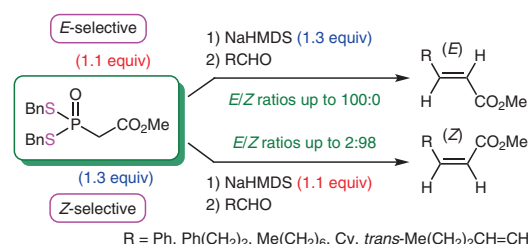


# Synthesis of Methyl 2-[Bis(benzylthio)phosphoryl]acetate as a Novel Horner–Wadsworth–Emmons-Type Reagent and Its Application to the Diastereodivergent Synthesis of (*E*)- and (*Z*)- $\alpha,\beta$ -Unsaturated Esters

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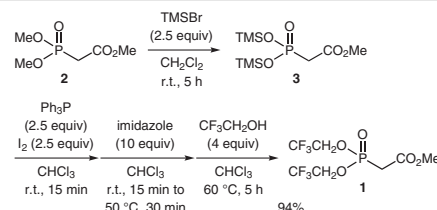
**Abstract** Methyl 2-[bis(benzylthio)phosphoryl]acetate has proven to be an efficient Horner–Wadsworth–Emmons (HWE)-type reagent for the diastereodivergent synthesis of (*E*)- and (*Z*)- $\alpha,\beta$ -unsaturated esters. Under the conditions of excess NaHMDS relative to the HWE-type reagent, the HWE-type reactions of methyl 2-[bis(benzylthio)phosphoryl]acetate with various aldehydes afforded the corresponding  $\alpha,\beta$ -unsaturated esters in an *E*-selective manner in up to 100:0 *E/Z* ratio. However, when an excess of the HWE-type reagent was used relative to NaHMDS, the stereoselectivity of the HWE-type reactions was dramatically changed from *E* to *Z*, yielding an *E/Z* ratio of up to 2:98.

**Key words** Horner–Wadsworth–Emmons reagent, phosphorus–sulfur bond,  $\alpha,\beta$ -unsaturated esters, diastereodivergent synthesis, olefination, aldehydes

One of the most extensively utilized reactions for the stereoselective construction of C=C double bonds is the reaction of aldehydes or ketones with stabilized phosphonate carbanions. This reaction is called the Horner–Wadsworth–Emmons (HWE) reaction, and various phosphonate derivatives have been developed as useful HWE reagents over the last half-century.<sup>1</sup> On the other hand, the importance of organic compounds such as phosphorothioates, phosphonothioates, phosphinothioates, and phosphonodithioates containing phosphorus–sulfur single bonds has increased over the same period, especially in the fields of agrochemicals, medicinal chemistry, and materials chemistry.<sup>2</sup> To the best of our knowledge, however, the synthesis of HWE-type

reagents in which both the phosphorus–oxygen single bonds of the HWE reagent are replaced with phosphorus–sulfur single bonds, has not yet been achieved. Because oxygen and sulfur are in the same group of the Periodic Table, but sulfur is in the same period as phosphorus, the above structural conversion from the HWE reagents to HWE-type reagents was expected to result in a significant change in reactivity.

We recently reported an efficient two-step synthesis of methyl 2-[bis(2,2,2-trifluoroethoxy)phosphoryl]acetate (Still–Gennari reagent; **1**) based on Garegg–Samuelsson reaction conditions (triphenylphosphine, iodine, and imidazole) from methyl 2-(dimethoxyphosphoryl)acetate (**2**) via methyl 2-[bis[(trimethylsilyl)oxy]phosphoryl]acetate (**3**) as an intermediate (Scheme 1).<sup>3,4</sup> This procedure has been found to be applicable not only to the synthesis of Still–Gennari reagent (**1**), but also to the synthesis of other HWE-type reagents that have phosphorus–sulfur or phosphorus–nitrogen single bonds instead of phosphorus–oxygen single bonds. Herein, we report an efficient synthesis of methyl 2-[bis(benzylthio)phosphoryl]acetate (**4a**) as a novel HWE-type reagent, and its application in the diastereoselective synthesis of (*E*)- and (*Z*)- $\alpha,\beta$ -unsaturated esters by an HWE-type reaction of **4a** with various aldehydes.



**Scheme 1** Two-step synthesis of the Still–Gennari reagent (**1**) from methyl 2-(dimethoxyphosphoryl)acetate (**2**)

**Table 1** Synthesis of Methyl 2-[Bis(organothio)phosphoryl]acetates **4a–d**

Entry	X	Yield <sup>a</sup> (%) of <b>4</b>
1	Bn	95 ( <b>4a</b> )
2	Ph	90 ( <b>4b</b> )
3	Ph(CH <sub>2</sub> ) <sub>2</sub>	88 ( <b>4c</b> )
4	<i>n</i> -C <sub>12</sub> H <sub>25</sub>	87 ( <b>4d</b> )

<sup>a</sup> Isolated yield.

Based on our previous work on the synthesis of **1**, we first investigated the two-step conversion of **2** into the methyl 2-[bis(organothio)phosphoryl]acetates **4a–d**. As a result, four products **4a–d** were obtained in yields of 87–95% from **2** by employing 2.5 equivalents of triphenylphosphine, 2.5 equivalents of iodine, 10.0 equivalents of imidazole, and 4.0 equivalents of the thiol, with 6.0 equivalents of 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) in the second step (Table 1).<sup>5</sup>

An HWE-type reaction was investigated by using 1.1 equivalents of methyl 2-[bis(benzylthio)phosphoryl]acetate (**4a**) and 1.1 equivalents of sodium hexamethyldisilazide (NaHMDS) with benzaldehyde (**5a**; 1.0 equiv) at 0 °C in THF. The  $\alpha,\beta$ -unsaturated esters (*E*)- and (*Z*)-**6a** were obtained in good yield, but it was difficult to obtain reproducible results with respect to the *E/Z* selectivity. However, when the amount of NaHMDS was increased to 1.3 equivalents, the (*E*)- $\alpha,\beta$ -unsaturated ester (*E*)-**6a** was formed exclusively and reproducibly (Table 2, entry 1).<sup>6</sup> The use of NaHMDS was slightly preferable to lithium hexamethyldisilazide (LiHMDS) or potassium hexamethyldisilazide (KHMDS) in terms of the yield and/or selectivity (entries 2 and 3). The HWE reaction of aldehydes under isopropylmagnesium bromide (*i*-PrMgBr) conditions generally tends to proceed with high *E*-selectivity,<sup>7</sup> whereas the reaction of **4a** with **5a** under *i*-PrMgBr conditions gave (*E*)-**6a** with a slightly lower *E*-selectivity (entry 4) than those achieved under other basic conditions. In the HWE-type reaction using the other HWE-type reagents **4b–d**, the (*E*)- $\alpha,\beta$ -unsaturated ester (*E*)-

**6a** was also obtained with 100% stereoselectivity (entries 5–7). The geometries of **6a** were confirmed on the basis of the coupling constants between the olefinic protons, and the *E/Z* ratios of **6a** were calculated by integration of the appropriate proton absorptions determined by <sup>1</sup>H NMR analysis.

**Table 2** HWE-Type Reaction of Methyl 2-[Bis(organothio)phosphoryl]acetates **4a–d** with Benzaldehyde (**5a**) in the Presence of Excess NaHMDS

Entry	HWE-type reagent	Yield <sup>a</sup> (%) of <b>6a</b>	<i>E/Z</i> <sup>b</sup>
1	<b>4a</b> (X = Bn)	99	100:0
2 <sup>c</sup>	<b>4a</b> (X = Bn)	97	99:1
3 <sup>d</sup>	<b>4a</b> (X = Bn)	86	100:0
4 <sup>e</sup>	<b>4a</b> (X = Bn)	90	96:4
5	<b>4b</b> (X = Ph)	78	100:0
6	<b>4c</b> [X = Ph(CH <sub>2</sub> ) <sub>2</sub> ]	90	100:0
7	<b>4d</b> (X = <i>n</i> -C <sub>12</sub> H <sub>25</sub> )	86	100:0

<sup>a</sup> Isolated yield.<sup>b</sup> Determined by <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) analysis.<sup>c</sup> LiHMDS was used instead of NaHMDS.<sup>d</sup> KHMDS was used instead of NaHMDS.<sup>e</sup> *i*-PrMgBr was used instead of NaHMDS.

Surprisingly, the (*Z*)- $\alpha,\beta$ -unsaturated ester (*Z*)-**6a** was found to be the major product when the quantity relationship between the HWE-type reagent **4a–d** and NaHMDS was reversed, as shown in Table 3 (entries 1–4). Furthermore, the *Z*-selectivity was improved when the reaction was carried out at –78 °C, and the highest selectivity (*E/Z* = 2:98) was obtained by the reaction of the HWE-type reagent **4a** (entry 5).<sup>8</sup> In other words, the newly developed HWE-type reagents **4a–d** can synthesize  $\alpha,\beta$ -unsaturated ester (*E*)- or (*Z*)-**6a** diastereoselectively, merely by changing the ratio of the HWE-type reagent **4a–d** to NaHMDS. For the reaction of **4a**, the use of NaHMDS gave a slightly more favorable yield and selectivity compared with LiHMDS or KHMDS (entries 6 and 7). Notably, the reaction of **4a** and **5a** under *i*-PrMgBr conditions showed *E*-selectivity (entry 8).<sup>7</sup> When benzaldehyde (**5a**) was reacted with **4d** having dodecylthio groups at –78 °C, the yield was remarkably low (entry 11).

**Table 3** HWE-Type Reaction of Methyl 2-[Bis(organothio)phosphoryl]acetates **4a–d** with Benzaldehyde (**5a**) in the Presence of an Excess of the HWE-Type Reagent

Entry	HWE-type reagent	Temp (°C)	Yield <sup>a</sup> (%) of <b>6a</b>	<i>E/Z</i> <sup>b</sup>
1	<b>4a</b> (X = Bn)	0	99	14:86
2	<b>4b</b> (X = Ph)	0	84	34:66
3	<b>4c</b> [X = Ph(CH <sub>2</sub> ) <sub>2</sub> ]	0	94	25:75
4	<b>4d</b> (X = <i>n</i> -C <sub>12</sub> H <sub>25</sub> )	0	81	31:69
5	<b>4a</b> (X = Bn)	−78	94	2:98
6 <sup>c</sup>	<b>4a</b> (X = Bn)	−78	90	5:95
7 <sup>d</sup>	<b>4a</b> (X = Bn)	−78	80	6:94
8 <sup>e</sup>	<b>4a</b> (X = Bn)	−78	18	85:15
9	<b>4b</b> (X = Ph)	−78	87	7:93
10	<b>4c</b> [X = Ph(CH <sub>2</sub> ) <sub>2</sub> ]	−78	96	4:96
11	<b>4d</b> (X = <i>n</i> -C <sub>12</sub> H <sub>25</sub> )	−78	7	46:54

<sup>a</sup> Isolated yield.<sup>b</sup> Determined by <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) analysis.<sup>c</sup> LiHMDS was used instead of NaHMDS.<sup>d</sup> KHMDS was used instead of NaHMDS.<sup>e</sup> *i*-PrMgBr was used instead of NaHMDS.

To clarify the differences between our HWE-type reagents **4a–d**, which are capable of diastereodivergent synthesis of  $\alpha,\beta$ -unsaturated ester **6a**, and the more commonly used HWE reagents, we examined the results of HWE reactions of the Still–Gennari reagent (**1**) and methyl 2-[bis(benzyloxy)phosphoryl]acetate (**7**) under the same conditions to those shown in Tables 2 and 3. Regardless of the ratio of the HWE reagent to NaHMDS, HWE reagent **1** exhibited a moderate *Z*-selectivity whereas the HWE reagent **7** exhibited a high *E*-selectivity (Table 4). There was no reversal of stereoselectivity depending on the amount of the

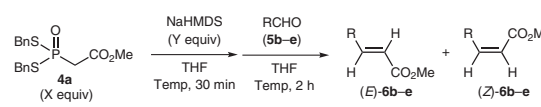
reagent for either of the HWE reagents **1** or **7**. The novel HWE-type reagent **4a** has a characteristic chemical structure in which the two phosphorus–oxygen single bonds of HWE reagent **7** are replaced by phosphorus–sulfur single bonds, and its reactivity was found to be significantly different from that of ordinary HWE reagents such as **1** and **7**.

On the basis of the results shown in Tables 2 and 3, we investigated the HWE-type reaction of HWE-type reagent **4a** with various aldehydes. The results of the *E*-selective HWE-type reaction using 1.1 equivalents of HWE-type reagent **4a** and 1.3 equivalents of NaHMDS to aldehydes **5b–e**,

**Table 4** HWE Reactions of the Still–Gennari Reagent (**1**) and Methyl 2-[Bis(benzyloxy)phosphoryl]acetate (**7**) with Benzaldehyde (**5a**)

Entry	HWE reagent	X (equiv)	Y (equiv)	Temp (°C)	Yield <sup>a</sup> (%) of <b>6a</b>	<i>E/Z</i> <sup>b</sup>
1	<b>1</b> (X = CF <sub>3</sub> CH <sub>2</sub> )	1.1	1.3	0	91	34:66
2	<b>1</b> (X = CF <sub>3</sub> CH <sub>2</sub> )	1.3	1.1	0	89	32:68
3	<b>1</b> (X = CF <sub>3</sub> CH <sub>2</sub> )	1.3	1.1	−78	95	17:83
4	<b>7</b> (X = Bn)	1.1	1.3	0	94	97:3
5	<b>7</b> (X = Bn)	1.3	1.1	0	99	97:3
6	<b>7</b> (X = Bn)	1.3	1.1	−78	95	96:4

<sup>a</sup> Isolated yield.<sup>b</sup> Determined by <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) analysis.

**Table 5** Diastereodivergent Synthesis of  $\alpha,\beta$ -Unsaturated Esters (*E*)- and (*Z*)-**6b–e** by the HWE-Type Reaction of Methyl 2-[Bis(benzylthio)phosphoryl]acetate (**4a**) with Aldehydes **5b–e**


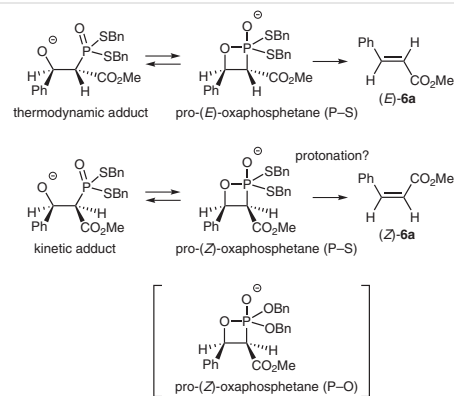
Entry	Aldehyde	X (equiv)	Y (equiv)	Temp (°C)	Yield <sup>a</sup> (%)	<i>E/Z</i> <sup>b</sup>
1	<b>5b</b> [R = Ph(CH <sub>2</sub> ) <sub>2</sub> ]	1.1	1.3	0	86 ( <b>6b</b> )	89:11
2	<b>5c</b> [R = Me(CH <sub>2</sub> ) <sub>6</sub> ]	1.1	1.3	0	77 ( <b>6c</b> )	96:4
3	<b>5d</b> (R = Cy)	1.1	1.3	0	96 ( <b>6d</b> )	10:90
4	<b>5e</b> [R = <i>trans</i> -Me(CH <sub>2</sub> ) <sub>2</sub> CH=CH]	1.1	1.3	0	80 ( <b>6e</b> )	79:21
5	<b>5b</b> [R = Ph(CH <sub>2</sub> ) <sub>2</sub> ]	1.3	1.1	–78	82 ( <b>6b</b> )	6:94
6	<b>5c</b> [R = Me(CH <sub>2</sub> ) <sub>6</sub> ]	1.3	1.1	–78	82 ( <b>6c</b> )	5:95
7	<b>5d</b> (R = Cy)	1.3	1.1	–78	78 ( <b>6d</b> )	2:98
8	<b>5e</b> [R = <i>trans</i> -Me(CH <sub>2</sub> ) <sub>2</sub> CH=CH]	1.3	1.1	–78	67 ( <b>6e</b> )	5:95

<sup>a</sup> Isolated yield.<sup>b</sup> Determined by <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) analysis.

and the *Z*-selective HWE-type reaction using the reverse ratio of the amounts of the HWE-type reagent **4a** and NaHMDS are shown in Table 5. When aldehydes **5b**, **5c**, and **5e** were used in the presence of an excess of NaHMDS, the reaction proceeded in an *E*-selective manner, as for aldehyde **5a**; the exception was aldehyde **5d**, which afforded the (*Z*)- $\alpha,\beta$ -unsaturated ester (*Z*)-**6c** as the main product (Table 5, entries 1–4). However, when the reaction of aldehyde **5d** was carried out at –40 °C, the selectivity was reversed, and the (*Z*)- $\alpha,\beta$ -unsaturated ester (*Z*)-**6c** was obtained as the major product (88%; *E/Z* = 95:5). On the other hand, with an excess of the HWE-type reagent, all the HWE-type reactions of **4a** and aldehydes **5b–e** proceeded in a *Z*-selective manner (entries 5–8).

Assuming that the pro-(*Z*)-oxaphosphetane (Scheme 2, P–S), which is kinetically generated from the novel HWE-type reagent **4a** and benzaldehyde (**5a**), is more stable than the conventional pro-(*Z*)-oxaphosphetane (P–O), an equilibrium occurs between the pro-(*Z*)-oxaphosphetane (P–S) and the pro-(*E*)-oxaphosphetane (P–S) under excess NaHMDS conditions. As a result, it is considered that (*E*)-**6a** is formed via the thermodynamically favored pro-(*E*)-oxaphosphetane (P–S). If pro-(*Z*)-oxaphosphetane (P–S) is protonated and destabilized under excess HWE-type reagent conditions, (*Z*)-**6a** would be obtained via the kinetically favored pro-(*Z*)-oxaphosphetane (P–S). Although the reaction mechanism is currently unknown, a similar HWE-type reaction of **4a** and **5a** under aqueous conditions (**5a/4a/NaHMDS/H<sub>2</sub>O** = 1:1.1:1.1:1.1) gave the  $\alpha,\beta$ -unsaturated ester **6a** in a *Z*-selective manner (*E/Z* = 1:99) and in 82% yield. Therefore, the excess of the HWE-type reagent **4a** is considered to be acting as some kind of proton source.

In conclusion, we efficiently synthesized novel HWE-type reagents **4a–d** from methyl 2-(dimethoxyphosphoryl)acetate (**2**) by using Garegg–Samuelsson reaction condi-

**Scheme 2** Plausible intermediates in the HWE-type reaction of methyl 2-[bis(benzylthio)phosphoryl]acetate (**4a**) with benzaldehyde (**5a**)

tions. The novel HWE-type reagent **4a** was found to diastereodivergently afford  $\alpha,\beta$ -unsaturated esters **6a–e** in HWE-type reactions, depending on the reaction conditions. Conditions using 1.1 equivalents of **4a** and 1.3 equivalents of NaHMDS to aldehydes **5a–e** are suitable for the preparation of (*E*)- $\alpha,\beta$ -unsaturated esters (*E*)-**6a–e**, whereas conditions using 1.3 equivalents of **4a** and 1.1 equivalents of NaHMDS to aldehydes **5a–e** are suitable for the preparation of (*Z*)- $\alpha,\beta$ -unsaturated esters (*Z*)-**6a–d**. Note that the HWE-type reagents **4a–d** in which both the phosphorus–oxygen single bonds of the HWE reagent are replaced by phosphorus–sulfur single bonds have not been reported previously, and we have succeeded for the first time in synthesizing **4a–d** and in performing their diastereodivergent HWE-type reactions with aldehydes **5a–e**. The mechanism of the diastereodivergent HWE-type reactions of methyl 2-[bis(organothio)phosphoryl]acetates **4a–d** with aldehydes **5a–e** remains unclear at present, but efforts towards its elucidation are currently underway in our laboratory.

## Conflict of Interest

The authors declare no conflict of interest.

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## Supporting Information

Supporting information for this article is available online at <https://doi.org/10.1055/a-2347-1027>.

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- (5) **Methyl 2-[Bis(benzylthio)phosphoryl]acetate (4a)**  
TMSBr (1.67 mL, 12.8 mmol) was added to a solution of methyl 2-(dimethoxyphosphoryl)acetate (**2**; 929 mg, 5.10 mmol) in anhyd CH<sub>2</sub>Cl<sub>2</sub> (15 mL) at r.t. under argon, and the mixture was stirred at r.t. for 1 h under argon. Evaporation of the solvent mixture in vacuo gave methyl 2-[bis(trimethylsilyl)oxy]phosphoryl]acetate (**3**), which was used without further purification.  
PPh<sub>3</sub> (3.38 g, 12.8 mmol) and I<sub>2</sub> (3.25 g, 12.8 mmol) were added to a solution of **3** in anhyd CHCl<sub>3</sub> (20 mL) at r.t. under argon, and the mixture was stirred at r.t. for 15 min under argon. Imidazole (3.47 g, 51.0 mmol) was then added, and the resulting mixture was stirred at r.t. for 45 min. A solution of BnSH (2.40 mL, 20.4 mmol) and DBU (4.60 mL, 30.6 mmol) in anhyd CHCl<sub>3</sub> (10 mL) was then added. The resulting mixture was stirred at r.t. for 4 h, then purified by flash column chromatography [Silica Gel PSQ 60B (Fuji Silysia Chemical), hexane–EtOAc (1:1)] to afford **4a**; yield: 1.78 g (95%); colorless needles (CHCl<sub>3</sub>–pentane); mp 36.0–36.8 °C.  
IR (KBr): 3029, 2967, 2913, 1733, 1496, 1454, 1438, 1418, 1257, 1205, 1191, 1114 cm<sup>−1</sup>. <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>): δ = 7.39–7.26 (m, 10 H), 4.27–4.13 (m, 4 H), 3.72 (s, 3 H), 3.22 (d, <sup>2</sup>J<sub>HP</sub> = 16.1 Hz, 2 H). <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>): δ = 165.2 (d, <sup>2</sup>J<sub>CP</sub> = 5.4 Hz), 136.4 (d, <sup>3</sup>J<sub>CP</sub> = 5.5 Hz), 129.2, 128.8, 127.9, 52.8, 45.4 (d, <sup>1</sup>J<sub>CP</sub> = 63.6 Hz), 35.0 (d, <sup>2</sup>J<sub>CP</sub> = 3.2 Hz). HRMS (ESI): *m/z* [M + Na]<sup>+</sup> calcd for C<sub>17</sub>H<sub>19</sub>NaO<sub>3</sub>PS<sub>2</sub>: 389.0411; found: 389.0407. Anal. Calcd for C<sub>17</sub>H<sub>19</sub>O<sub>3</sub>PS<sub>2</sub>: C, 55.72; H, 5.23. Found: C, 55.74; H, 5.21.
- (6) **Methyl (E)-3-Phenylacrylate [(E)-6a]<sup>7c</sup>; Typical (E)-Selective Procedure**  
A 1.0 mol/L solution of NaHMDS in THF (484 μL, 0.484 mmol) was added to a solution of methyl 2-[bis(benzylthio)phosphoryl]acetate (**4a**; 150 mg, 0.409 mmol) in anhyd THF (2.5 mL), and the resulting mixture was stirred at 0 °C for 30 min under argon. PhCHO (**5a**) (38.0 μL, 0.372 mmol) was added and the mixture was stirred at 0 °C for 2 h under argon, then treated with 1 N aq HCl (2.5 mL) and extracted with CHCl<sub>3</sub> (3 × 10 mL). The extracts were dried (MgSO<sub>4</sub>), filtered, and concentrated in vacuo to give an oily residue that was purified by column chromatography [Silica Gel 60N (Kanto Chemical); hexane–EtOAc (20:1)] to afford (E)-**6a**; yield (59.9 mg, 99%, *E/Z* = 100:0); colorless needles (hexane); mp 30.0–30.2 °C.  
IR (KBr): 2947, 2846, 1718, 1638, 1495, 1452, 1315, 1172 cm<sup>−1</sup>. <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>): δ = 7.70 (d, *J* = 16.0 Hz, 1 H), 7.55–7.51 (m, 2 H), 7.41–7.37 (m, 3 H), 6.45 (d, *J* = 16.0 Hz, 1 H), 3.81 (s, 3 H). <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>): δ = 167.5, 144.9, 134.3, 130.3, 128.9, 128.1, 117.8, 51.7. HRMS (ESI): *m/z* [M + Na]<sup>+</sup> calcd for C<sub>10</sub>H<sub>10</sub>NaO<sub>2</sub>: 185.0578; found: 185.0588. Anal. Calcd for C<sub>10</sub>H<sub>10</sub>O<sub>2</sub>: C, 74.06; H, 6.22. Found: C, 74.04; H, 6.30.
- (7) (a) Sano, S.; Ando, T.; Yokoyama, K.; Nagao, Y. *Synlett* **1998**, 777. (b) Sano, S.; Teranishi, R.; Nagao, Y. *Tetrahedron Lett.* **2002**, *43*, 9183. (c) Sano, S.; Takemoto, Y.; Nagao, Y. *ARKIVOC* **2003**, 93. (d) Sano, S.; Takemoto, Y.; Nagao, Y. *Tetrahedron Lett.* **2003**, *44*, 8853. (e) Claridge, T. D. W.; Davies, S. G.; Lee, J. A.; Nicholson, R. L.; Roberts, P. M.; Russell, A. J.; Smith, A. D.; Toms, S. M. *Org. Lett.* **2008**, *10*, 5437. (f) Sano, S.; Matsumoto, T.; Nanataki, H.; Tempaku, S.; Nakao, M. *Tetrahedron Lett.* **2014**, *55*, 6248.
- (8) **Methyl (Z)-3-Phenylacrylate [(Z)-6a]<sup>9</sup>; Typical (Z)-Selective Procedure**  
A 1.0 mol/L solution of NaHMDS in THF (409 μL, 0.409 mmol) was added to a solution of methyl 2-[bis(benzylthio)phosphoryl]acetate (**4a**) (177 mg, 0.484 mmol) in anhyd THF (2.5 mL), and the resulting solution was stirred at −78 °C for 30 min under argon. PhCHO (**5a**) (38.0 μL, 0.372 mmol) was added, and the mixture was stirred at −78 °C for 2 h under argon, then treated with 1 N aq HCl (2.5 mL) and extracted with CHCl<sub>3</sub> (3 × 10 mL). The extracts were dried (MgSO<sub>4</sub>), filtered, and concentrated in vacuo to give an oily residue that was purified by column chromatography [Silica Gel 60N (Kanto Chemical); hexane–EtOAc (20:1)] to afford a mixture of (E)- and (Z)-**6a** as a colorless oil; yield: 56.9 mg (94%, *E/Z* = 2:98).  
IR (neat): 2950, 1725, 1632, 1495, 1436, 1200, 1169 cm<sup>−1</sup>. <sup>1</sup>H NMR (500 MHz, CDCl<sub>3</sub>): δ = 7.60–7.57 (m, 2 H), 7.39–7.31 (m, 3 H), 6.96 (d, *J* = 12.6 Hz, 1 H), 5.96 (d, *J* = 12.6 Hz, 1 H), 3.72 (s, 3 H). <sup>13</sup>C NMR (125 MHz, CDCl<sub>3</sub>): δ = 166.6, 143.5, 134.7, 129.7, 129.1, 128.0, 119.2, 51.4. HRMS (ESI): *m/z* [M + Na]<sup>+</sup> calcd for C<sub>10</sub>H<sub>10</sub>NaO<sub>2</sub>: 185.0578; found: 185.0577.
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