

LETTERS
TO THE EDITOR

Fe-Catalyzed Synthesis of Methyl-(2*E*,4*Z*)-deca-2,4-dienoate, a Component of Sex Pheromones of *Pityogenes chalcographus* and *Acanthoscelides obtectus*

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Abstract—Stereoselective synthesis of methyl-(2*E*,4*Z*)-deca-2,4-dienoate, a component of sex pheromones of *Pityogenes chalcographus* and *Acanthoscelides obtectus*, was performed on the basis of Fe-catalyzed cross-coupling of methyl-(2*E*,4*Z*)-5-chloropenta-2,4-dienoate with *n*-pentylmagnesium bromide.

Keywords: methyl-(2*E*,4*Z*)-deca-2,4-dienoate, Fe-catalyzed cross-coupling, BaMnO₄, pheromones, *Pityogenes chalcographus*, *Acanthoscelides obtectus*

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Methyl-(2*E*,4*Z*)-deca-2,4-dienoate **1** is a component of sex pheromone of *Pityogenes chalcographus* [1], a dangerous forest pest [2]. Besides, along with (*R,E*)-tetradeca-2,4,5-trienoate it is a part of pheromone of *Acanthoscelides obtectus*, a legumes pest [3]. Ester **1** was obtained by transesterification of natural ethyl-(2*E*,4*Z*)-deca-2,4-dienoate with subsequent purification by clathrate formation with urea [4], the Wittig olefination [5], or Heck reaction [6].

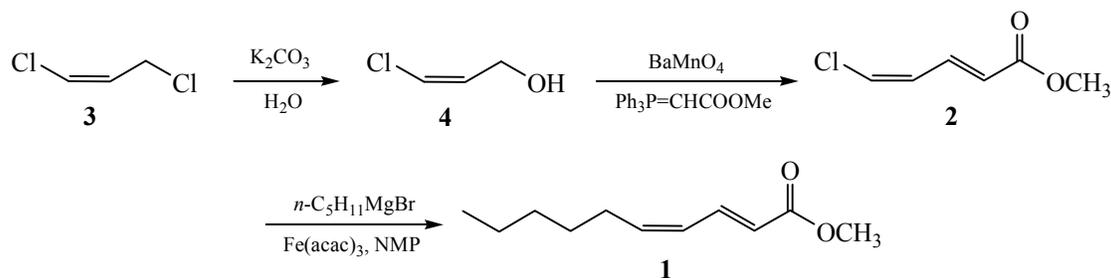
Here we propose a new stereoselective approach to the synthesis of methyl-(2*E*,4*Z*)-deca-2,4-dienoate **1** based on Fe-catalyzed cross-coupling of methyl-(2*E*,4*Z*)-5-chloropenta-2,4-dienoate **2** with *n*-pentylmagnesium bromide. Recently, the examples of successful use of Fe-catalysis for the formation of carbon–carbon bond appeared [7–9], including the synthesis of natural compounds [10–13] and pharmaceutical substances [10, 14, 15]. The advantages of the iron salts Fe(III) and Fe(II) usually used in cross-coupling are low cost, availability, high reaction rates, the absence of ligands, low toxicity, and ecological safety [7,16].

As a starting compound (*Z*)-1,3-dichloropropene **3** was used, a side product of large-scale production of allyl chloride [17]. Alkaline hydrolysis of compound **3** in the presence of K₂CO₃ smoothly affords (*Z*)-3-chloroprop-2-en-1-ol **4**. One-pot oxidation of the latter

with barium manganate BaMnO₄ [18] followed by olefination with methyl(triphenylphosphoranylidene)acetate by Wittig is an effective route for the synthesis of methyl-(2*E*,4*Z*)-5-chloropenta-2,4-dienoate **2**. This strategy allows avoiding preparation and isolation of extremely labile, toxic, and difficult to handle *cis*-3-chloroacrolein. Also, the use of more stable and easy to handle BaMnO₄ made it possible to substantially reduce the consumption of the oxidant as compared to activated MnO₂ (used usually in 10–50-fold excess [19]). Oxidation of (*Z*)-3-chloroprop-2-en-1-ol **4** with 4 equiv. of BaMnO₄ in the presence of methyl(triphenylphosphoranylidene)acetate in dichloromethane at room temperature leads to the mixture of methyl-(2*E*,4*Z*)-5-chloropenta-2,4-dienoate **2** and its (*Z*,4*Z*)-isomer in the ratio 4 : 1, easily separable by column chromatography. Cross-coupling of vinyl chloride **2** with *n*-pentylmagnesium bromide in the presence of catalytic amounts of Fe(acac)₃ in the mixture THF–*N*-methylpyrrolidone at room temperature affords the target methyl-(2*E*,4*Z*)-deca-2,4-dienoate **1** in 78% yield (Scheme 1).

The structure, stereochemical configuration, and isomeric purity of the obtained compounds is proved by high-performance GC, the data of NMR spectroscopy and chromatomass spectrometry. The (2*E*,4*Z*)-configuration of the synthesized dienes is proved by

Scheme 1.



the coupling constants of the vinyl hydrogens, $J_{2,3} = 15.3$ – 15.6 and $J_{4,5} = 7.3$ Hz, typical for the (*E*)- and (*Z*)-configuration, respectively, as well as by the upfield shift of the allyl carbon atom of ester **1** by ~ 4 ppm as compared to the (*2E,4E*)-analogs [20].

The advantages of the elaborated method of synthesis of pheromone **1** are the use of industrially available (*Z*)-isomer of 1,3-dichloropropene, a few number of stages, high yield, and isomeric purity of the target product as well as low cost of the Fe-catalyst.

(2Z)-3-Chloroprop-2-en-1-ol (4). A mixture of 2 g (0.018 mol) of (*Z*)-1,3-dichloropropene **3**, 3.18 g (0.023 mol) of K_2CO_3 in 14 mL of water was stirred at boiling to complete conversion of **3** (5 h, GC control). After cooling, the reaction mixture was saturated with NaCl and extracted with ether (4 \times 10 mL). Combined extracts were dried over $MgSO_4$ and the solvent was removed at atmospheric pressure. Yield 1.31 g (79%). 1H NMR spectrum, δ , ppm: 3.60 br.s (1H, OH), 4.33 d.d (2H, $\underline{CH_2}CH=$, $J = 6.2, 1.5$ Hz), 5.93–6.00 m (1H, $CH_2\underline{CH}=\underline{}$), 6.13 d.t (1H, $ClCH=$, $J = 7.3, 1.5$ Hz). ^{13}C NMR spectrum, δ_C , ppm: 57.83 ($\underline{CH_2}CH=$), 119.24 ($ClCH=$), 130.62 ($CH_2\underline{CH}=\underline{}$). Mass spectrum, m/z (I_{rel} , %): 92 (1) [M] $^+$, 91 (6), 61 (3), 58 (4), 57 (100), 55 (9), 49 (4), 44 (7), 39 (11), 38 (5), 37 (4).

Methyl-(2E,4Z)-5-chloropenta-2,4-dienoate (2). A suspension of 0.174 g (1.88 mmol) of (*Z*)-3-chloroprop-2-en-1-ol **4**, 1.93 g (7.52 mmol) of $BaMnO_4$, and 0.63 g (1.88 mmol) of methyl(triphenylphosphoranylidene)acetate in 8 mL of dry CH_2Cl_2 was vigorously stirred at room temperature to complete conversion of the substrate (20 h, GC control). The solid phase was separated by centrifuging, the organic phase was filtered through a layer of silica and concentrated. The residue was separated by column chromatography (SiO_2 , hexane–ethyl acetate, 93 : 7) to obtain 0.187 g (68 %) of **2** and 0.045 g (16 %) of the (*2Z,4Z*)-isomer.

1H NMR spectrum, δ , ppm: 3.78 s (3H, CH_3), 6.03 d (1H, C^2H , $J = 15.6$ Hz), 6.38 d (1H, C^5H , $J = 7.3$ Hz), 6.46 d.d (1H, C^4H , $J = 11.0, 7.3$ Hz), 7.69 d.d (1H, C^3H , $J = 15.6, 11.0$ Hz). ^{13}C NMR spectrum, δ_C , ppm: 51.71 (CH_3), 124.00 ($CH=$), 126.36 ($CH=$), 127.60 ($CH=$), 136.84 ($CH=$), 166.77 (C^1). Mass spectrum, m/z (I_{rel} , %): 146 (20) [M] $^+$, 117 (14), 115 (43), 111 (100), 89 (17), 87 (51), 53 (7), 52 (9), 51 (68), 50 (15).

Methyl-(2E,4Z)-deca-2,4-dienoate (1). To a solution of 0.1 g (0.68 mmol) of methyl-(*2E,4Z*)-5-chloropenta-2,4-dienoate **2**, 7 mg (0.02 mmol) $Fe(acac)_3$ in the mixture of 1 mL of THF and 0.6 mL of NMP in an argon atmosphere at 0°C was slowly added 0.75 mL of the 1 M solution of *n*-pentylmagnesium bromide in THF. The reaction mixture was stirred for 0.5 h at room temperature, treated with 10% HCl and 8 mL of hexane, the organic layer separated, the water layer extracted with hexane (3 \times 5 mL). Organic extracts were combined, washed with saturated solution of $NaHCO_3$, dried with $MgSO_4$, and concentrated. The product was purified by column chromatography (SiO_2 , hexane–ethyl acetate, 9 : 1). Yield 0.097 g (78%). 1H NMR spectrum, δ , ppm: 0.89 t (3H, $C^{10}H_3$, $J = 7$ Hz), 1.26–1.35 m (4H, $2CH_2$), 1.39–1.45 m (2H, C^7H_2), 2.30 q (2H, C^6H_2 , $J = 7.6$ Hz), 3.75 s (3H, CH_3O), 5.84–5.89 m (2H, C^2H , C^5H), 6.12 t (1H, C^4H_2 , $J = 11.5$ Hz), 7.62 d.d (1H, C^3H_2 , $J = 15.3, 11.5$ Hz). ^{13}C NMR spectrum, δ_C , ppm: 13.96 (C^{10}), 22.45 (C^9), 28.20 (C^6), 29.00 (C^7), 31.35 (C^8), 51.46 (CH_3O), 120.63 (C^2), 126.35 (C^4), 139.75 (C^3), 141.87 (C^5), 167.73 (C^1). Mass spectrum, m/z (I_{rel} , %): 182 [M] $^+$, 16, 113 (34), 111 (100), 82 (29), 81 (85), 79 (46), 67 (52), 66 (33), 55 (34), 53 (31), 41 (52).

1H and ^{13}C NMR spectra were registered in $CDCl_3$ on an AV-500 instrument [500 MHz (1H) and 125 MHz (^{13}C)]. Chemical shifts were measured with respect to TMS (1H) or the signal of the solvent (^{13}C , δ_C 77.0 ppm). The mass spectra were obtained on a

GCMS-QP2010S Shimadzu instrument [electronic ionization at 70 eV, the range of detected masses 33–350 Da, capillary column HP-1MS (30 m × 0.25 mm × 0.25 μm), temperature of injector 280°C, of ionization chamber 200°C, ramp from 50 to 300°C at a rate 10°C/min, carrier gas helium (1.1 mL/min)].

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