Acta Scientifica Naturalis

Former Annual of Konstantin Preslavsky University of Shumen: Chemistry, Physics, Biology, Geography

Journal homepage: asn.shu.bg

Bifunctionalized Allenes. Part XXIII.

An Efficient Method for Regioselective Synthesis of 5-Phosphorylated Allenecarboxylates

Hasan H. Hasanov, Ivaylo K. Ivanov, Valerij Ch. Christov

Department of Chemistry, Faculty of Natural Sciences,

Konstantin Preslavsky University of Shumen, 115 Universitetska Str., BG-9712 Shumen, Bulgaria

Abstract: *An efficient method for regioselective synthesis of 5-(dimethoxyphosphoryl)-allenecarboxylates by an atom economical [2,3]-sigmatropic rearrangement of the mediated 3-(dimethoxyphosphanyloxy)-alk-4-ynoates is described. Alkyl 5-(dimethoxyphosphoryl)-alka-3,4-dienoates can be readily prepared via reaction of alkyl 3-hydroxy-alk-4-ynoates with dimethylchlorophosphite in the presence of a base. Alkyl 3-hydroxy-alk-4-ynoates were prepared by reaction of the metallated acetylenes with commercially available alkyl 3-oxoalkanoates.*

Keywords: alkyl 3-hydroxy-alk-4-ynoates, 5-(dimethoxyphosphoryl)-allenecarboxylates, [2,3]-sigmatropic rearrangement, regioselective synthesis

Introduction

In the past three decades, synthesis and use of allene derivatives have been expanded in preparative organic chemistry. The presence of two π electron clouds separated by a single sp hybridized carbon atom is the identifying structural characteristic of allenes, and it is this unique structural and electronic arrangement that is responsible for the extraordinary reactivity profile displayed by allenic compounds [1].

Functionalized allenes have attracted a growing attention because of their versatility as key building blocks for organic synthesis. The synthetic potential of functionalized allenes has been explored extensively in

recent years, and this has led to the development of novel methods for the construction of a variety of functionalized heterocyclic and carbocyclic systems [2].

A plethora of methods exists for the construction of alka-2,3-dienoates, including the Wittig [3], Wittig-Horner [4] or the Horner-Wadsworth-Emons [5] olefination of ketenes, iron-catalyzed olefination of ketenes with diazoacetate [6] and by other methods [7]. There are methods [8] for the synthesis of phosphorus-containing allenes (phosphonates [9], phosphinates [10], and phosphine oxides [11]) including reactions of α -alkynols with chloride-containing derivatives of phosphorus acids followed by [2,3]-sigmatropic rearrangement.

As a part of our research program on the chemistry of the bifunctionalized allenes, we required a convenient method to introduce a phosphonate group in the 5-position to the ester group of the allenecarboxylates. The above mentioned groups attract increasing attention as useful functionalities in organic synthesis. Of particular interest are the applications of these groups as temporary transformers of chemical reactivity of the allenic system in the synthesis of eventually heterocyclic compounds.

In a continuation to our previous reports on the synthesis [12–14] and electrophilic cyclization reactions [16, 18] of bifunctionalized allenes, we have found an efficient method for regioselective synthesis of 5-(dimethoxyphosphoryl)-allenecarboxylates by an atom economical [2,3]-sigmatropic rearrangement of the mediated 3-(dimethoxyphosphanyloxy)-alk-4-ynoates.

Results and Discussion

Since its discovery five decades ago [9a,10a,b], the reversible interconversion of propargylic phosphites, phosphonites and phosphinites to allenyl phosphonates, phosphinates and phosphine oxides has become one of the most studied and synthetically useful [2,3]-sigmatropic rearrangement. Numerous synthetic applications of the rearrangement have been reported, including its use in the synthesis of allenic steroids as substrate-induced inactivation of aromatase [17a], in the efficient synthesis of (2*R*)-2-amino-5-phosphonopentanoic acid (AP5) as a powerful and selective N-methyl-*D*-aspartate (NMDA) antagonist [17b], in the preparation of the phosphonate analogues of phosphatidyl derivatives [17c,d], and, in the synthesis of new acyclic analogues of nucleotides containing a purine or pyrimidine moiety and an allenic skeleton [17e,f].

Our strategy for the synthesis of the 5-(dimethoxyphosphoryl)-allenecarboxylates, using our experience on the preparation of the bifunctionalized [12–14], and trifunctionalized allenes [15], relies on the well-precedented 2,3-sigmatropic shift of propargylic phosphites to allenephosphonates. Precedent exists for such an approach to the synthesis of allenic compounds, however, to the best of our knowledge, the use of propargylic alcohols bearing an electron-withdrawing group such as **4**, to give the corresponding allenic esters **6**, possessing a phosphonate group in the five position of allenecarboxylate system, has not been reported. In

order to assess this approach towards the target 5-phosphorylated allenecarboxylates **6**, a range of propargylic alcohols **4a-e** was prepared by the reaction of the metallated acetylenes **2a-d** with commercially available alkyl 3-oxoalkanoates **3a,b** (Scheme 1 and Table 1).

Scheme 1

Table 1. Preparation of the Propargylic Alcohols **4a-e** from the Metallated Acetylenes **2a-d** and the Alkyl 3-Oxoalkanoates **3a,b**

Entry	Product	R	R ¹	R ²	Yield ^a , %
1	4a	H	Me	Me	75
2	4b	H	Et	Et	73
3	4c	Pr	Et	Et	83
4	4d	Bu	Et	Et	80
5	4e	Ph	Et	Et	78

^aIsolated yields by chromatographical purification

With the required propargyl alcohols **4a-e** in hand, we were then able to investigate the proposed reaction with the corresponding chloro-containing phosphorus reagent such as dimethylchlorophosphite in the presence of a base and subsequent [2,3]-sigmatropic rearrangement of the mediated 5-(dimethoxyphosphanyloxy)-alk-4-ynoates **5a-e**. For instance, the alkyl 5-(dimethoxyphosphoryl)-alka-3,4-dienoates **6a-e** can be readily prepared *via* an atom economical 2,3-sigmatropic rearrangement of the mediated alkoxycarbonyl-functionalized propargyl phosphite **5a-e**, intermediate formed by reaction of the alkyl 3-hydroxy-alk-4-ynoates **4a-e** with dimethylchlorophosphite, prepared *in situ* from phosphorus trichloride in the presence of triethylamine, and 2 *equiv* of methanol and 2 *equiv* of pyridine, according to Scheme 2 and Table 2.

Table 2. Synthesis of the Alkyl 5-(Dimethoxyphosphoryl)-alka-3,4-dienoates **6a-e** by [2,3]-Sigmatropic Rearrangement of the Mediated 5-(Dimethoxyphosphanyloxy)-alk-4-ynoates **5a-e** Prepared *via* Reaction of the Alkyl 3-Hydroxy-alk-4-ynoates **4a-e** with Dimethylchlorophosphite in the Presence of a Base

Entry	Product	R	R ¹	R ²	Yield ^a , %
1	6a	H	Me	Me	75
2	6b	H	Et	Et	70
3	6c	Pr	Et	Et	66
4	6f	Bu	Et	Et	64
5	6e	Ph	Et	Et	61

^aIsolated yields by chromatographical purification

After a conventional work-up, all allenic products **6a-e** were isolated by column chromatography and identified by ¹H, ¹³C, and ³¹P NMR and IR spectra as well as by elemental analysis.

In conclusion, a convenient and efficient method for regioselective synthesis of a new family of 1,5-diacceptor-substituted allenes, namely 5-(dimethoxyphosphoryl)-alk-3,4-dienoates, derived by [2,3]-sigmatropic rearrangement of the intermediate formed 5-(dimethoxyphosphanyloxy)-alk-4-ynoates in the reactions of alkyl 3-hydroxy-alk-4-ynoates with dimethylchlorophosphite in the presence of a base has been explored.

Further investigations on this potentially important synthetic methodology are currently in progress. At the same time, the synthetic application of the prepared 5-(dimethoxyphosphoryl)-allenecarboxylates for synthesis of different heterocyclic compounds is now under investigation in our laboratory as a part of our general synthetic strategy for investigation of the scope and limitations of the electrophilic cyclization reactions of bifunctionalized allenes. Results of these investigations will be reported in due course.

Experimental

General

All new synthesized compounds were purified by column chromatography and characterized on the basis of NMR, IR and microanalytical data. NMR spectra were recorded on Bruker Avance II+600 (^1H at 600.1 MHz, ^{13}C at 150.9 MHz, ^{31}P at 242.9 MHz) spectrometers for solutions in CDCl_3 . Chemical shifts are in parts per million downfield from internal TMS (^1H and ^{13}C) and external 85% H_3PO_4 (^{31}P). J values are given in Hertz. IR spectra were recorded with an FT-IRAffinity-1 Shimadzu spectrophotometer. Elemental analyses were carried out by the Microanalytical Service Laboratory of Faculty of Chemistry and Pharmacy, University of Sofia using Vario EL3 CHNS(O). Column chromatography was performed on Kieselgel F₂₅₄60 (70-230 mesh ASTM, 0.063-0.200 mm, Merck). The solvents were purified by standard methods. Reactions were carried out in oven-dried glassware under an argon atmosphere and exclusion of moisture. All compounds were checked for purity on TLC plates Kieselgel F₂₅₄60, Merck.

Starting Materials

Alkyl 3-oxoalkanoates, pentyne, hexyne, phenylacetylene, ethynylmagnesium chloride (0.5M solution in THF), phosphorus trichloride, triethylamine and pyridine were commercially available and were purified by usual methods.

General Procedure for the Synthesis of the Alkyl 3-Hydroxy-alk-4-ynoate (**4**)

Ethylmagnesium bromide [prepared from magnesium (1.22 g, 50 mmol) and ethyl bromide (5.50 g, 50 mmol) in THF (50 mL)] is added dropwise under stirring to monosubstituted alkynes **1b-d** [pentyne, hexyne, or phenylacetylene (50 mmol)] and then the mixture is refluxed for 2 h. The solution of the prepared monosubstituted alkynyl magnesium bromides **2b-d** or ethynylmagnesium chloride **1** **2a** is added dropwise under stirring to the alkyl 3-oxoalkanoates **3a,b** (100 mmol). The mixture is refluxed for 6 h and after cooling is hydrolyzed with a saturated aqueous solution of ammonium chloride. The organic layer is separated, washed with water, and dried over anhydrous sodium sulfate. Solvent and the excess of alkyl 3-oxoalkanoate are removed by distillation. Purification of the residue is achieved by column chromatography (silica gel, Kieselgel Merck 60 F₂₅₄) with ethyl acetate/hexane. The pure products **4a-e** had the following properties:

Methyl 3-hydroxy-2,2,3-trimethyl-pent-4-ynoate (4a). Orange oil, yield: 75%. Eluent for TLC: ethyl acetate : hexane = 1:3, R_f 0.52; IR (neat, cm^{-1}): 1735 (C=O), 2116 (C $\equiv$ C), 3288 (HC $\equiv$), 3482 (OH). ^1H NMR (CDCl_3 , 600.1 MHz, δ): 1.23, 1.29 (ss, 6H, MeCMe), 1.33 (s, 3H, Me), 2.43 (s, 1H, HC $\equiv$), 3.71 (s, 3H, MeO), 4.44 (s, 1H, OH). ^{13}C NMR (CDCl_3 , 150.9 MHz, δ): 20.4 (CH₃), 22.2 (CH₃), 24.4 (CH₃), 50.5 (C), 52.5 (CH₃), 70.5 (C), 71.8 (CH), 86.8 (C), 81.3 (C), 178.6 (C). Anal. Calcd for $\text{C}_9\text{H}_{14}\text{O}_3$: C 63.51, H 8.29; found: C 63.45, H 8.24.

Ethyl 2,2-diethyl-3-hydroxy-3-methyl-pent-4-ynoate (4b). Orange oil, yield: 73%. Eluent for TLC: ethyl acetate : hexane = 1:3, R_f 0.55; IR (neat, cm^{-1}): 1730 (C=O), 2108 (C $\equiv$ C), 3275 (HC $\equiv$), 3480 (OH). ^1H NMR (CDCl_3 , 600.1 MHz, δ): 1.19 (t, J 7.6 Hz, 6H, $2\times\text{MeCH}_2$), 1.25 (t, J 7.1 Hz, 3H, MeCH_2O), 1.41 (s, 1H, Me), 1.69–1.99 (m, 4H, $2\times\text{MeCH}_2$), 2.41 (s, 1H, HC $\equiv$), 4.02–4.13 (m, 4H, MeCH_2O), 4.61 (s, 1H, OH). ^{13}C NMR (CDCl_3 , 150.9 MHz, δ): 8.8 (CH_3), 9.3 (CH_3), 10.9 (CH_3), 22.3 (CH_2), 23.9 (CH_2), 24.3 (CH_3), 55.9 (C), 60.0 (CH_2), 70.3 (C), 71.4 (CH), 86.7 (C), 175.7 (C). Anal. Calcd for $\text{C}_{12}\text{H}_{20}\text{O}_3$: C 67.89, H 9.50; found: C 67.96, H 9.54.

Ethyl 2,2-diethyl-3-hydroxy-3-methyl-oct-4-ynoate (4c). Light yellow oil, yield: 83%. Eluent for TLC: ethyl acetate : hexane = 1:10, R_f 0.58; IR (neat, cm^{-1}): 1711 (C=O), 2253 (C $\equiv$ C), 3487 (OH). ^1H NMR (CDCl_3 , 600.1 MHz, δ): 0.84–0.92 (m, 6H, $2\times\text{MeCH}_2$), 0.91–1.01 (m, 3H, $\text{Me-CH}_2\text{CH}_2$), 1.31 (t, J 7.1 Hz, 3H, MeCH_2O), 1.43 (s, 1H, Me), 1.46–1.52 (m, 2H, $\text{Me-CH}_2\text{CH}_2$), 1.56–2.01 (m, 4H, $2\times\text{CH}_2\text{-Me}$), 2.15 (t, J 6.8 Hz, 2H, $\text{CH}_2\text{-C}\equiv$), 4.19–4.24 (m, 2H, MeCH_2O), 5.01 (s, 1H, OH). ^{13}C NMR (CDCl_3 , 150.9 MHz, δ): 9.8 (CH_3), 10.4 (CH_3), 13.4 (CH_3), 14.2 (CH_3), 20.7 (CH_2), 22.0 (CH_2), 24.8 (CH_2), 25.1 (CH_2), 25.4 (CH_3), 58.2 (C), 61.6 (CH_2), 71.6 (C), 83.8 (C), 84.8 (C), 176.6 (C). Anal. Calcd for $\text{C}_{15}\text{H}_{26}\text{O}_3$: C 70.83, H 10.30; found: C 70.79, H 10.36.

Ethyl 2,2-diethyl-3-hydroxy-3-methyl-non-4-ynoate (4d). Light yellow oil, yield: 80%. Eluent for TLC: ethyl acetate : hexane = 1:10, R_f 0.56; IR (neat, cm^{-1}): 1711 (C=O), 2254 (C $\equiv$ C), 3490 (OH). ^1H NMR (CDCl_3 , 600.1 MHz, δ): 0.88–0.92 (m, 6H, $2\times\text{MeCH}_2$), 1.01–1.07 (m, 3H, $\text{Me-CH}_2\text{CH}_2\text{CH}_2$), 1.18 (t, J 7.0 Hz, 3H, MeCH_2O), 1.43 (s, 1H, Me), 1.55–1.79 (m, 4H, $\text{Me-CH}_2\text{CH}_2\text{CH}_2$), 1.85–2.06 (m, 4H, $2\times\text{CH}_2\text{-Me}$), 2.17 (t, J 6.9 Hz, 2H, $\text{CH}_2\text{CH}_2\text{-C}\equiv$), 4.19–4.24 (m, 2H, MeCH_2O), 4.96 (s, 1H, OH). ^{13}C NMR (CDCl_3 , 150.9 MHz, δ): 9.9 (CH_3), 10.4 (CH_3), 13.7 (CH_3), 14.2 (CH_3), 18.4 (CH_2), 21.9 (CH_2), 25.0 (CH_2), 25.2 (CH_2), 25.5 (CH_3), 30.7 (CH_2), 57.3 (C), 60.4 (CH_2), 71.2 (C), 83.8 (C), 85.0 (C), 176.5 (C). Anal. Calcd for $\text{C}_{18}\text{H}_{28}\text{O}_3$: C 71.60, H 10.52; found: C 71.54, H 10.56.

Ethyl 2,2-diethyl-3-hydroxy-3-methyl-5-phenyl-pent-4-ynoate (4e). Yellow oil, yield: 78%. Eluent for TLC: ethyl acetate : hexane = 1:10, R_f 0.61; IR (neat, cm^{-1}): 1441, 1492 (Ph), 1713 (C=O), 2251 (C $\equiv$ C), 3474 (OH). ^1H NMR (CDCl_3 , 600.1 MHz, δ): 0.95–1.12 (m, 6H, $2\times\text{MeCH}_2$), 1.30 (t, J 7.2 Hz, 3H, MeCH_2O), 1.56 (s, 1H, Me), 1.62–2.11 (m, 4H, $2\times\text{CH}_2\text{-Me}$), 4.19–4.31 (m, 2H, MeCH_2O), 4.92 (s, 1H, OH), 7.18–7.38 (m, 5H, Ph). ^{13}C NMR (CDCl_3 , 150.9 MHz, δ): 9.8 (CH_3), 10.7 (CH_3), 15.3 (CH_3), 24.9 (CH_2), 25.1 (CH_2), 25.3 (CH_3), 57.6 (C), 61.3 (CH_2), 71.9 (C), 85.1 (C), 93.1 (C), 122.9, 128.2, 128.3, 131.5 (Ph), 176.9 (C). Anal. Calcd for $\text{C}_{18}\text{H}_{24}\text{O}_3$: C 74.97, H 8.39; found: C 75.03, H 8.44.

General Procedure for the Synthesis of the Alkyl 5-(dimethoxyphosphoryl)-alka-3,4-dienoates (6)

To a solution of phosphorus trichloride (2.75 g, 20 mmol) and triethylamine (2.23 g, 22 mmol) in dry diethyl ether (60 mL) at -70°C , a solution of alkyl 3-hydroxy-alk-4-ynoates **4a-e** (20 mmol) in the same solvent (20 mL) was added dropwise with stirring. After 30 min stirring at the same temperature, a solution of pyridine (3.16 g, 44 mmol) and methanol (1.28 g, 40 mmol) in dry diethyl ether (50 mL) was added. The reaction mixture was stirred for 1 h at the same temperature and for 8 h at room temperature. Then the mixture was washed with water, 2N HCl, extracted with ether, washed with saturated NaCl, and dried over anhydrous sodium sulfate. After evaporation of the solvent, the residue was chromatographed on a column (silica gel, Kieselgel Merck 60 F₂₅₄) with a mixture of ethyl acetate and hexane as an eluent to give the pure products as yellow oils, which had the following properties.

Methyl 5-(dimethoxyphosphoryl)-2,2,3-trimethyl-penta-3,4-dienoate (6a). Yellow oil, yield: 75%. Eluent for TLC: ethyl acetate : hexane = 1:1, R_f 0.50; IR (neat, cm^{-1}): 1260 (P=O), 1736 (C=O), 1959 (C=C=C). ^1H NMR (CDCl_3 , 600.1 MHz, δ): 1.35, 1.36 (ss, 6H, MeCMe), 1.77 (dd, J 3.1 Hz, J 8.2 Hz, 3H, MeC=), 3.71 (s, 3H, MeO), 3.77 (d, J 10.8 Hz, 6H, 2MeO), 5.39 (m, 1H, HC=). ^{13}C NMR (CDCl_3 , 150.9 MHz, δ): 14.9 (J 5.1 Hz, CH_3), 24.5 (J 3.2 Hz, CH_3), 44.7 (J 5.0 Hz, C), 52.4 (CH_3), 53.0 (J 15.0 Hz, CH_3), 81.1 (J 197.4 Hz, C), 106.2 (J 7.8 Hz, C), 176.0 (J 1.0 Hz, C), 210.1 (J 0.9 Hz, C). ^{31}P NMR (CDCl_3 , 242.9 MHz, δ): 18.6. Anal. Calcd for $\text{C}_{11}\text{H}_{19}\text{O}_5\text{P}$: C 50.38, H 7.30; found: C 50.44, H 7.25.

Ethyl 5-(dimethoxyphosphoryl)-2,2-diethyl-3-methyl-penta-3,4-dienoate (6b). Yellow oil, yield: 70%. Eluent for TLC: ethyl acetate : hexane = 5:1, R_f 0.52; IR (neat, cm^{-1}): 1259 (P=O), 1728 (C=O), 1958 (C=C=C). ^1H NMR (CDCl_3 , 600.1 MHz, δ): 0.84 (t, J 7.3 Hz, 6H, $2\times\text{MeCH}_2$), 1.14 (t, J 7.0 Hz, 3H, MeCH₂O), 1.48 (dd, J 2.7 Hz, J 8.1 Hz, 3H, Me), 1.51-1.60 (m, 4H, $2\times\text{CH}_2\text{Me}$), 3.76 (d, J 9.3 Hz, 6H, 2MeO), 3.97-4.07 (m, 2H, MeCH₂O), 5.39-5.46 (m, 1H, HC=). ^{13}C NMR (CDCl_3 , 150.9 MHz, δ): 7.9 (CH_3), 8.4 (CH_3), 14.4 (J 5.0 Hz, CH_3), 15.1 (J 3.0 Hz, CH_2), 24.0 (J 14.8 Hz, CH_3), 24.7 (J 5.1 Hz, C), 53.1 (CH_2), 60.9 (J 198.7 Hz, C), 103.1 (J 8.0 Hz, C), 174.6 (J 0.9 Hz, C), 211.5 (J 0.7 Hz, C). ^{31}P NMR (CDCl_3 , 242.9 MHz, δ): 18.5. Anal. Calcd for $\text{C}_{14}\text{H}_{25}\text{O}_5\text{P}$: C 55.25, H 8.28; found: C 55.32, H 8.22.

Ethyl 5-(dimethoxyphosphoryl)-2,2-diethyl-3-methyl-octa-3,4-dienoate (6c). Pale yellow oil, yield: 66%. Eluent for TLC: ethyl acetate : hexane = 1:1, R_f 0.55; IR (neat, cm^{-1}): 1267 (P=O), 1724 (C=O), 1954 (C=C=C). ^1H NMR (CDCl_3 , 600.1 MHz, δ): 0.85 (t, J 7.2 Hz, 6H, $2\times\text{MeCH}_2$), 0.93 (t, J 6.3 Hz, 3H, Me-CH₂CH₂), 1.18 (t, J 7.0 Hz, 3H, MeCH₂O), 1.42-1.60 (m, 4H, $2\times\text{CH}_2\text{Me}$), 1.46 (dd, J 2.9 Hz, J 8.1 Hz, 3H, Me), 1.70-1.79 (m, 2H, MeCH₂CH₂), 2.27-2.35 (m, 2H, MeCH₂CH₂), 3.78 (d, J 9.3 Hz, 6H, 2MeO), 3.98-4.11 (m, 2H, MeCH₂O). ^{13}C NMR (CDCl_3 , 150.9 MHz, δ): 10.1 (CH_3), 14.1 (CH_3), 14.4 (J 4.7 Hz, CH_3), 14.7 (J 4.8 Hz, CH_3), 25.1 (CH_2), 31.8 (J 6.1 Hz, CH_2), 32.4 (J 5.8 Hz, CH_2), 51.3 (J 14.7 Hz, CH_3), 51.5 (J 4.8 Hz,

C), 60.2 (C), 96.9 (*J* 186.4 Hz, CH₂), 111.4 (*J* 7.8 Hz, C), 177.2 (C), 204.7 (*J* 1.1 Hz, C). ³¹P NMR (CDCl₃, 242.9 MHz, δ): 21.5. Anal. Calcd for C₁₇H₃₁O₅P: C 58.94, H 9.02; found: C 58.87, H 8.97.

Ethyl 5-(dimethoxyphosphoryl)-2,2-diethyl-3-methyl-nona-3,4-dienoate (6d). Pale yellow oil, yield: 64%. Eluent for TLC: ethyl acetate : hexane = 1:1, R_f 0.49; IR (neat, cm⁻¹): 1262 (P=O), 1728 (C=O), 1949 (C=C=C). ¹H NMR (CDCl₃, 600.1 MHz, δ): 0.78 (t, *J* 7.2 Hz, 6H, 2xMeCH₂), 0.80 (t, *J* 6.3 Hz, 3H, Me-CH₂CH₂CH₂), 0.96 (t, *J* 7.0 Hz, 3H, MeCH₂O), 1.42-1.61 (m, 4H, 2xCH₂Me), 1.46 (dd, *J* 2.9 Hz, *J* 8.2 Hz, 3H, Me), 1.51-1.64 (m, 2H, MeCH₂CH₂CH₂), 2.34-2.48 (m, 2H, MeCH₂CH₂CH₂), 3.79 (d, *J* 9.3 Hz, 6H, 2MeO), 3.98-4.11 (m, 2H, MeCH₂O). ¹³C NMR (CDCl₃, 150.9 MHz, δ): 9.9 (CH₃), 13.3 (CH₃), 13.9 (CH₃), 15.2 (*J* 5.1 Hz, CH₃), 20.4 (*J* 4.6 Hz, CH₂), 25.1 (CH₂), 30.1 (*J* 15.4 Hz, CH₂), 32.0 (*J* 8.1 Hz, CH₂), 51.4 (*J* 4.7 Hz, C), 51.7 (*J* 15.0 Hz, CH₃), 59.8 (CH₂), 93.4 (*J* 184.3 Hz, C), 110.4 (*J* 7.9 Hz, C), 177.0 (C), 208.1 (*J* 1.0 Hz, C). ³¹P NMR (CDCl₃, 242.9 MHz, δ): 21.1. Anal. Calcd for C₁₈H₃₃O₅P: C 59.98, H 9.23; found: C 60.04, H 9.26.

Ethyl 5-(dimethoxyphosphoryl)-2,2-diethyl-3-methyl-5-phenyl-penta-3,4-dienoate (6e). Pale yellow oil, yield: 61%. Eluent for TLC: ethyl acetate : hexane = 1:1, R_f 0.60; IR (neat, cm⁻¹): 1265 (P=O), 1447, 1495 (Ph), 1728 (C=O), 1946 (C=C=C). ¹H NMR (CDCl₃, 600.1 MHz, δ): 0.79 (t, *J* 7.3 Hz, 6H, 2xMeCH₂), 1.31 (t, *J* 7.1 Hz, 3H, MeCH₂O), 1.80 (d, *J* 8.0 Hz, 3H, Me), 1.40-1.62 (m, 4H, 2xCH₂Me), 3.79 (d, *J* 12.7 Hz, 6H, 2MeO), 4.01-4.14 (m, 2H, MeCH₂O), 7.24-7.84 (m, 5H, Ph). ¹³C NMR (CDCl₃, 150.9 MHz, δ): 10.1 (CH₃), 14.2 (CH₃), 15.6 (*J* 4.6 Hz, CH₃), 25.1 (CH₂), 51.3 (*J* 5.0 Hz, C), 52.2 (*J* 15.2 Hz, CH₃), 60.3 (CH₂), 92.2 (*J* 183.5 Hz, C), 118.3 (*J* 8.1 Hz, C), 118.2, 125.4, 128.9, 129.6 (Ph), 177.4 (C), 206.4 (*J* 1.2 Hz, C). ³¹P NMR (CDCl₃, 242.9 MHz, δ): 19.6. Anal. Calcd for C₂₀H₂₉O₅P: C 63.15, H 7.68; found: C 63.22, H 7.64.

Acknowledgements

Financial support by the Research Fund of the Konstantin Preslavsky University of Shumen under Projects Nos. RD-08-158/2018, RD-08-94/2019, and RD-08-117/2020 are gratefully acknowledged.

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