effect for *E*-hydrolysis of 2-benzylidenepropyl 1,3-diacetate **1a** in the presence of PPL[a]



Entry	Solvent	Reaction time	Yield **3a** (%)	Yield **2a** (%)	Recovery **1a** (%)
1	MeOH	5 d	Trace	N.D.[c]	99
2	EtOH	5 d	35	N.D.	55
3	*i*-PrOH	5 d	24	N.D.	67
4	PB[b]	23 h	59	19	13
5	DMSO–PB[b] (1:4)	21 h	61	16	16
6	DMSO–PB[b] (1:1)	25 h	98	Trace	N.D.

[a] All reactions were carried out with 1 equiv of 2-benzylidenepropyl 1,3-diacetate **1a** and 100 w/w % of PPL in 3 mL of solvent at rt.
[b] Phosphate buffer (1/15 M, pH 7.0).
[c] Not detected.

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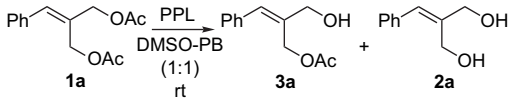
Table 2
Amount effect for *E*-hydrolysis of 2-benzylidenepropyl 1,3-diacetate **1a** in the presence of PPL[a]

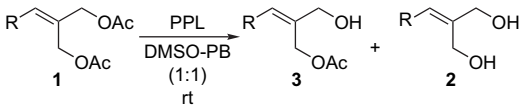


Entry	Amount of PPL (w/w %)	Reaction time (h)	Yield **3a** (%)	Yield **2a** (%)	Recovery **1a** (%)
1	10	25	65	N.D.[b]	31
2	20	25	81	N.D.	15
3	50	25	92	N.D.	5.8
4	100	25	98	Trace	N.D.

[a] All reactions were carried out with 1 equiv of 2-benzylidenepropyl 1,3-diacetate **1a** and PPL in 3 mL of a 1:1 mixture of DMSO–PB [phosphate buffer (1/15 M, pH 7.0)] at rt.
[b] Not detected.

Then, the regioselective hydrolysis of 2-benzylidene-1,3-propylene diacetates substituted on the benzene ring by electron-donating or electron-withdrawing groups was examined: the results from hydrolysis of various substituted 2-benzylidene-1,3-propylene diacetates **1b**–**1h** and 2-alkylidene-1,3-propylene diacetate **1i** in the presence of 100 w/w % of PPL in a 1:1 mixture of DMSO–PB are collected in Table 3. We selected methoxy and methyl substituents as representative electron-donating groups (see entries 2 and 5–8), trifluoromethyl and chloro substituents as electron-withdrawing groups (see entries 3 and 4), and 2-(3-phenylpropylidene)-1,3-propylene diacetate (**1i**) for an aliphatic species (see entry 9). Fortunately, all monosubstituted 2-benzylidene-1,3-propylene diacetates **1b**–**1g** reacted in the presence of 100 w/w % of PPL in a 1:1 mixture of DMSO–PB to afford the corresponding *Z*-monoacetylated products in excellent yields with high regioselectivities. 2-(2,4,6-Trimethylbenzylidene)-1,3-propylene diacetate (**1h**) was a poor substrate for hydrolysis using PPL probably due to its steric hindrance by *ortho*-substituents on the benzene ring and the corresponding *Z*-monoacetate **3h** was obtained in 17% yield. The reaction of the 2-(3-phenylpropylidene)-1,3-propylene diacetate (**1i** in entry 9) afforded *Z*-monoacetate in lower regioselectivity than ones of substituted 2-benzylidene-1,3-propylene diacetates **1a**–**1h**. Although the corresponding *Z*-isomer **3i**[2b] was obtained in 67% yield, the diol **2i** was produced as a by-product in 13% yield and the starting material **1i** was recovered in 8.1% yield. Furthermore, 2-naphthylidene-1,3-propylene diacetate **1j** containing a polycyclic ring was easily converted to the corresponding *Z*-isomer **3j** in 89% yield with high regioselectivity. In the case of the diacetates **1k**–**1m** substituted a heterocyclic ring as a furyl or thienyl group, the regioselective hydrolysis effectively proceeded to afford the corresponding *Z*-isomers **3k**–**3m** in 67–90% yield. The *E*-isomers were not detected from the crude products as shown in all entries of Table 3.

Table 3
E-Hydrolysis of substituted 2-benzylidenepropyl 1,3-diacetates **1a**–**1h** and 2-alkylidenepropyl 1,3-diacetate **1i** in the presence of PPL[a]



Entry	**1**	R	Reaction time (h)	Yield **3** (%)	Yield **2** (%)	Recovery **1** (%)
1	**1a**	Ph	25	98	Trace	N.D.[b]
2	**1b**	4-$MeOC_6H_4$	20	95	N.D.	1.7
3	**1c**	4-$CF_3C_6H_4$	24	92	N.D.	1.7
4	**1d**	4-ClC_6H_4	4	84	N.D.	3.7
5	**1e**	4-MeC_6H_4	18	85	N.D.	1.6
6	**1f**	3-MeC_6H_4	27	95	N.D.	2.3
7	**1g**	2-MeC_6H_4	21	92	N.D.	0.4
8	**1h**	2,4,6-$Me_3C_6H_2$	48	17	N.D.	66
9	**1i**	$PhCH_2CH_2$	19	67[2b]	13	8.1
10	**1j**	2-Naphthyl	24	89	1.9	7.1
11	**1k**	2-Furyl	22	67	N.D.	15
12	**1l**	2-Thienyl	18	85	1.7	Trace
13	**1m**	3-Thienyl	18	90	N.D.	0.9

[a] All reactions were carried out with 1 equiv of substituted 2-benzylidenepropyl 1,3-diacetates **1** and 100 w/w % of PPL in 3 mL of a 1:1 mixture of DMSO–PB at rt.
[b] Not detected.

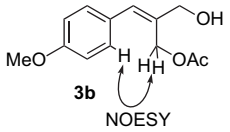


Figure 1. Determination of the structure of **3b**.

The structure of monoacetate **3b** was determined to be the *Z*-isomer by NOESY analysis as shown in Figure 1. The NOESY correlationships were observed between the aromatic and the methylene protons adjacent to the acetate group. All other monoacetates (**3a**, **3c**–**3m**) were also determined to be *Z*-isomer by NOESY analysis.

It is proposed that both acetylation and hydrolysis proceed at the *E*-positioned hydroxymethyl group of the substituent on the alkylidene part, which effects sterical hindrance on the *Z*-positioned one.

3. Conclusions

In summary, it was found that the hydrolysis of 2-alkylidene-1,3-propylene diacetate in the presence of porcine pancreas lipase (PPL) efficiently works to afford the corresponding *Z*-monoacetates in good to high yields with high regioselectivities. PPL Type II is much better choice for the hydrolysis of 2-alkylidene-1,3-propylene diacetate because it is cheaper than lipase AK, AY, and PS-D.[1] Monoacetates of 2-alkylidene-1,3-propanediols are potentially useful intermediates in organic synthesis and may be used as building blocks in syntheses of natural products.[5]

4. Experimental

4.1. General

The ^1H NMR spectra were measured with a Bruker Ultrashield™ 400 Plus (400 MHz) spectrometer. The chemical shifts are expressed in parts per million downfield from tetramethylsilane (δ=0.00) as an internal standard. Splitting patterns are indicated as s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet; br, broad signal. The high-resolution mass spectra (HRMS) of the compounds with a high molecular weight were recorded using a Waters LCT Premier (ESI-TOF-MS) spectrometer. For thin layer chromatographic (TLC) analyses, Merck precoated TLC plates (silica gel 60 F_{254}, Art 5715) were used.

4.2. Typical procedure for preparation of 2-benzylidene-1,3-propylene diacetate 1a

To a colorless solution of 301 mg (1.84 mmol, 1 equiv) of 2-benzylidene-1,3-propanediol **2a**[2] in 1.0 mL of pyridine was added at rt 0.70 mL (7.34 mmol, 4 equiv) of acetic anhydride. The mixture was stirred at rt for 10 h, and quenched with 3 mL of MeOH at 0 °C. To the reaction mixture was added toluene, and evaporated. The crude product was chromatographed on silica gel with a 1:7 mixture of ethyl acetate and hexane to afford 452 mg (99% yield) of **1a**.

4.2.1. 2-(4-Methoxybenzylidene)-1,3-propylene diacetate, ***1b***

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.10 (s, 3H, $COCH_3$), 2.11 (s, 3H, $COCH_3$), 3.82 (s, 3H, OCH_3), 4.73 (s, 2H, CH_2OAc), 4.80 (s, 2H, CH_2OAc), 6.79 (s, 1H, =CH), 6.89 (d, J=8.8 Hz, 2H, ArH-3), 7.20 (d, J=8.8 Hz, 2H, ArH-2); ^{13}C NMR (100 MHz, $CDCl_3$): δ=20.9, 21.0, 55.3, 60.8, 66.8, 113.9, 127.8, 129.3, 130.2, 134.5, 159.3, 170.8, 170.9; HRMS (ESI-TOF): calcd for $C_{15}H_{18}O_5Na$ $(M+Na)^+$: 301.1046, found: 301.1066.

4.2.2. 2-(4-Trifluoromethylbenzylidene)-1,3-propylene diacetate, ***1c***

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.09 (s, 3H, $COCH_3$), 2.13 (s, 3H, $COCH_3$), 4.75 (s, 2H, CH_2OAc), 4.77 (s, 2H, CH_2OAc), 6.85 (s, 1H, =CH), 7.37 (d, J=8.1 Hz, 2H, ArH-2), 7.62 (d, J=8.1 Hz, 2H, ArH-3); ^{13}C NMR (100 MHz, $CDCl_3$): δ=20.8, 20.9, 60.4, 65.8, 124.0 (q, $^1J_{C-F}$=272 Hz), 125.4 (q, $^3J_{C-F}$=3.7 Hz), 129.1, 129.8 (q, $^2J_{C-F}$= 32.7 Hz), 132.3, 133.2, 139.0, 170.6, 170.7; HRMS (ESI-TOF): calcd for $C_{15}H_{15}F_3O_4Na$ $(M+Na)^+$: 339.0815, found: 339.0838.

4.2.3. 2-(4-Chlorobenzylidene)-1,3-propylene diacetate, ***1d***

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.09 (s, 3H, $COCH_3$), 2.12 (s, 3H, $COCH_3$), 4.74 (s, 2H, CH_2OAc), 4.75 (s, 2H, CH_2OAc), 6.78 (s, 1H, =CH), 7.19 (d, J=8.4 Hz, 2H, ArH-2), 7.33 (d, J=8.4 Hz, 2H, ArH-3); ^{13}C NMR (100 MHz, $CDCl_3$): δ=20.86, 20.94, 60.5, 66.1, 128.7, 130.1, 131.8, 132.9, 133.7, 133.8, 170.6, 170.7; HRMS (ESI-TOF): calcd for $C_{14}H_{15}ClO_4Na$ $(M+Na)^+$: 305.0551, found: 305.0544.

4.2.4. 2-(4-Methylbenzylidene)-1,3-propylene diacetate, ***1e***

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.09 (s, 3H, $COCH_3$), 2.11 (s, 3H, $COCH_3$), 2.35 (s, 3H, CH_3), 4.74 (s, 2H, CH_2OAc), 4.79 (s, 2H, CH_2OAc), 6.81 (s, 1H, =CH), 7.14 (d, J=8.4 Hz, 2H, ArH), 7.17 (d, J=8.4 Hz, 2H, ArH); ^{13}C NMR (100 MHz, $CDCl_3$): δ=20.9, 21.0, 21.2, 60.8, 66.5, 128.7, 129.2, 130.2, 132.4, 134.5, 137.8, 170.7, 170.8; HRMS (ESI-TOF): calcd for $C_{15}H_{18}O_4Na$ $(M+Na)^+$: 285.1097, found: 285.1073.

4.2.5. 2-(3-Methylbenzylidene)-1,3-propylene diacetate, ***1f***

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.09 (s, 3H, $COCH_3$), 2.11 (s, 3H, $COCH_3$), 2.35 (s, 3H, CH_3), 4.75 (s, 2H, CH_2OAc), 4.79 (s, 2H, CH_2OAc), 6.82 (s, 1H, =CH), 7.05 (m, 2H, ArH), 7.11 (d, J=7.8 Hz, 1H, ArH), 7.25 (t, J=7.8 Hz, 1H, ArH-5); ^{13}C NMR (100 MHz, $CDCl_3$): δ=20.9, 21.0, 21.4, 60.7, 66.4, 125.8, 128.3, 128.6, 129.5, 130.8, 134.5, 135.3, 138.0, 170.7, 170.8; HRMS (ESI-TOF): calcd for $C_{15}H_{18}O_4Na$ $(M+Na)^+$: 285.1097, found: 285.1112.

4.2.6. 2-(2-Methylbenzylidene)-1,3-propylene diacetate, ***1g***

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.06 (s, 3H, $COCH_3$), 2.12 (s, 3H, $COCH_3$), 2.25 (s, 3H, CH_3), 4.67 (s, 2H, CH_2OAc), 4.77 (s, 2H, CH_2OAc), 6.84 (s, 1H, =CH), 7.09–7.23 (m, 4H, ArH); ^{13}C NMR (100 MHz, $CDCl_3$): δ=19.9, 20.9, 21.0, 60.8, 65.9, 125.7, 128.0, 128.9, 130.0, 131.3, 133.4, 134.5, 136.5, 170.70, 170.74; HRMS (ESI-TOF): calcd for $C_{15}H_{18}O_4Na$ $(M+Na)^+$: 285.1097, found: 285.1073.

4.2.7. 2-(2,4,6-Trimethylbenzylidene)-1,3-propylene diacetate, ***1h***

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ=1.99 (s, 3H, $COCH_3$), 2.11 (s, 6H, $CH_3\times2$), 2.12 (s, 3H, $COCH_3$), 2.27 (s, 3H, CH_3), 4.40 (s, 2H, CH_2OAc), 4.78 (s, 2H, CH_2OAc), 6.62 (s, 1H, =CH), 6.85 (s, 2H, ArH-3); ^{13}C NMR (100 MHz, $CDCl_3$): δ=20.1, 20.7, 21.0, 61.0, 65.3, 128.1, 131.4, 132.2, 132.3, 135.7, 136.9, 170.8; HRMS (ESI-TOF): calcd for $C_{17}H_{22}O_4Na$ $(M+Na)^+$: 313.1410, found: 313.1383.

4.2.8. 3-Phenyl-2-propylidene-1,3-propylene diacetate, ***1i***

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.03 (s, 3H, $COCH_3$), 2.06 (s, 3H, $COCH_3$), 2.48 (m, 2H, CH_2CH=), 2.70 (t, J=7.3 Hz, 2H, CH_2Ph), 4.55 (s, 4H, CH_2OAc$\times$2), 5.81 (t, J=7.5 Hz, 1H, =CH), 7.18 (m, 3H, ArH), 7.28 (m, 2H, ArH); ^{13}C NMR (100 MHz, $CDCl_3$): δ=20.9, 21.0, 29.6, 35.4, 59.7, 66.5, 126.1, 128.4, 128.5, 129.8, 135.2, 141.0, 170.7, 170.8; HRMS (ESI-TOF): calcd for $C_{16}H_{20}O_4Na$ $(M+Na)^+$: 299.1254, found: 299.1215.

4.2.9. 2-(2-Naphthylidene)-1,3-propylene diacetate, ***1j***

Colorless powder; mp 33–34 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.11 (s, 3H, $COCH_3$), 2.14 (s, 3H, $COCH_3$), 4.81 (s, 2H, CH_2OAc), 4.88 (s, 2H, CH_2OAc), 7.00 (s, 1H, =CH), 7.37 (dd, J=1.7, 8.5 Hz, 1H, ArH), 7.49 (m, 2H, ArH), 7.71 (s, 1H, ArH-1), 7.82 (m, 3H, ArH); ^{13}C NMR (100 MHz, $CDCl_3$): δ=20.9, 21.0, 60.8, 66.4, 126.40, 126.42, 126.6, 127.7, 128.05, 128.09, 128.14, 131.3, 132.7, 132.8, 133.1, 134.4, 170.7, 170.8; HRMS (ESI-TOF): calcd for $C_{18}H_{18}O_4Na$ $(M+Na)^+$: 321.1097, found: 321.1100.

4.2.10. 2-(2-Furylidene)-1,3-propylene diacetate, ***1k***

Pale yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.09 (s, 3H, $COCH_3$), 2.10 (s, 3H, $COCH_3$), 4.73 (s, 2H, CH_2OAc), 5.10 (s, 2H, CH_2OAc), 6.40 (d, J=3.4 Hz, 1H, ArH-3), 6.42 (dd, J=1.8, 3.4 Hz, 1H, ArH-4), 6.49 (s, 1H, =CH), 7.45 (d, J=1.8 Hz, 1H, ArH-5); ^{13}C NMR (100 MHz, $CDCl_3$): δ=20.9, 21.0, 61.4, 66.4, 111.5, 112.4, 120.9, 128.0, 143.2, 150.8, 170.7, 171.0; HRMS (ESI-TOF): calcd for $C_{12}H_{14}O_5Na$ $(M+Na)^+$: 261.0733, found: 261.0727.

4.2.11. 2-(2-Thienylidene)-1,3-propylene diacetate, ***1l***

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.10 (s, 3H, $COCH_3$), 2.11 (s, 3H, $COCH_3$), 4.75 (s, 2H, CH_2OAc), 4.95 (s, 2H, CH_2OAc), 6.88 (s, 1H, =CH), 7.04 (dd, J=3.6, 5.0 Hz, 1H, ArH-4), 7.08 (d, J=3.6 Hz, 1H, ArH-3), 7.35 (d, J=5.0 Hz, 1H, ArH-5); ^{13}C NMR (100 MHz, $CDCl_3$): δ=20.9, 21.0, 61.1, 66.8, 126.9, 127.2, 127.3, 128.9, 129.3, 137.7, 170.7, 170.9; HRMS (ESI-TOF): calcd for $C_{12}H_{14}O_4SNa$ $(M+Na)^+$: 277.0505, found: 277.0532.

4.2.12. 2-(3-Thienylidene)-1,3-propylene diacetate, ***1m***

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.11 (s, 6H, $COCH_3\times2$), 4.74 (s, 2H, CH_2OAc), 4.85 (s, 2H, CH_2OAc), 6.76 (s, 1H, =CH), 7.08 (dd, J=1.2, 5.0 Hz, 1H, ArH-4), 7.26 (m, 1H, ArH-2), 7.32 (dd, J=3.0, 5.0 Hz, 1H, ArH-5); ^{13}C NMR (100 MHz, $CDCl_3$): δ=20.9, 21.0, 61.0, 66.7, 124.8, 125.9, 128.3, 128/7, 130.1, 136.3, 170.7, 170.9; HRMS (ESI-TOF): calcd for $C_{12}H_{14}O_4SNa$ $(M+Na)^+$: 277.0505, found: 277.0500.

4.3. Typical procedure for hydrolysis using PPL

To a pale yellow suspension of 124 mg (0.500 mmol, 1 equiv) of 2-benzylidene-1,3-propylene diacetate **1a** and 124 mg (100 w/w %) of PPL in 3 mL of a 1:1 mixture of DMSO–1/15 M phosphate buffer (pH 7.0) was stirred at rt for 25 h. The reaction mixture was filtered on Celite, and washed with AcOEt. The filtrate was added to water, and then extracted three times with AcOEt. The combined AcOEt layers were washed with brine, and dried over anhydrous $MgSO_4$. The mixture was filtered, and the filtrate was evaporated. The crude product was chromatographed on silica gel with a 2:3 mixture of AcOEt and hexane to afford 101 mg (98% yield) of **3a**.

4.3.1. (Z)-2-Hydroxymethyl-3-phenyl-2-propenyl acetate, ***3a***

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.08 (s, 3H, $COCH_3$), 2.64 (br s, 1H, OH), 4.28 (s, 2H, CH_2OH), 4.82 (s, 2H, CH_2OAc), 6.81 (s, 1H, =CH), 7.23–7.36 (m, 5H, ArH); ^{13}C NMR (100 MHz, $CDCl_3$): δ=20.9, 60.9, 65.3, 127.5, 128.4, 128.8, 131.5, 135.6, 135.8, 171.5; HRMS (ESI-TOF): calcd for $C_{12}H_{14}O_3Na$ $(M+Na)^+$: 229.0835, found: 229.0806.

4.3.2. (Z)-2-Hydroxymethyl-3-(4-methoxy)phenyl-2-propenyl acetate, ***3b***

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.10 (s, 3H, $COCH_3$), 2.57 (br s, 1H, OH), 3.80 (s, 3H, OCH_3), 4.26 (s, 2H, CH_2OH), 4.83 (s, 2H, CH_2OAc), 6.74 (s, 1H, =CH), 6.88 (d, J=8.8 Hz, 2H, ArH-3), 7.19

(d, J=8.8 Hz, 2H, ArH-2); ^{13}C NMR (100 MHz, $CDCl_3$): δ=21.0, 55.3, 61.1, 65.7, 113.9, 128.3, 130.1, 131.5, 134.0, 159.1, 171.5; HRMS (ESI-TOF): calcd for $C_{13}H_{16}O_4Na$ $(M+Na)^+$: 259.0941, found: 259.0913.

4.3.3. (Z)-2-Hydroxymethyl-3-(4-trifluoromethyl)phenyl-2-propenyl acetate, ***3c***

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.10 (s, 3H, $COCH_3$), 2.33 (br s, 1H, OH), 4.31 (s, 2H, CH_2OH), 4.78 (s, 2H, CH_2OAc), 6.84 (s, 1H, =CH), 7.37 (d, J=8.4 Hz, 2H, ArH-2), 7.61 (d, J=8.4 Hz, 2H, ArH-3); ^{13}C NMR (100 MHz, $CDCl_3$): δ=20.9, 60.5, 65.1, 124.1 (q, $^1J_{C-F}$= 272 Hz), 125.4 (q, $^3J_{C-F}$=3.7 Hz), 129.0, 129.5 (q, $^2J_{C-F}$=32.6 Hz), 129.8, 137.7, 139.5, 171.3; HRMS (ESI-TOF): calcd for $C_{13}H_{13}F_3O_3Na$ $(M+Na)^+$: 297.0709, found: 297.0679.

4.3.4. (Z)-2-Hydroxymethyl-3-(4-chloro)phenyl-2-propenyl acetate, ***3d***

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.11 (s, 3H, $COCH_3$), 2.22 (br s, 1H, OH), 4.28 (s, 2H, CH_2OH), 4.79 (s, 2H, CH_2OAc), 6.76 (s, 1H, =CH), 7.19 (d, J=8.4 Hz, 2H, ArH-2), 7.33 (d, J=8.4 Hz, 2H, ArH-3); ^{13}C NMR (100 MHz, $CDCl_3$): δ=20.9, 60.6, 65.3, 128.6, 130.1, 130.3, 133.5, 134.2, 136.3, 171.3; HRMS (ESI-TOF): calcd for $C_{12}H_{13}O_3ClNa$ $(M+Na)^+$: 263.0445, found: 263.0441.

4.3.5. (Z)-2-Hydroxymethyl-3-(4-methyl)phenyl-2-propenyl acetate, ***3e***

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.10 (s, 3H, $COCH_3$), 2.23 (br s, 1H, OH), 2.35 (s, 3H, CH_3), 4.28 (s, 2H, CH_2OH), 4.84 (s, 2H, CH_2OAc), 6.78 (s, 1H, =CH), 7.15 (s, 4H, ArH); ^{13}C NMR (100 MHz, $CDCl_3$): δ=21.0, 21.2, 61.0, 65.7, 128.7, 129.1, 131.9, 132.9, 134.9, 137.5, 171.5; HRMS (ESI-TOF): calcd for $C_{13}H_{16}O_3Na$ $(M+Na)^+$: 243.0992, found: 243.0969.

4.3.6. (Z)-2-Hydroxymethyl-3-(3-methyl)phenyl-2-propenyl acetate, ***3f***

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.10 (s, 3H, $COCH_3$), 2.27 (t, J=5.9 Hz, 1H, OH), 2.35 (s, 3H, CH_3), 4.28 (d, J=5.9 Hz, 2H, CH_2OH), 4.83 (s, 2H, CH_2OAc), 6.78 (s, 1H, =CH), 7.05 (m, 2H, ArH), 7.10 (d, J=7.7 Hz, 1H, ArH), 7.24 (t, J=7.7 Hz, 1H, ArH-5); ^{13}C NMR (100 MHz, $CDCl_3$): δ=21.0, 21.4, 61.0, 65.5, 125.8, 128.30, 128.33, 129.5, 131.9, 135.4, 135.7, 138.0, 171.4; HRMS (ESI-TOF): calcd for $C_{13}H_{17}O_3$ $(M+H)^+$: 221.1172, found: 221.1139.

4.3.7. (Z)-2-Hydroxymethyl-3-(2-methyl)phenyl-2-propenyl acetate, ***3g***

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.05 (s, 3H, $COCH_3$), 2.24 (s, 3H, CH_3), 2.73 (br s, 1H, OH), 4.29 (s, 2H, CH_2OH), 4.70 (s, 2H, CH_2OAc), 6.80 (s, 1H, =CH), 7.09–7.21 (m, 4H, ArH); ^{13}C NMR (100 MHz, $CDCl_3$): δ=19.9, 20.9, 61.1, 64.9, 125.7, 127.7, 129.0, 129.9, 130.5, 135.1, 135.8, 136.5, 171.5; HRMS (ESI-TOF): calcd for $C_{13}H_{16}O_3Na$ $(M+Na)^+$: 243.0992, found: 243.0969.

4.3.8. (Z)-2-Hydroxymethyl-3-(2,4,6-trimethyl)phenyl-2-propenyl acetate, ***3h***

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.01 (s, 3H, $COCH_3$), 2.13 (s, 6H, $CH_3\times2$), 2.22 (br s, 1H, OH), 2.27 (s, 3H, CH_3), 4.30 (s, 2H, CH_2OH), 4.47 (s, 2H, CH_2OAc), 6.57 (s, 1H, =CH), 6.85 (s, 2H, ArH-3); ^{13}C NMR (100 MHz, $CDCl_3$): δ=20.3, 20.8, 21.0, 61.3, 64.5, 128.1, 129.7, 131.9, 135.8, 136.67, 136.71, 171.4; HRMS (ESI-TOF): calcd for $C_{15}H_{20}O_3Na$ $(M+Na)^+$: 271.1305, found: 271.1293.

4.3.9. (Z)-2-Hydroxymethyl-5-phenyl-2-pentenyl acetate, ***3i***[2b]

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.04 (s, 3H, $COCH_3$), 2.19 (br s, 1H, OH), 2.46 (q, J=7.4 Hz, 2H, CH_2CH=), 2.69 (t, J=7.4 Hz, 2H, CH_2Ph), 4.07 (s, 2H, CH_2OH), 4.61 (s, 2H, CH_2OAc), 5.74 (t, J=7.4 Hz, 1H, =CH), 7.18 (m, 3H, ArH), 7.28 (m, 2H, ArH); ^{13}C NMR (100 MHz, $CDCl_3$): δ=20.9, 29.5, 35.6, 60.1, 65.6, 126.0, 128.38, 128.44, 132.2, 134.3, 141.3, 171.3; HRMS (ESI-TOF): calcd for $C_{14}H_{18}O_3Na$ $(M+Na)^+$: 257.1148, found: 257.1107.

4.3.10. (Z)-2-Hydroxymethyl-3-(2-naphthyl)-2-propenyl acetate, ***3j***

Colorless powder; mp 65–66 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.11 (s, 3H, $COCH_3$), 2.42 (br s, 1H, OH), 4.33 (s, 2H, CH_2OH), 4.91 (s, 2H, CH_2OAc), 6.95 (s, 1H, =CH), 7.37 (dd, J=1.7, 8.5 Hz, 1H, ArH), 7.47 (m, 2H, ArH), 7.70 (s, 1H, ArH-1), 7.81 (m, 3H, ArH); ^{13}C NMR (100 MHz, $CDCl_3$): δ=21.0, 61.0, 65.5, 126.2, 126.3, 126.7, 127.6, 127.9, 128.0, 128.1, 131.6, 132.6, 133.2, 133.3, 136.0, 171.4; HRMS (ESI-TOF): calcd for $C_{16}H_{16}O_3Na$ $(M+Na)^+$: 279.0992, found: 279.1013.

4.3.11. (Z)-2-Hydroxymethyl-3-(2-furyl)-2-propenyl acetate, ***3k***

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.09 (s, 3H, $COCH_3$), 2.60 (br s, 1H, OH), 4.26 (s, 2H, CH_2OH), 5.10 (s, 2H, CH_2OAc), 6.37 (d, J=3.3 Hz, 1H, ArH-3), 6.41 (dd, J=1.8, 3.3 Hz, 1H, ArH-4), 6.48 (s, 1H, =CH), 7.43 (d, J=1.8 Hz, 1H, ArH-5); ^{13}C NMR (100 MHz, $CDCl_3$): δ=21.0, 61.7, 65.4, 111.39, 111.44, 118.3, 133.0, 142.8, 151.3, 171.5; HRMS (ESI-TOF): calcd for $C_{10}H_{12}O_4Na$ $(M+Na)^+$: 219.0628, found: 219.0602.

4.3.12. (Z)-2-Hydroxymethyl-3-(2-thienyl)-2-propenyl acetate, ***3l***

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.11 (s, 3H, $COCH_3$), 2.27 (br s, 1H, OH), 4.29 (s, 2H, CH_2OH), 4.96 (s, 2H, CH_2OAc), 6.85 (s, 1H, =CH), 7.03 (dd, J=3.6, 5.0 Hz, 1H, ArH-4), 7.05 (m, 1H, ArH-3), 7.32 (dd, J=1.2, 5.0 Hz, 1H, ArH-5); ^{13}C NMR (100 MHz, $CDCl_3$): δ=20.9, 61.3, 65.9, 124.1, 126.7, 127.3, 128.6, 133.8, 138.2, 171.4; HRMS (ESI-TOF): calcd for $C_{10}H_{12}O_3SNa$ $(M+Na)^+$: 235.0399, found: 235.0360.

4.3.13. (Z)-2-Hydroxymethyl-3-(3-thienyl)-2-propenyl acetate, ***3m***

Colorless oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ=2.11 (s, 3H, $COCH_3$), 2.37 (br s, 1H, OH), 4.27 (s, 2H, CH_2OH), 4.87 (s, 2H, CH_2OAc), 6.72 (s, 1H, =CH), 7.08 (d, J=5.0 Hz, 1H, ArH-4), 7.25 (m, 1H, ArH-2), 7.31 (dd, J=2.9, 5.0 Hz, 1H, ArH-5); ^{13}C NMR (100 MHz, $CDCl_3$): δ=21.0, 61.2, 65.8, 124.2, 125.7, 126.0, 128.4, 134.8, 136.7, 171.5; HRMS (ESI-TOF): calcd for $C_{10}H_{12}O_3SNa$ $(M+Na)^+$: 235.0399, found: 235.0399.

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References and notes

1. (a) Hisano, T.; Onodera, K.; Toyabe, Y.; Mase, N.; Yoda, H.; Takabe, K. *Tetrahedron Lett.* **2005**, *46*, 6293 and the references cited therein; (b) Takabe, K.; Mase, N.; Hisano, T.; Yoda, H. *Tetrahedron Lett.* **2003**, *44*, 3267.
2. (a) Miura, T.; Kawashima, Y.; Takahashi, M.; Murakami, Y.; Imai, N. *Synth. Commun.* **2007**, *37*, 3105; (b) Miura, T.; Okazaki, K.; Ogawa, K.; Otomo, E.; Umetsu, S.; Takahashi, M.; Kawashima, Y.; Jyo, Y.; Koyata, N.; Murakami, Y.; Imai, N. *Synthesis*, in press.
3. PPL Type II is commercially available from Sigma.
4. Miura, T.; Kawashima, Y.; Umetsu, S.; Kanamori, D.; Tsuyama, N.; Jyo, Y.; Murakami, Y.; Imai, N. *Chem. Lett.* **2007**, *36*, 814.
5. Daub, G. W.; Edwards, J. P.; Okada, C. R.; Allen, J. W.; Maxey, C. T.; Wells, M. S.; Goldstein, A. S.; Dibley, M. J.; Wang, C. J.; Ostercamp, D. P.; Chung, S.; Cunningham, P. S.; Berliner, M. A. *J. Org. Chem.* **1997**, *62*, 1976.