Available Online at http://www.recentscientific.com

ISSN: 0976-3031

International Journal of Recent Scientific Research
Vol. 6, Issue, 6, pp.4526-4537, June, 2015

International Journal of Recent Scientific Research

RESEARCH ARTICLE

BIFUNCTIONALIZED ALLENES. PART XVII. SYNTHESIS OF 2,5-DIHYDRO-1,2-OXAPHOSPHOLES AND 4-PHOSPHORYL-3,6-DIHYDRO-2H-PYRANS BY ELECTROPHILIC CYCLIZATION AND COINAGE METAL-CATALYZED CYCLOISOMERIZATION OF PHOSPHORYLATED -HYDROXYALLENES

***Christov. VC, Ismailov. IE and Ivanov. IK**

Department of Organic Chemistry & Technology, Faculty of Natural Sciences,
Konstantin Preslavsky University of Shumen, 115, Universitetska str., BG-9712 Shumen, Bulgaria

ARTICLE INFO

Article History:

Received 14th, May, 2015
Received in revised form 23th, May, 2015
Accepted 13th, June, 2015
Published online 28th, June, 2015

Key words:

Phosphorylated -hydroxyallenes, electrophilic cyclization, 2,5-dihydro-1,2-oxaphospholes, coinage metal-catalyzed cycloisomerization, 3,6-dihydro-2*H*-pyrans.

ABSTRACT

A convenient and efficient regioselective synthesis of phosphorylated β-hydroxyallenes by an atom economical [2,3]-sigmatropic rearrangement of the mediated propargyl phosphite or phosphinite which can be readily prepared *via* reaction of protected 5-methyl-dec-6-yn-5-ol with dimethyl chlorophosphite or chlorodiphenyl phosphine respectively is described. This paper discusses a reaction of phosphorylated β-hydroxyallenes with protected or unprotected hydroxy group involving 5-*endo-trig* cyclization. Reaction of dimethyl [1-(2-hydroxypropyl)-3-methyl-hepta-1,2-dienyl] phosphonates with electrophiles that produces 2-oxo-2,5-dihydro-1,2-oxaphospholes due to the participation of the phosphonate neighboring group in the cyclization is described. On the other hand, hept-(1*E*)-en-1-yl phosphine oxides were prepared as mixtures with 2,5-dihydro-1,2-oxaphosphol-2-ium chlorides in a ratio of about 1:2 by chemo-, regio-, and stereoselective electrophilic addition to the C^2-C^3-double bond in the allene moiety and subsequent concurrent attack of the external (chloride anion) and internal (phosphine oxide group) nucleophiles. Phosphorylated β-hydroxyallenes were smoothly converted into the corresponding 4-phosphoryl-3,6-dihydro-2*H*-pyrans by using 5 mol % of coinage metal salt as catalyst in 6-*endo-trig* cycloisomerization reaction.

INTRODUCTION

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 (Bates and Satcharoen, 2002; Ma, 2007; Hassan, 2007; Pinho e Melo, 2009; Back *et al*, 2010).

A plethora of methods exists for the construction of hydroxyallenes, including prototropic rearrangement of propargylic alcohols (Enomoto, 1986; Oroshnik, 1953; Phadtare and Zemlicka, 1989), metal-catalyzed nucleophilic addition of propargylic derivatives to aldehydes (Crabbé, 1979; Hoffman and Weldmann, 1985; Boldrini *et al*, 1987; Corey *et al*, 1989, 1990; Corey and Jones, 1991; Ma *et al*, 2002; Ye *et al*, 2012), Cu(I)-catalyzed reaction of propargylic chlorides with Grignard reagents (Deng *et al*, 2007; Li, 2009a,b), metal-catalyzed reaction of propargylic oxiranes with organometallic compounds (Alexakis *et al*, 1989, 1991; Marshall and Pinney, 1993; Krause *et al*, 2002, 2004; Deutsch *et al*, 2007; Aksin-Artok *et al*, 2011; Poonoth and Krause, 2011) and ketones (Aurrecoechea and Solay, 1995; Aurrecoechea *et al*, 1998), and by other methods (Marshall and Tang, 1993; Krause *et al*, 2012).

There are methods (Mark, 1970; Landor, 1982; Saalfrank and Lurz, 1993; Hashmi, 2004) for the synthesis of phosphorus-containing allenes (phosphonates (Macomber, 1977; Denmark and Marlin, 1991; Cai and Blackburn, 1997; Saalfrank *et al*,1999; Kumar *et al*, 2008, 2009), and phosphine oxides (Nicolaou *et al*, 1990; Curfin and Okamura, 1990; Grissom and Huang, 1995; Darcel *et al*, 1996; De Frutos and Echavarren, 1997; Schmittel *et al*, 2001; Guo *et al*, 2008; Srinivas *et al*, 2011) including reactions of α-alkynols with chloride-containing derivatives of phosphorus acids followed by [2,3]-sigmatropic rearrangement. Several diethylphosphono-substituted α-allenic alcohols were prepared

*Corresponding author: **Christov. VC**
Department of Organic Chemistry & Technology, Faculty of Natural Sciences, Konstantin Preslavsky University of Shumen, 115, Universitetska str., BG-9712 Shumen, Bulgaria

by (Brel, 1999, 2006; Brel and Abramkin, 2002) directly from alcohols by Horner-Mark rearrangement of unstable propargylic phosphites.

Transition metal-catalyzed cyclization of functionalized allenes bearing a nucleophilic center has attracted considearble attention in recent years (Zimmer *et al*, 2010). Particularly, the cyclization reactions of allenols catalyzed by Ag(I) (Olsson and Claesson, 1979; Nikam *et al*, 1986; Marshall and Sehon, 1995; Marshall *et al*, 1995), Hg(II) (Gelin *et al*, 1972; Chilot *et al*, 1981), Pd(0) (Kang *et al*, 1998, 1999; Uemura *et al*, 1999), Pd(II) (Ma and Gao 2000, 2002), or Ru(III) (Trost and Pinkerton, 1999, Yoneda *et al*, 2000) have become quite useful methodologies for the synthesis of five-, or six-membered oxygen-containing heterocycles. Krause's group has reported a highly efficient and stereoselective synthesis of 2,5-dihydrofurans by Au(I)- and Au(III)-catalyzed (Krause *et al*, 2005, 2006, 2008) cycloisomerization of α-hydroxyallenes (Krause *et al*, 2001, 2002, 2007). Moreover, the method is not restricted to the cycloisomerization of α-hydroxyallenes to 2,5-dihydrofurans (Krause *et al*, 2001, 2002), rather, it was recently extended by Krause's group to the corresponding endo-cyclization of β-hydroxyallenes (Gockel and Krause, 2006) to the corresponding six-membered *O*-heterocycles. The method of choice, however, is the use of transition metal catalysts since this combines high reactivities and excellent yields with a tolerance to many functional groups.

Acyclic analogs of nucleotides containing an allenic skeleton were prepared by Brel and coworkers (Brel *et al*, 2005a) directly from alcohols by Horner-Mark [2,3]-sigmatropic rearrangement of unstable propargylic phosphites. Intramolecular cyclization of the alkoxides tethered to the allenyl moiety in the presence of $AgNO_3$ yielded 3,6-dihydro-2*H*-pyran-4-yl- and 4,5-dihydro-3-furanyl-phosphonates (Brel *et al*, 2005b, 2006).

On the other hand, the literature data on the reactions of phosphorylated allenes with electrophilic reagents reveal that the reactions proceed with cyclization of the allenic system bearing the phosphoryl group (O=P-C=C=C) to give heterocyclic compounds in most cases and the outcome depends on the structure of the starting allenic compound as well as the type of electrophile used (Angelov, 1983; Khusainova and Pudovik 1987; Allabugin and Brel, 1997; Ma, 2009).

As a part of our research program on the chemistry of the bifunctionalized allenes, we required a convenient method to introduce a phosphorus-containing group such as phosphonate or phosphine oxide group as well as a β-hydroxyalkyl group in the first position to the allenic system of double bonds. 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 (Christov *et al*, 2014a) and cyclization reactions (Christov *et al*, 2014b, 2015) of phosphorylated α-hydroxyallenes, we have found a convenient and efficient method for regioselective synthesis of phosphorylated β-hydroxyallenes by an atom economical [2,3]-sigmatropic rearrangement of the mediated 5-(tetrahydro-2*H*-pyran-2-yloxy)-hex-2-ynyl phosphite or phosphinite, which to be used as starting materials in the electrophilic cyclization and coinage metal-catalyzed cycloisomerization reactions to 2,5-dihydro-1,2-oxaphospholes and 4-phosphoryl-3,6-dihydro-2*H*-pyrans respectively.

MATERIALS AND METHODS

General Information

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 DRX Brucker Avance-250 (Bruker BioSpin, Karlsruhe, Germany) (^{1}H at 250.1 MHz, ^{13}C at 62.9 MHz, ^{31}P at 101.2 MHz) and Brucker Avance II+600 (Bruker BioSpin GmbH, Karlsruhe, Germany) (^{1}H at 600.1 MHz, ^{13}C at 150.9 MHz, ^{31}P at 242.9 MHz) spectrometers for solutions in $CDCl_3$. All ^{1}H and ^{13}C NMR experiments were measured referring to the signal of internal TMS and ^{31}P NMR experiments were measured referring to the signal of external 85% H_3PO_4. *J* values are given in hertz. IR spectra were recorded with an FT-IRAfinity-1 Shimadzu spectrophotometer (Shimadzu, Tokyo, Japan). Elemental analyses were carried out by the Microanalytical Service Laboratory of Faculty of Chemistry and Pharmacy, University of Sofia, Bulgaria, using Vario EL*3* CHNS(O) (Elementar Analysensysteme, Hanau, Germany). Column chromatography was performed on Kieselgel F_{254}60 (70–230 mesh ASTM, 0.063-0.200 nm, Merck). Et_2O and THF were distilled from Na wire/benzophenone, CH_2Cl_2 was distilled over CaH_2, and other organic solvents used in this study were dried over appropriate drying agents by standard methods and distilled prior to use. All other chemicals used in this study were commercially available and were used without additional purification unless otherwise noted. 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 F_{254} 60 (Merck).

Procedure (Robertson, 1960; Miyashita *et al*, 1977) ***for Synthesis of the 2-(1-Methyl-but-3-yn-1-yloxy)-tetrahydro-2H-pyran* 2**

A solution of the pent-4-yn-2-ol **1** (60 mmol) and DHP (3,4-dihydro-2H-pyran) (7.57 g, 90 mmol) in dry methylene chloride (50 mL) containing PPTS (pyridinium p-toluenesulfonate) (1.50 g, 6 mmol) is stirred for 4h at room temperature. Then the reaction was quenched with saturated $NaHCO_3$ end extracted with methylene chloride. The organic layer was dried over anhydrous sodium sulfate. After evaporation of the solvent, the residue was chromatographied on a column (silica gel, Kieselgel Merck 60 F_{254}) with a mixture of ethyl acetate and hexane (3:1) as an eluent. The pure product **2** had the following properties:

***2-(1-Methyl-but-3-yn-1-yloxy)-tetrahydro-2H-pyran* (2).**

This compound was obtained as colourless oil, yield: 87%. R_f 0.55. IR (neat, ν_{max}, cm^{-1}): 1125 (C-O-C), 2106 (C≡C), 3292 (≡C-H). ^{1}H-NMR (250.1 MHz): δ_H 1.09-1.25, 3.65-3.77, 4.74-4.81 (mmm, 9H, OTHP), 1.27 (d, *J* = 7.2 Hz, 3H, Me-CHO), 2.02 (m, 1H, H-C≡), 2.38, 2.59 (overlapping multiplets, 2H, CH-C≡), 3.80-3.89 (m, 1H, Me-CHO). ^{13}C-NMR (62.9 MHz) δ_C 20.1 (CH_2), 22.7 (CH_3), 25.8 (CH_2), 26.4 (CH_2), 31.9 (CH_2), 63.8 (CH_2), 67.0 (CH), 75.2 (CH), 81.2 (C), 95.9 (CH). Anal. Calcd for $C_{10}H_{16}O_2$ requires: C 71.39, H 9.59. Found: C 71.32, H 9.65.

***Procedure for Synthesis of the 5-Methyl-9-(tetrahydro-2H-pyran-2-yloxy)-dec-6-yn-5-ol* 5**

Ethylmagnesium bromide [prepared from magnesium (1.22 g, 50 mmol) and ethyl bromide (5.50 g, 50 mmol) in dry THF (50 mL)] is added dropwise under stirring to substituted alkynyloxy-tetrahydro-2*H*-pyran **2** (50 mmol) and then the mixture is refluxed for 2h. The solution of the prepared pentynyl magnesium bromide **3** is added dropwise under stirring to the hexan-2-one **4** (100 mmol). The mixture is refluxed for 24 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 over anhydrous sodium sulfate. Solvent and the excess of ketone are removed by distillation. Purification of the residue is achieved by column chromatography (silica gel, Kieselgel Merck 60 F_{254}) with ethyl acetate-hexane (5:1). The pure product **5** had the following properties:

***5-Methyl-9-(tetrahydro-2H-pyran-2-yloxy)-dec-6-yn-5-ol* (5).**

This compound was obtained as colourless oil, yield: 55%. R_f 0.51. IR (neat, ν_{max}, cm^{-1}): 1122 (C-O-C), 3408 (OH). ^{1}H-NMR (250.1 MHz): δ_H 0.88 (t, *J* = 6.5 Hz, 3H, Me-$(CH_2)_3$), 1.15-1.37, 3.60-3.81, 4.73-4.81 (overlapping multiplets, 9H, OTHP), 1.28 (d, *J* = 7.1 Hz, 3H, Me-CHO), 1.30-1.58 (m, 2H, Me-$(CH_2)_2$), 1.37 (s, 3H, Me-C), 2.54 (s, 1H, OH), 2.57-2.64 (m, 2H, O-CH-CH_2-C≡), 3.83-3.88 (m, 1H, Me-CHO). ^{13}C-NMR (62.9 MHz) δ_C 14.7 (CH_3), 20.1 (CH_2), 22.7 (CH_3), 24.3 (CH_2), 24.7 (CH_2), 25.1 (CH_2), 25.6 (CH_2), 30.0 (CH_3), 31.8 (CH_2), 45.3 (CH_2), 63.9 (CH_2), 68.1 (C), 75.7 (CH), 78.4 (C), 82.3 (C), 96.1 (CH). Anal. Calcd for $C_{16}H_{28}O_3$ requires: C 71.60, H 10.52. Found: C 71.66, H 10.44.

***Procedure for Synthesis of the Dimethyl 3-Methyl-1-[2-(tetrahydro-2H-pyran-2-yloxy)-propyl]- hepta-1,2-dienephosphonate* 7**

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 was added dropwise with stirring a solution of the 5-methyl-9-(tetrahydro-2*H*-pyran-2-yloxy)-dec-6-yn-5-ol **5** (20 mmol) in the same solvent (20 mL). After 30 min stirring at the same condition a solution of pyridine (3,16 g, 44 mmol) and of methanol (1,28 g, 40 mmol) in dry diethyl ether (50 mL) were added. The reaction mixture was stirred for an hour at the same temperature and for 10 hours at room temperature. The mixture was then 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 chromatographied on a column (silica gel, Kieselgel Merck 60 F_{254}) with a mixture of ethyl acetate and hexane (10:1) as an eluent to give the pure product **7** as an oil, which had the following properties:

***Dimethyl 3-Methyl-1-[2-(tetrahydro-2H-pyran-2-yloxy)-propyl]-hepta-1,2-dienephosphonate* (7).**

This compound was obtained as orange oil, yield: 71%. R_f 0.45. IR (neat, ν_{max}, cm^{-1}): 1118 (C-O-C), 1258 (P=O), 1955 (C=C=C). ^{1}H-NMR (600.1 MHz): δ_H 0.90 (t, *J* = 7.3 Hz, 3H, Me-$(CH_2)_3$), 1.17 (d, *J* = 6.0 Hz, 3H, Me-CHO), 1.20-1.23, 1.24-1.29, 1.42-1.47, 3.84-3.95, 4.90-4.94 (overlapping multiplets, 9H, OTHP), 1.32-1.38 (m, 2H, Me-C$H_2(CH_2)_2$), 1.51-1.57 (m, 2H, Me-$CH_2CH_2CH_2$), 1.76 (d, *J* = 7.0 Hz, 3H, Me-C=), 2.14-2.42 (m, 2H, O-CH-CH_2-C=), 2.35-2.42 (m, 2H, Me-$(CH_2)_2CH_2$), 3.73 (d, *J* = 11.1 Hz, 3H, MeO), 4.67-4.71 (m, 1H, Me-CHO). ^{13}C-NMR (150.9 MHz) δ_C 13.9 (CH_3), 18.8 (*J* = 5.3 Hz, CH_3), 19.7 (CH_2), 20.0 (*J* = 7.8 Hz, CH_3), 20.4 (CH_2), 25.3 (CH_2), 29.4 (CH_2), 32.0 (CH_2), 36.1 (*J* = 6.7 Hz, CH_2), 36.9 (*J* = 8.9 Hz, CH_2), 52.8 (*J* = 6.4 Hz, CH_3), 62.9 (*J* = 12.1 Hz, CH), 63.7 (CH_2), 88.4 (*J* = 191.8 Hz, C), 96.2 (CH), 102.4 (*J* = 13.2 Hz, C), 208.3 (*J* = 5.1 Hz, C). ^{31}P-NMR (242.9 MHz): δ_P 21.9. Anal. Calcd for $C_{18}H_{33}O_5P$ requires: C 59.98, H 9.23. Found: C 59.93, H 9.16.

***Procedure for the Synthesis of the 2-(3-Diphenylphosphinoyl-1,5-dimethyl-nona-3,4-dienyloxy)-tetrahydro-2H-pyran* 9**

To a solution of the 5-methyl-9-(tetrahydro-2*H*-pyran-2-yloxy)-dec-6-yn-5-ol **5** (20 mmol) and triethylamine (2.23 g, 22 mmol) in dry diethyl ether (60 mL) at -70°C, a solution of freshly distilled diphenylchloro phosphine (4.41 g, 20 mmol) in the same solvent (20 mL) was added dropwise with stirring. The reaction mixture was stirred for an hour at the same temperature and for 8 h at room temperature and then washed with water, 2N HCl, extracted with diethyl ether, and the extract was washed with saturated NaCl, and dried over anhydrous sodium sulfate. The solvent was removed using a rotatory evaporator, and the residue was purified by column chromatography on a silica gel (Kieselgel Merck 60 F_{254}) with ethyl acetate-hexane (10:1) to give the pure product **9** as an oil, which had the following properties:

***2-(3-Diphenylphosphinoyl-1,5-dimethyl-nona-3,4-dienyloxy)-tetrahydro-2H-pyran* (9).**

This compound was obtained as yellow oil, yield: 79%. R_f 0.43. IR (neat, ν_{max}, cm^{-1}): 1122 (C-O-C), 1156 (P=O), 1436, 1490 (Ph), 1951 (C=C=C). ^{1}H-NMR (600.1 MHz): δ_H 0.81 (t, *J* = 7.3 Hz, 3H, Me-$(CH_2)_3$), 1.11-1.16, 1.23-1.28, 1.44-1.49, 3.86-3.94, 4.88-4.93 (overlapping multiplets, 9H, OTHP), 1.17 (d, *J* = 6.1 Hz, 3H, Me-CHO), 1.35-1.39 (m, 2H, Me-C$H_2(CH_2)_2$), 1.49-1.55 (m, 2H, Me-$CH_2CH_2CH_2$), 1.79 (d, *J* = 7.1 Hz, 3H, Me-C=), 2.04-2.16 (m, 2H, O-CH-CH_2-C=), 2.29-2.36 (m, 2H, Me-$(CH_2)_2CH_2$), 4.66-4.70 (m, 1H, Me-CHO), 7.37-7.88 (m, 10H, 2Ph). ^{13}C-NMR (150.9 MHz) δ_C 13.9 (CH_3), 19.1 (*J* = 5.4 Hz, CH_3), 19.8 (*J* = 8.0 Hz, CH_3), 21.1

(CH_2), 21.3 (CH_2), 25.4 (CH_2), 29.3 (CH_2), 32.1 (CH_2), 35.1 (J = 6.2 Hz, CH_2), 35.6 (J = 8.7 Hz, CH_2), 62.7 (J = 12.2 Hz, CH), 62.9 (CH_2), 93.8 (J = 103.6 Hz, C), 96.2 (CH), 102.9 (J = 13.2 Hz, C), 127.7-133.2 (2Ph), 207.9 (J = 6.6 Hz, C). ^{31}P-NMR (242.9 MHz): δ_P 32.6. Anal. Calcd for $C_{28}H_{37}O_3P$ requires: C 74.31, H 8.24. Found: C 74.39, H 8.20.

***Procedure for the Synthesis of the Dimethyl [1-(2-Hydroxypropyl)-3-methyl-hepta-1,2- dienyl]phosphonate* 10 *and the 4-Diphenylphosphinoyl-6-methyl-deca-4,5-dien-2-ol* 11**

A solution of the dimethyl 3-methyl-1-[2-(tetrahydro-2*H*-pyran-2-yloxy)-propyl]-hepta-1,2-dienephosphonate **7** or the 2-(3-diphenylphosphinoyl-1,5-dimethyl-nona-3,4-dienyloxy) tetrahydro-2 *H*-pyran **9** (5 mmol) and PPTS (0.5 mmol) in ethanol (10 mL) was stirred at room temperature for 6 h.

The mixture was then washed with water, extracted with methylene chloride and dried over anhydrous sodium sulfate. After evaporation of the solvent, the residue was chromatographied on a column (silica gel, Kieselgel Merck 60 F_{254}) with a mixture of ethyl acetate and hexane (10:1) as an eluent to give the pure products **10** or **11** as oils, which had the following properties:

***Dimethyl [1-(2-Hydroxypropyl)-3-methyl-hepta-1,2-dienyl]phosphonate* (10)**

This compound was obtained as yellow oil, yield: 83%. R_f 0.59. IR (neat, ν_{max}, cm^{-1}): 1259 (P=O), 1951 (C=C=C), 3420 (OH). ^{1}H-NMR (600.1 MHz): δ_H 0.91 (t, J = 7.3 Hz, 3H, Me-$(CH_2)_3$), 1.22 (d, J = 6.4 Hz, 3H, Me-CHO), 1.33-1.38 (m, 2H, Me-CH_2(CH_2)$_2$), 1.41-1.47 (m, 2H, Me-CH_2C$H_2$$CH_2$), 1.78 (d, J = 6.9 Hz, 3H, Me-C=), 2.03-2.06 (m, 2H, O-CH-CH_2-C=), 2.27-2.33 (m, 2H, Me-(CH_2)$_2$CH_2), 2.88 (s, 1H, OH), 3.74 (d, J = 11.1 Hz, 3H, MeO), 4.59-4.62 (m, 1H, Me-CHO). ^{13}C-NMR (150.9 MHz) δ_C 13.8 (CH_3), 18.0 (J = 5.8 Hz, CH_3), 22.2 (CH_2), 22.7 (J = 7.9 Hz, CH_3), 29.3 (CH_2), 33.0 (J = 6.6 Hz, CH_2), 39.4 (J = 12.1 Hz, CH_2), 52.9 (J = 6.3 Hz, CH_3), 66.9 (J = 9.7 Hz, CH), 88.6 (J = 190.3 Hz, C), 102.3 (J = 15.9 Hz, C), 208.1 (J = 5.2 Hz, C). ^{31}P-NMR (242.9 MHz): δ_P 22.6. Anal. Calcd for $C_{13}H_{25}O_4P$ requires: C 56.51, H 9.12. Found: C 56.43, H 9.19.

***4-Diphenylphosphinoyl-6-methyl-deca-4,5-dien-2-ol* (11)**

This compound was obtained as orange oil, yield: 88%. R_f 0.58. IR (neat, ν_{max}, cm^{-1}): 1167 (P=O), 1436, 1491 (Ph), 1949 (C=C=C), 3401 (OH). ^{1}H-NMR (600.1 MHz): δ_H 0.82 (t, J = 7.2 Hz, 3H, Me-$(CH_2)_3$), 1.20 (d, J = 6.4 Hz, 3H, Me-CHO), 1.40-1.44 (m, 2H, Me-CH_2(CH_2)$_2$), 1.46-1.51 (m, 2H, Me-CH_2C$H_2$$CH_2$), 1.80 (d, J = 7.1 Hz, 3H, Me-C=), 2.04-2.10 (m, 2H, O-CH-CH_2-C=), 2.30-2.36 (m, 2H, Me-(CH_2)$_2$CH_2), 2.90 (s, 1H, OH), 4.58-4.61 (m, 1H, Me-CHO), 7.35-7.89 (m, 10H, 2Ph). ^{13}C-NMR (150.9 MHz) δ_C 13.9 (CH_3), 18.7 (J = 5.9 Hz, CH_3), 21.1 (CH_2), 22.9 (J = 8.0 Hz, CH_3), 29.2 (CH_2), 32.9 (J = 6.4 Hz, CH_2), 39.5 (J = 12.4 Hz, CH_2), 67.3 (J = 9.8 Hz, CH), 94.6 (J = 102.4 Hz, C), 102.2 (J = 15.7 Hz, C), 128.0-132.5 (2Ph), 209.0 (J = 5.4 Hz, C). ^{31}P-NMR (242.9 MHz): δ_P 34.5. Anal. Calcd for [$C_{23}H_{29}O_2P$] requires: C 74.98, H 7.93. Found: C 75.04, H 7.88.

General Procedure for the Reactions of the Phosphorylated -Hydroxyallenes* 7, 9-11 *with Electrophilic Reagents

To a solution of the phosphorylated β-hydroxyallene with protected (**7** or **9**) or unprotected (**10** or **11**) hydroxy group (3.0 mmol) in dry dichloromethane (10 mL) at -20 °C was added dropwise with stirring a solution of electrophilic reagent (sulfuryl chloride, bromine, phenylsulfenyl chloride or benzeneselenenyl chloride) (3.6 mmol) in the same solvent (10 mL). The reaction mixture was stirred at the same temperature for 2 hours and 2 hours at room temperature.

After evaporation of the solvent, the residue was chromatographed on a silica gel column (ethyl acetate and hexane 4:1 or 5:1) as an eluent to give the pure products **12-14** as oils, which had the following properties:

***2[2-(4-Bromo-5-butyl-2-methoxy-5-methyl-2-oxo-2,5-dihydro-1,2-oxaphosphol-3-yl)-1-methylethyl]-tetrahydro-2H-pyran* (12a)**

This compound was obtained as yellow oil, yield: 80%. R_f 0.51. IR (neat, ν_{max}, cm^{-1}): 1016 (C-O-P), 1121 (C-O-C), 1585 (P=O), 1584 (C=C). ^{1}H-NMR (600.1 MHz): δ_H 0.92 (t, J = 6.2 Hz, 3H, Me-$(CH_2)_3$), 1.12-1.26, 3.32-3.71, 4.61-4.69 (overlapping multiplets, 9H, OTHP), 1.29 (d, J = 6.3 Hz, 3H, Me-CH), 1.24-1.35, 1.42-1.49, 1.72-1.88 (overlapping multiplets, 6H, (CH_2)$_3$-Me), 1.57 (s, 3H, Me-C), 2.38-2.55 (m, 2H, CH_2), 3.77 (d, J = 11.6 Hz, 3H, MeO), 4.50-4.60 (m, 1H, Me-CH). ^{13}C-NMR (150.9 MHz) δ_C 14.0, 19.6, 22.7 (J = 7.5 Hz), 23.2 (J = 4.7 Hz), 23.3, 25.3, 25.7 (J = 7.8 Hz), 31.1, 35.6 (J = 5.8 Hz), 39.4 (J = 7.9 Hz), 52.5 (J = 15.2 Hz), 62.7, 70.0 (J = 8.1 Hz), 89.5 (J = 9.8 Hz), 96.3, 125.7 (J = 156.0 Hz), 142.3 (J = 51.1 Hz). ^{31}P-NMR (242.9 MHz): δ_P 33.5. Anal. Calcd for $C_{17}H_{30}O_5PBr$ requires: C 48.01, H 7.11. Found: C 48.05, H 7.13.

***1-(5-Butyl-2-methoxy-5-methyl-2-oxo-4-phenylsulfenyl-2,5-dihydro-1,2-oxaphosphol-3-yl)propan-2-ol* (12b)**

This compound was obtained as yellow oil, yield: 87%. R_f 0.55. IR (neat, ν_{max}, cm^{-1}): 1024 (C-O-P), 1259 (P=O), 1581 (C=C), 3410 (OH). ^{1}H-NMR (600.1 MHz): δ_H 0.91 (t, J = 6.3 Hz, 3H, Me-$(CH_2)_3$), 1.26 (d, J = 6.1 Hz, 3H, Me-CH), 1.27-1.34, 1.60-1.68, 1.86-2.04 (overlapping multiplets, 6H, (CH_2)$_3$-Me), 1.46 (s, 3H, Me-C), 2.55-2.67 (m, 2H, CH_2), 3.28 (s, 1H, OH), 3.73 (d, J = 11.4 Hz, 3H, MeO), 3.92-3.98 (m, 1H, Me-CH), 7.14-7.41 (m, 5H, Ph). ^{13}C-NMR (150.9 MHz) δ_C 14.1, 23.0, 23.6 (J = 4.6 Hz), 28.2 (J = 4.7 Hz), 38.5 (J = 5.8 Hz), 39.4 (J = 7.8 Hz), 52.4 (J = 15.1 Hz), 65.8 (J = 8.1 Hz), 88.2 (J = 9.9 Hz), 126.7-134.5, 126.8 (J = 100.9 Hz), 164.2 (J = 15.4 Hz). ^{31}P-NMR (242.9 MHz): δ_P 34.5. Anal. Calcd for $C_{18}H_{27}O_4PS$ requires: C 58.36, H 7.35. Found: C 58.30, H 7.37.

***5-Butyl-2,2-diphenyl-5-methyl-4-phenylselenenyl-3-[(tetrahydro-2H-pyran-2-yloxy)prop-2-yl]-2,5- dihydro-1,2-oxaphosphol-2-onium chloride* (13a)**

This compound was obtained as yellow oil, yield: 51%. R_f 0.59. IR (neat, ν_{max}, cm^{-1}): 1112 (C-O-C), 1439, 1477 (Ph), 1577 (C=C). ^{1}H-NMR (600.1 MHz): δ_H 0.91 (t, *J* = 6.3 Hz, 3H, Me-$(CH_2)_3$), 1.10-1.26, 3.47-3.66, 4.55-4.60 (overlapping multiplets, 9H, OTHP), 1.25-1.30, 1.47-1.53, 1.80-2.00 (overlapping multiplets, 6H, $(CH_2)_3$-Me), 1.36 (d, *J* = 6.2 Hz, 3H, Me-CH), 1.60 (s, 3H, Me-C), 2.84-3.01 (m, 2H, CH_2), 3.77-3.89 (m, 1H, Me-CH), 7.15-7.73 (m, 15H, 3Ph). ^{13}C-NMR (150.9 MHz) δ_C 14.0, 19.8, 22.3 (*J* = 10.1 Hz), 22.6 (*J* = 4.7 Hz), 25.1 (*J* = 7.9 Hz), 25.6, 31.2, 35.1 (*J* = 6.0 Hz), 40.2 (*J* = 7.8 Hz), 63.2, 75.8 (*J* = 8.0 Hz), 95.5 (*J* = 9.9 Hz), 96.1, 127.6-137.8, 152.4 (*J* = 96.1 Hz), 168.0 (*J* = 85.3 Hz). ^{31}P-NMR (242.9 MHz): δ_P 82.8. Anal. Calcd for $C_{34}H_{43}O_3PSeCl$ requires: C 63.30, H 6.72. Found: C 63.37, H 6.70.

***3-Methyl-3-chloro-2-phenylselenenyl-1-[2-(tetrahydro-2H-pyran-2-yloxy)prop-2-yl]hept-(1E)-en-1-yl diphenyl phosphine oxide* (14a)**

This compound was obtained as orange oil, yield: 25%. R_f 0.42. IR (neat, ν_{max}, cm^{-1}): 1122 (C-O-C), 1150 (P=O), 1437, 1478 (Ph), 1592 (C=C). ^{1}H-NMR (600.1 MHz): δ_H 0.87 (t, *J* = 6.0 Hz, 3H, Me-$(CH_2)_3$), 1.11-1.26, 3.52-3.63, 4.58-4.64 (overlapping multiplets, 9H, OTHP), 1.28 (d, *J* = 6.1 Hz, 3H, Me-CH), 1.31-1.39, 1.37-1.45, 2.36-2.43 (overlapping multiplets, 6H, $(CH_2)_3$-Me), 1.77 (s, 3H, Me-C), 2.56-2.65 (m, 2H, CH_2), 3.95-4.05 (m, 1H, Me-CH), 7.38-7.73 (m, 15H, 3Ph). ^{13}C-NMR (150.9 MHz) δ_C 14.1, 19.9, 22.5, 22.8 (*J* = 5.1 Hz), 25.5, 25.7 (*J* = 5.9 Hz), 29.1 (*J* = 5.1 Hz), 31.3, 39.8 (*J* = 5.8 Hz), 42.6 (*J* = 4.7 Hz), 63.0, 74.1 (*J* = 7.8 Hz), 81.3 (*J* = 8.2 Hz), 95.8, 127.8 (*J* = 100.5 Hz), 128.4-138.9, 152.7 (*J* = 85.2 Hz). ^{31}P-NMR (242.9 MHz): δ_P 21.9. Anal. Calcd for $C_{34}H_{42}ClO_3PSe$ requires: C 63.40, H 6.57. Found: C 63.35, H 6.52.

***5-Butyl-4-chloro-2,2-diphenyl-5-methyl-3-(2-hydroxypropyl)-2,5-dihydro-1,2-oxaphosphol-2-onium chloride* (13b)**

This compound was obtained as yellow oil, yield: 57%. R_f 0.60. IR (neat, ν_{max}, cm^{-1}): 1440, 1495 (Ph), 1585 (C=C), 3397 (OH). ^{1}H-NMR (600.1 MHz): δ_H 0.91 (t, *J* = 6.3 Hz, 3H, Me-$(CH_2)_3$), 1.13-1.21, 1.26-1.37, 2.27-2.46 (overlapping multiplets, 6H, $(CH_2)_3$-Me), 1.29 (d, *J* = 6.1 Hz, 3H, Me-CH), 1.68 (s, 3H, Me-C), 2.66 (s, 1H, OH), 2.77-2.88 (m, 2H, CH_2), 4.05-4.14 (m, 1H, Me-CH), 7.79-8.24 (m, 10H, 2Ph). ^{13}C-NMR (150.9 MHz) δ_C 14.1, 22.2 (*J* = 4.9 Hz), 23.0, 23.6 (*J* = 4.4 Hz), 27.3 (*J* = 8.1 Hz), 34.8 (*J* = 5.9 Hz), 38.6 (*J* = 8.0 Hz), 70.4 (*J* = 7.8 Hz), 94.2 (*J* = 9.9 Hz), 124.7 (*J* = 97.4 Hz), 125.4-136.1, 165.7 (*J* = 39.6 Hz). ^{31}P-NMR (242.9 MHz): δ_P 84.0. Anal. Calcd for $C_{23}H_{29}O_2PCl_2$ requires: C 62.88, H 6.65. Found: C 62.86, H 6.66.

***5,6-Dichloro-4-diphenylphosphoryl-6-methyl-dec-(4E)-en-2-ol* (14b)**

This compound was obtained as orange oil, yield: 29%. R_f 0.44. IR (neat, ν_{max}, cm^{-1}): 1171 (P=O), 1438, 1485 (Ph), 1606 (C=C), 3310 (OH). ^{1}H-NMR (600.1 MHz): δ_H 0.89 (t, *J* = 6.1 Hz, 3H, Me-$(CH_2)_3$), 1.29 (d, *J* = 6.3 Hz, 3H, Me-CH), 1.36-1.45, 1.46-1.51, 2.28-2.45 (overlapping multiplets, 6H, $(CH_2)_3$-Me), 1.83 (s, 3H, Me-C), 2.47-2.57 (m, 2H, CH_2),3.27 (s, 1H, OH), 4.03-4.13 (m, 1H, Me-CH), 7.54-7.90 (m, 10H, 2Ph). ^{13}C-NMR (150.9 MHz) δ_C 14.0, 22.6 (*J* = 5.1 Hz), 22.7, 27.4 29.3 (*J* = 4.9 Hz), 38.7 (*J* = 6.0 Hz), 43.0 (*J* = 4.8 Hz), 73.1 (*J* = 7.9 Hz), 78.0 (*J* = 8.0 Hz), 124.8 (*J* = 100.1 Hz), 129.3-135.8, 152.7 (*J* = 40.1 Hz). ^{31}P-NMR (242.9 MHz): δ_P 21.6. Anal. Calcd for $C_{23}H_{29}Cl_2O_2P$ requires: C 62.88, H 6.65. Found: C 62.84, H 6.60.

***General Procedure for Coinage Metal-catalyzed Cycloisomerization of the 1-(2-Hydroxypropyl)-allenephosphonate* 10 *and 1-(2-Hydroxypropyl) Allenyl Phosphine Oxide* 11**

Coinage metal salt catalyst (0.15 mmol) was added to a solution of the 1-(2-hydroxypropyl)-allenephosphonate **10** or 1-(2-hydroxypropyl) allenyl phosphine oxide **11** (3.0 mmol) in dry dichloromethane (10 mL). The mixture was stirred at room temperature and in the dark for the hours indicated in the **Table 1**. Saturated sodium chloride solution was added to precipitate the silver ions. The product was extracted by chloroform. The organic layer was dried over anhydrous sodium sulfate. After evaporation of the solvent, the residue was chromatographed on a column (silica gel, Kieselgel Merck 60 F_{254}) with a mixture of ethyl acetate and hexane (6:1) as an eluent to give the pure products **15** as oils, which had the following properties:

***Dimethyl (6-butyl-2,6-dimethyl-3,6-dihydro-2H-pyran-4-yl)phosphonate* (15a)**

This compound was obtained as orange oil, yield: 21-66% (Table 1). R_f 0.61. IR (neat, ν_{max}, cm^{-1}): 1126 (C-O-C), 1242 (P=O), 1624 (C=C). ^{1}H-NMR (600.1 MHz): δ_H 0.89 (t, *J* = 7.1 Hz, 3H, Me-$(CH_2)_3$), 1.28-1.38, 1.44-1.60 (overlapping multiplets, 6H, $(CH_2)_3$-Me), 1.33 (s, 3H, Me-C), 1.46 (d, *J* =11.6 Hz, 3H, Me-CH), 2.31-2.57 (m, 2H, CH_2), 3.69-3.71 (m, 1H, Me-CH), 3.77 (d, *J* =11.3 Hz, 6H, 2MeO), 6.56 (d, *J* =11.6 Hz, 1H, HC=). ^{13}C-NMR (150.9 MHz) δ_C 14.0, 19.7, 23.0, 26.9, 27.5 (*J* = 4.5 Hz), 28.7 (*J* = 15.0 Hz), 39.4 (*J* = 4.0 Hz), 52.5 (*J* = 14.7 Hz), 66.7 (*J* = 7.8 Hz), 67.9 (*J* = 7.8 Hz), 67.9 (*J* = 7.9 Hz), 127.8 (*J* = 188.7 Hz), 150.6 (*J* = 10.1 Hz). ^{31}P-NMR (242.9 MHz): δ_P 17.1. Anal. Calcd for $C_{13}H_{25}O_4P$ requires: C 56.51, H 9.12. Found: C 56.55, H 9.15.

***(6-Butyl-2,6-dimethyl-3,6-dihydro-2H-pyran-4-yl) diphenyl phosphine oxide* (15b)**

This compound was obtained as orange oil, yield: 19-63% (Table 1). R_f 0.58. IR (neat, ν_{max}, cm^{-1}): 1120 (C-O-C), 1173 (P=O), 1438, 1495 (Ph), 1621 (C=C). ^{1}H-NMR (600.1 MHz): δ_H 0.83 (t, *J* = 6.2 Hz, 3H, Me-$(CH_2)_3$), 1.24-1.30, 1.31-1.57 (overlapping multiplets, 6H, $(CH_2)_3$-Me), 1.28 (d, *J* =11.6 Hz, 3H, Me-CH), 1.29 (s, 3H, Me-C), 2.31-2.59 (m, 2H, CH_2), 3.50-3.60 (m, 1H, Me-CH), 6.65 (d, *J* =12.4 Hz, 1H, HC=), 7.47-7.78 (m, 10H, 2Ph). ^{13}C-NMR (150.9 MHz) δ_C 14.0, 21.5, 23.6, 25.8, 26.8 (*J* = 4.6 Hz), 38.1 (*J* = 14.8 Hz), 39.3 (*J* = 4.7 Hz), 68.8 (*J* = 7.8 Hz), 70.8 (*J* = 8.0 Hz), 130.0 (*J* = 179.9

Hz), 128.5-134.6, 149.2 (J = 8.8 Hz). ^{31}P-NMR (242.9 MHz): δ_P 21.6. Anal. Calcd for $C_{23}H_{29}O_2P$ requires: C 74.98, H 7.93. Found: C 74.95, H 7.95.

RESULTS AND DISCUSSION

Synthesis of Phosphorylated -Hydroxyallenes

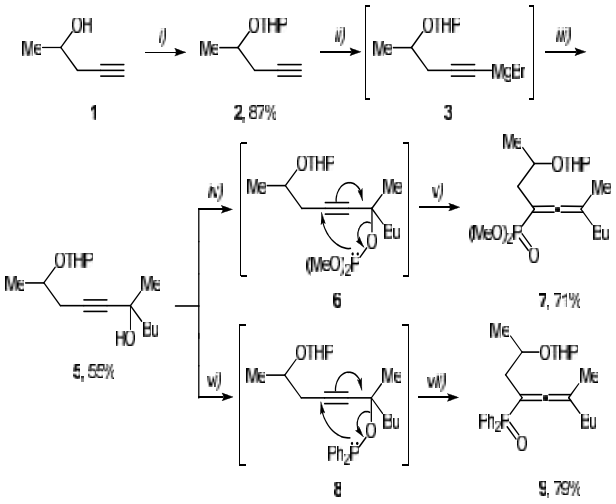
Our strategy for the synthesis of the phosphorylated β-hydroxyallenes, using our experience on the preparation of the phosphorylated α-hydroxyallenes (Christov *et al*, 2014a), relies on the well-precedented [2,3]-sigmatropic shift of propargylic phosphites to allenephosphonates (Macomber, 1977; Denmark and Marlin, 1991; Cai and Blackburn, 1997; Saalfrank *et al*, 1999; Kumar *et al*, 2008, 2009) and propargylic phosphinites to allenyl phosphine oxides (Nicolaou *et al*, 1990; Curfin and Okamura, 1990; Grissom and Huang, 1995; Darcel *et al*, 1996; De Frutos and Echavarren, 1997; Schmittel *et al*, 2001; Guo *et al*, 2008; Srinivas *et al*, 2011).

In order to assess this approach towards the target 1,1-bifunctionalized allenes, a range of the phosphorylated -hydroxyallenes **7**, **9**, **10**, and **11**, was prepared by the following four-step procedure (Christov *et al*, 2014b) including i) protection of hydroxy group in the pent-4-yn-2-ol **1**; ii) subsequent reaction with Grignard reagent and butylmethyl ketone to give the 6-methyl-dec-4-yne-2,6-diol **5** with protected hydroxy group at position 2; iii) interaction with chloride of phosphorus acid in the presence of a base; and finally iv) [2,3]-sigmatropic rearrangement of the mediated protected propargyl phosphite or phosphinite.

As a starting point for our investigation, we first examined the protection of hydroxy group in the pent-4-yn-2-ol **1** with DHP in the presence of PPTS (Robertson, 1960; Miyashita *et al*, 1977) (**Scheme 1**). Thus, the formed 2-(1-methyl-but-3-ynyloxy)-tetrahydro-2*H*-pyran **2** was isolated by column chromatography with excellent yield (87%). Reaction of the protected pent-4-yn-2-ol **2** with ethyl magnesium bromide and subsequent dropwise addition of the *in situ* generated pentynyl magnesium bromide **3** to the hexan-2-one **4** and reflux for 24 hours gives the 5-methyl-9-(tetrahydro-2*H*-pyran-2-yloxy)-dec-6-yn-5-ol **5**, which is stable and was isolated by column chromatography in 55% yield.

With the required dec-4-yne-2,6-diol **5** with protected hydroxy group at 2 position in hand, we were then able to investigate the proposed reactions with the corresponding chloro-containing phosphorus reagents such as dimethyl chlorophosphite and chlorodiphenyl phosphine in the presence of a base and subsequent [2,3]-sigmatropic rearrangement of the mediated 4-(tetrahydro-2*H*-pyran-2-yloxy)-propargyl phosphite **6** or phosphinite **8**.

In the first instance, the dimethyl 1-(tetrahydro-2*H*-pyran-2-yloxy)-hepta-1,2-dienephosphonates **7** can be readily prepared *via* an atom economical 2,3-sigmatropic rearrangement of the 4-(tetrahydro-2*H*-pyran-2-yloxy)-propargyl phosphite **6**, intermediate formed by reaction of the 9-(tetrahydro-2*H*-pyran-2-yloxy)-dec-6-yn-5-ol **5** with dimethyl chlorophosphite, prepared *in situ* from phosphorus trichloride in the presence of triethylamine and 2 *equiv* of methanol and 2 *equiv* of pyridine, according to **Scheme 1**.



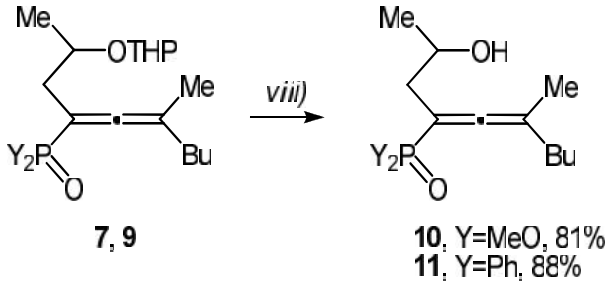
Scheme 1 Synthesis of the phosphorylated -hydroxyallenes with protected hydroxy group **7** and **9** by 2,3-sigmatropic rearrangement of the propargyl phosphite **6** and phosphinite **8**.

Reagents and Conditions**:** *i)* DHP (1.5 eq), PPTS (0.1 eq), CH_2Cl_2, rt, 4h, distillation; *ii)* EtMgBr (1 eq), THF, reflux, 2h; *iii)* dropwise addition of **3** to MeC(O)Bu **4** (2 eq), reflux, 24h, column chromatography; *iv)* PCl_3 (1 eq), Et_3N (1.1 eq), Et_2O, -70 ^oC, 30 min stirring, pyridine (2.2 eq), MeOH (2 eq), Et_2O, -70 ^oC; *v)* [2,3-σ]-rearrangement, -70 ^oC, 1h, rt, 10h; *vi)* Ph_2PCl (1 eq), Et_3N (1.1 eq), Et_2O, -70 ^oC, 1h, rt, 10h, column chromatography; *vii)* [2,3-σ]-rearrangement, -70 ^oC, 1h, rt, 8h, column chromatography.

Next, the reaction of the 9-(tetrahydro-2*H*-pyran-2-yloxy)-dec-6-yn-5-ol **5** with chlorodiphenyl phosphine in the presence of triethylamine at -70^oC gave the expected 2-(3-diphenylphosphinoyl-nona-3,4-dienyloxy)-tetrahydro-2H-pyran **9** in very good yield (79%) as a result of [2,3]-sigmatropic rearrangement of the 4-(tetrahydro-2*H*-pyran-2-yloxy)-propargyl phosphinite **8** for 8 hours at room temperature, according to the reaction sequence outlined in **Scheme 1**.

A new family of phosphorylated β-hydroxyallenes with protected hydroxy group **7** and **9** were synthesized *via* an atom economical and regioselective [2,3]-sigmatropic rearrangement of the intermediate formed propargyl phosphite **6** or phosphinite **8** in the reaction of the protected dec-6-yn-5-ol **5** with dimethylchloro phosphite or chlorodiphenyl phosphine in the presence of triethylamine. Compounds **7** and **9** were stable enough to be handled at ambient temperature.

The hydroxy group was deprotected by stirring the ethanol solution of the protected hydroxypropyl-allenephosphonate **7** and hydroxypropyl-allenyl phosphine oxide **9** in the presence of 0.1 *equiv* PPTS at room temperature for 6 hours, according to **Scheme 2**.



Scheme 2 Synthesis of the phosphorylated -hydroxyallenes **10** and **11**

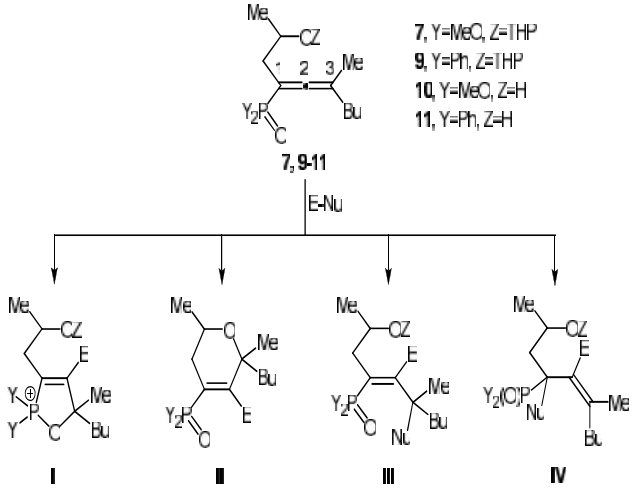
***Reagents and Conditions*: *viii)* PPTS (0.1 eq), EtOH, rt, 6h, stirring, column chromatography.**

After a conventional work-up, all allenic products **7**, **9**, **10**, and **11** were isolated as stable yellow or orange oils by column chromatography and identified by ^{1}H, ^{13}C, and ^{31}P NMR and IR spectra as well as by elemental analysis.

Phosphorylated β-hydroxyallenes **7**, **9-11** isolated in preparative amounts allowed us to study their chemical behavior in the reactions with electrophilic reagents and the coinage metal-catalyzed cycloisomerization. The present paper is a part of our long-term objective to investigate both the advantages and the limitations of the electrophilic cyclization and cycloisomerization reactions of the phosphorylated β-hydroxyallenes **7**, **9**–**11**.

Electrophilic Cyclization of Phosphorylated -Hydroxyallenes

It is necessary to draw attention to the fact that conceptually two distinct modes of cyclization of the phosphorylated β-hydroxyallenes are possible. They depend on the electrophilic atom that forms a new bond with the central carbon of the allenic system, which seems likely (Angelov, 1983; Khusainova and Pudovik, 1987; Allabugin and Brel, 1997; Ma, 2009; Brel, 2006). It is evident that these pathways are closely connected with the intramolecular neighboring group participation of the phosphoryl and/or the hydroxyalkyl groups as internal nucleophile(s) in the final step of the cyclization.

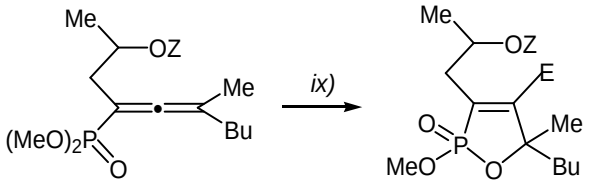


Scheme 3 Probable products of the electrophilic reaction of the phosphorylated -hydroxyallenes **7**, **9**–**11**.

Besides the 5-*endo-trig* cyclization (Baldwin, 1976) to the 2,5-dihydro-1,2-oxaphospholes **I** or 6-*endo-trig* cyclization (Baldwin, 1976) to the 4-phosphoryl-3,6-dihydro-2*H*-pyrans **II**, the electrophilic addition might afford the 2,3-adducts **III** and/or the 3,2-adducts **IV** (**Scheme 3**).

We started the present study with the reaction of the dimethyl 1-(2-hydroxy-propyl)-3-methyl-hepta-1,2-dienephosphonates with protected (**7**) or unprotected (**10**) hydroxy group with bromine or benzenesulfenyl chloride (**Scheme 4**). We conducted the reactions under the optimized reaction conditions determined in the similar reactions of the phosphorylated α-hydroxyallenes earlier (Christov *et al*, 2014b) – solvent CH_2Cl_2 at −20 °C using 1.0 *equiv* of the allenephosphonate and 1.2 *equiv* of the electrophilic reagent.

We have to say that the reaction in the favour of 5-*endo-trig* mode afforded the 2-methoxy-2-oxo-2,5-dihydro-1,2-oxaphospholes **12a,b** to have very good yields (80 and 87 %) and it does not depend on the nature of the substituent on the hydroxy group, as a result of the neighboring group participation of phosphonate group in the cyclization.



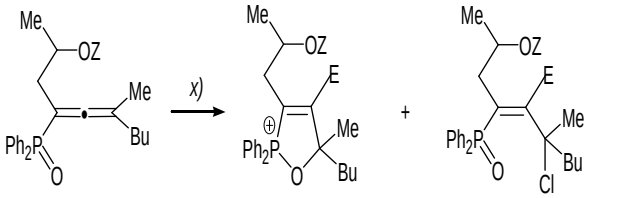
Scheme 4 Synthesis of the 2-oxo-2,5-dihydro-1,2-oxaphospholes **12** by electrophilic cyclization of the phosphorylated β-hydroxyallenes **7** and **10**.

Reagents and Conditions: *ix)* Br_2 or PhSCl (1.2 eq), CH_2Cl_2, -20 ^{o}C, 2 h, rt, 2h, stirring, work-up, column chromatography.

In order to outline the general terms of this methodology, the reaction of the 1-(2-hydroxypropyl)-allenyl phosphine oxides with protected and unprotected hydroxyl group **9** and **11** with sulfuryl chloride or benzeneselenenyl chloride was thorougly investigated.

Surprisingly, once we applied the current standard conditions to the 1,1-bifunctionalized allenes comprising a phosphine oxide and a 2-hydroxypropyl groups such as **9** and **11** (**Scheme 5**), the interaction afforded mixtures of the 2,2-diphenyl-2,5-dihydro-1,2-oxaphosphol-2-ium chlorides **13a**,**b** and the hept-(1*E*)-en-1-yl diphenyl phosphine oxides **14a**,**b** in the ratio about 2:1 in 76% and 86% total yield.

These reaction pathways may be interpreted as a result of the concurrent neighboring group participation of the phosphine oxide group as an internal nucleophile to give cyclic products **13a**,**b** and the highly regio- and stereoselective association of the external nucleophile, indicating a highly chemoselectively addition reaction of the electrophilic reagent to the C^2-C^3-double bond of the allenic system with formation of the (1*E*)-2,3-adducts **14a**,**b**.



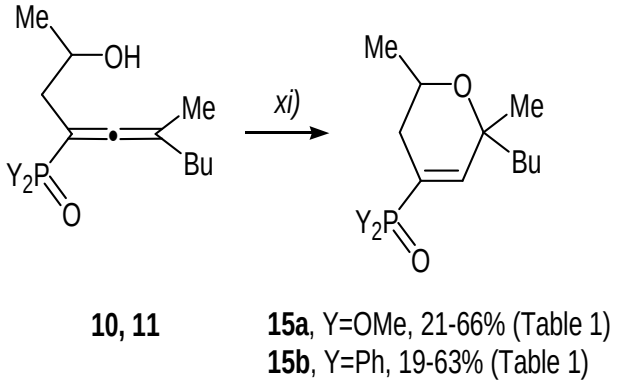
Scheme 5 Synthesis of the 2,5-dihydro-1,2-oxaphosphol-2-ium chlorides **13** and the 1-(2-hydroxypropyl)-hept-(1*E*)-en-1-yl phosphine oxides **14** by reaction of the phosphorylated β-hydroxyallenes **9** and **11** with electrophilic reagents.

Reagents and Conditions*: *x) PhSeCl or SO_2Cl_2 (1.2 eq), CH_2Cl_2, -20 ^oC, 2 h, rt, 2h, stirring, work-up, column chromatography.

The stereo selectivity could be explained by the favorable *trans* arrangement of the electrophile and the phosphine oxide group and *anti* attack of the external nucleophile. This is supposed to arise from attack on the allenic C^2-C^3 double bond *anti* to the phosphoryl group which assists in the cyclization by neighboring group participation as an internal nucleophile.

Coinage Metal-catalyzed Cycloisomerization of Phosphorylated -Hydroxyallenes

In addition to the above mentioned preparation of 2,5-dihydro-1,2-oxaphospholes by electrophilic cyclization of the 1-(2-hydroxypropyl)-allenephosphonates **7** and **10** and allenyl phosphine oxides **9** and **11** due to the participation of the phosphonate or phosphine oxide neighboring group in the 5-*endo-trig* cyclization, the next step in our study was to explore the possibilities of the cycloisomerization reaction of the above mentioned compounds **10** and **11** in the presence of coinage metal salts as catalysts. We conducted the reaction under the optimized reaction conditions determined in the similar reactions of the phosphorylated α-hydroxyallenes earlier (Christov *et al*, 2015) – solvent methylene chloride, 5 mol % catalyst and room temperature. The reaction occurred via an 6-*endo-trig* cyclization to give the 4-phosphoryl-3,6-dihydro-2*H*-pyrans **15a,b** (**Scheme 6**).



Scheme 6 Synthesis of the 4-phosphoryl-3,6-dihydro-2*H*-pyrans **15** by coinage metal-catalyzed cycloisomerization of the phosphorylated β-hydroxyallenes **10** and **11**

Reagents and Conditions*: *xi) Coinage metal catalyst (**Table 1**, 5 mol %), CH_2Cl_2, rt, stirring (**Table 1**), work-up, column chromatography.

The type of catalyst and its influence on the yields and the reaction time of the cycloisomerization of the 1-(2-hydroxypropyl)-allenephosphonate **10** and allenyl phosphine oxide **11** was also of great interest to us. We performed a series of experiments with the sole intention of determining the best catalysts bearing in mind two criteria – highest yield and shortest reaction time (**Scheme 6**). We applied the following coinage metal salts as catalysts: $AgNO_3$, $AgClO_4$, AuCl, $AuCl_3$, $Pd(PPh_3)_4$, $PtCl_2$, $CuCl_2$, $NiCl_2$, $SnCl_2$, $AlCl_3$, $PdCl_2$, $ZnCl_2$, CuCl, CuBr, and CuI. The data reveal that both Au and Ag are excellent catalysts. Pd(I), Pt, and Cu(II) are very good catalysts for our experiments. It becomes obvious that Ni, Sn, Al, Pd(II), and Zn are relatively good catalysts. It is the Cu(I) catalysts that are bad. **Table 1** presents the characteristics of all the above-mentioned catalysts in the cycloisomerization reaction of the compounds **10** and **11**.

Table 1 Synthesis of the 4-phosphoryl-3,6-dihydro-2*H*-pyrans **15** by coinage metal-catalyzed cycloisomerization of the phosphorylated β-hydroxyallenes **10** and **11**

Entry	Catalyst	Reaction time[a] 10 (h)	15a, Yield (%)	Reaction time[a] 11 (h)	15b, Yield (%)
1	$AgNO_3$	15	60[b]	13	59[c]
2	$AgClO_4$	12	60[c]	11	58[c]
3	AuCl	6	66[c]	5	63[c]
4	$AuCl_3$	6	63[b]	6	61[c]
5	$Pd(PPh_3)_4$	16	51[c]	13	49[b]
6	$PtCl_2$	18	54[b]	16	48[c]
7	$CuCl_2$	17	50[c]	17	52[b]
8	$NiCl_2$	24	44[c]	21	38[b]
9	$SnCl_2$	24	39[b]	25	32[c]
10	$AlCl_3$	24	40[b]	22	40[c]
11	$PdCl_2$	20	39[b]	17	35[c]
12	$ZnCl_2$	24	34[c]	20	30[b]
13	CuCl	42	26[c]	37	24[b]
14	CuBr	49	21[b]	45	23[c]
15	CuI	54	23[b]	55	19[c]

[a] On the average; [b] Yields determined by ^1H- and ^{31}P-NMR analysis; [c] Isolated yield by chromatographic purification on silica gel.

The results are explicit enough – a catalytic 6-*endo-trig* cycloisomerization occurs and the hydroxy group participates as an internal nucleophile to give the 4-phosphoryl-3,6-dihydro-2*H*-pyrans **15** in good yields.

CONCLUSIONS

In conclusion, a couple of new phosphorylated -hydroxyallenes were synthesized by a convenient, efficient, atom economical and regioselective method. Reaction of the phosphorylated β-hydroxyallenes with protected or unprotected hydroxy groups with different electrophilic reagents occurs via 5-*endo-trig* cyclization. Treatment of the 1-(2-hydroxypropyl)-allenephosphonates with electrophiles gives the 2-methoxy-2-oxo-2,5-dihydro-1,2-oxaphospholes as a

result of the neighboring group participation of the phosphonate group in the cyclization, while the hept-1*E*-en-1-yl phosphine oxides were prepared as mixtures with the 2,5-dihydro-1,2-oxaphosphol-2-ium halides in a ratio of about 1:2 by chemo-, regio-, and stereo-selective electrophilic addition to the C^2-C^3-double bond in the allene moiety and subsequent concurrent attack of the external (chloride anion) and internal (phosphine oxide group) nucleophiles. We have developed a coinage metal-catalyzed cycloisomerization reaction of the phosphorylated -hydroxyallenes, which provides an efficient route to the 4-phosphoryl-3,6-dihydro-2*H*-pyrans which are produced as a result of the participation of the neighboring hydroxy group as an internal nucleophile in the cyclization process.

Due to the easy availability of starting materials, the convenient operation and mild conditions, the readily availability of the reagents and catalysts, the good yields and the usefulness of the 2,5-dihydro-1,2-oxaphospholes and the 4-phosphoryl-3,6-dihydro-2*H*-pyrans, the cyclization reactions may show potential and will be useful in organic synthesis as well in their application in target-oriented synthesis. Further investigation on the chemistry of other phosphorylated allenols for the synthesis of different heterocyclic systems is being intensively carried out in our laboratory. Moreover, results of an initial investigation of the biological activity of the compounds prepared were encouraging, and the antibacterial and antifungal activities of selected compounds are now under investigation in our University.

Acknowledgments

Financial support of our work by the Research Fund of the Konstantin Preslavsky University of Shumen (Projects Nos. RD-08-208/2014 and RD-08-248/2015), National Research Fund of Bulgaria (Project No. DRNF-02-13/2009) and Human Resources Development Operational Programme of the European Union (BG051PO001- 3.3.06-0003/2012) is gratefully acknowledged.

References

Aksin-Artok, Ö. and Krause, N. 2011. Combined Rhodium/Gold catalysis: From propargyloxiranes to 2,5-dihydrofurans in one pot. Adv. Synth. Catal. 353: 385–391.

Alabugin, I.V. and Brel, V.K. 1997. Phosphorylated allenes: structure and interaction with electrophilic reagents. Russ. Chem. Rev. 66: 205–224.

Alexakis, A.; Marek, I.; Mangeney, P. and Normant, J.F. 1989. Diastereoselective synthesis of α-allenic alcohols from propargylic epoxides. Tetrahedron Lett. 30: 2387–2390.

Alexakis, A.; Marek, I.; Mangeney, P. and Normant, J.F. 1991. Diastereoselective syn or anti opening of propargylic epoxides. Synthesis of α-allenic alcohols. Tetrahedron 47: 1677–1696.

Angelov, C.M. 1983. Five-membered heterocyclization of phosphorus-containing allenes by their reaction with electrophiles–possibilities and restrictions. Phosphorus Sulfur 1: 177–193.

Aurrecoechea, J.M. and Solay, M. 1995. Stereoselective samarium diiodide-promoted intermolecular coupling of alkynyloxiranes with ketones. Synthesis of 2,3-pentadiene-1,5-diols. Tetrahedron Lett. 36: 2501–2504.

Aurrecoechea, J.M.; Alonso, E. and Solay, M. 1998. Synthesis of allenic diols by samarium diiodide-promoted coupling between alkynyloxiranes and ketones. Tetrahedron 54: 3833–3850.

Back, T.G.; Clary, K.N. and Gao, D. 2010. Cycloadditions and cyclizations of acetylenic, allenic, and conjugated dienyl sulfones. Chem. Rev. 110: 4498–4553.

Baldwin, J.E. 1976. Rules for ring closure. Chem. Commun. 734–736.

Bates, R.W. and Satcharoen, V. 2002. Nucleophilic transition metal based cyclization of allenes. Chem. Soc. Rev. 31: 12–21.

Boldrini, G.P.; Lodi, L.; Tagliavini, E.; Tarasco, C.; TrombinI, C. and Umanl-Ronchi, A. 1987. Synthesis of enantiomerically enriched homoallylic alcohols and of 1,2-dien-1-ols using chiral tin(IV) complexes containing diethyl tartrate as an auxiliary ligand. *J. Org. Chem*. 52: 5447–5452.

Bongers, N. and Krause, N. 2008. Golden opportunities in stereoselective catalysis. Angew. Chem. Int. Ed. 47: 2178–2181.

Brel, V.K. 1999. Synthesis and cyclization of diethylphosphono-substituted α-allenic alcohols to 4-(diethylphosphono)-2,5-dihydrofurans. Synthesis 463–466.

Brel, V.K. 2006. Phosphonoallenes for building organophosphorus derivatives. Heteroatom Chem. 17: 547–556.

Brel, V.K. and Abramkin, E.V. 2002. Cyclization of allenyl phosphonates to 3-chloro-4-(diethylphosphono)-2,5-dihydrofurans induced by $CuCl_2$. Mendeleev Commun. 12: 64–65.

Brel, V.K.; Belsky, V.K.; Stash, A.I.; Zavodnik, V.E. and Stang, P.J. 2005. Synthesis and molecular structure of new unsaturated analogues of nucleotides containing six-membered rings. Eur. *J. Org. Chem*. 512–521.

Cai, B. and Blackburn, G.M. 1997. The syntheses and reactions of 3,4-bisphosphono-1,2,4,5-tetraenes. Synth. Commun. 27: 3943–3949.

Chilot, J.-J.; Doutheau, A. and Gore, J. 1982. Heterocyclisation de diols βγ'-alleniques. Tetrahedron Lett. 23: 4693–4696.

Christov, V.C.; Ismailov, I.E. and Ivanov, I.K.; 2015. Bifunctionalized allenes. Part XVI. Synthesis of 3-phosphoryl-2,5-dihydrofurans by coinage metal-catalyzed cycloisomerization of phosphorylated α-hydroxyallenes. Molecules 20: 7263–7275.

Corey, E.J. and Jones, G.B. 1991. Enantioselective route to α-hydroxy aldehyde and acid derivatives. Tetrahedron Lett. 32: 5713–5716.

Corey, E.J.; Imwinkelried, R.; Pikul, S. and Xiang, Y.B. 1989. Practical enantioselective Diels-Alder and aldol reactions using a new chiral controller system. *J. Am. Chem. Soc*. 111: 5493–5495.

Corey, E.J.; Yu, C.-M. and Lee, D.-H. 1990. Copper catalyzed asymmetric propargylation of aldehydes. *J. Am. Chem. Soc.* 112: 878–879.

Crabbé, P.; Fillion, H.; André, D. and Luche, J.-L. 1979. Efficient homologation of acetylenes to allenes. *J. Chem. Soc. Chem. Commun*. 859–860.

Curfin, M.L. and Okamura, W.H. 1990. Synthetic and kinetic studies of the intramolecular Diels-Alder reactions of cycloalkenylallenylphosphine oxides. *J. Org. Chem*. 55: 5278–5287.

Darcel, C.; Bruneau, C. and Dixneuf, P.H. 1996. Straightforward syntheses of dienyl- and diallenylphosphine oxides from α-allenols. Synthesis 711–714.

De Frutos, O.; and Echavarren, A.M. 1997. An approach to the synthesis of the benzo[b]fluorene core of the kinamycins by an arylalkyne-allene cycloaddition. Tetrahedron Lett. 38: 7941–7943.

Deng, Y.; Jin, X. and Ma, S. 2007. Studies on Highly stereoselective addition-elimination reactions of 3-(methoxycarbonyl)-1,2-allen-4-ols with MX. An efficient synthesis of 3-(methoxycarbonyl)-2-halo-1,3(*Z*)-dienes. *J. Org. Chem*. 72: 5901–5904.

Denmark, S.E. and Marlin, J.E. 1991. Carbanion-accelerated Claisen rearrangements. 7. Phosphine oxide and phosphonate anion stabilizing groups. *J. Org. Chem*. 56: 1003–1013.

Deutsch, C.; Gockel, B.; Hoffmann-Röder, A. and Krause, N. 2007. Golden opportunities in stereoselective catalysis: Optimization of chirality transfer and catalyst efficiency in the Gold-catalyzed cycloisomerization of α-hydroxyallenes to 2,5-dihydrofurans. Synlett 1790–1794.

Deutsch, C.; Lipshutz, B.H. and Krause, N. 2007. Small but effective: Copper hydride catalyzed synthesis of α-hydroxyallenes. Angew. Chem. Int. Ed. 46: 1650–1653.

Enomoto, M.; Katsuki, T. and Yamaguchi, M. 1986. Highly regioselective isomerization of acetylenes to allenes. Tetrahedron Lett. 27: 4599–4600.

Gelin, R.; Gelin, S. and Albrand, M. 1972. Oxymercuration-demercuration d'alcools α-alleniques. Bull. Soc. Chim. Fr. 1946–1949.

Gockel, B. and Krause, N. 2006. Golden times for allenes: Gold-catalyzed cycloisomerization of α-hydroxyallenes to dihydropyrans. Org. Lett. 8: 4485–4488.

Grissom, J.W. and Huang, D. 1995. Low-temperature tandem enyne allene radical cyclizations: Efficient synthesis of 2,3-dihydroindenes from simple enediynes. Angew. Chem. Int. Ed. 34: 2037–2039.

Guo, H.; Qian, R.; Guo, Y. and Ma, S. 2008. Neighboring group participation of phosphine oxide functionality in the highly regio- and stereoselective iodohydroxylation of 1,2-allenylic diphenyl phosphine oxides. *J. Org. Chem*. 73: 7934–7938.

Hashmi, A.S. K. and Hutchings, G.J. 2006. Gold catalysis. Angew. Chem. Int. Ed. 45: 7896–7936.

Hashmi, A.S.K. Synthesis of Allenes in Modern Allene Chemistry; Krause, N., Hashmi, A.S.K., Eds.; Wiley-VCH: Weinheim, Gremany, 2004; Volume 1, pp. 3–50.

Hassan, H.H.A.M. 2007. Recent progress in the chemistry of allenes. Curr. Org. Synth. 4: 413–439.

Hoffman, R.W. and Weldmann, U. 1985. Stereoselective synthesis of alcohols, XIX. The sense of asymmetric induction on addition to α-chiral aldehydes. Chem. Ber. 118: 3966–3979.

Hoffmann-Röder, A. and Krause, N. 2005. The golden gate to catalysis. Org. Biomol. Chem. 3: 387–391.

Hoffman-Roder, A. and Krause, N. 2001. Gold(III) chloride catalyzed cyclization of α-hydroxyallenes to 2,5-dihydrofurans. Org. Lett. 3: 2537–2538.

Ismailov, I.E.; Ivanov, I.K. and Christov, V.C. 2014. Bifunctionalized allenes. Part XIII. A convenient and efficient method for regioselective synthesis of phosphorylated α-hydroxyallenes with protected and unprotected hydroxy group. Molecules 19: 6309–6329.

Ismailov, I.E.; Ivanov, I.K. and Christov, V.C. 2014. Bifunctionalized Allenes. Part XIV. A Convenient and efficient regioselective synthesis of phosphorylated -hydroxyallenes with protected and unprotected hydroxy group. Bulg. Chem. Commun. 46: Special Issue A, 39-46.

Ismailov, I.E.; Ivanov, I.K.; and Christov, V.C. 2014. Bifunctionalized allenes. Part XV. Synthesis of 2,5-dihydro-1,2-oxaphospholes by electrophilic cyclization reaction of phosphorylated α-hydroxyallenes. Molecules 19: 11056–11076.

Kang, S.-K.; Baik, T.-G. and Kulak, A.N. 1999. Palladium(0)-catalyzed coupling cyclization of functionalized allenes with hypervalent iodonium salts. Synlett 324–326.

Kang, S.-K.; Yamaguchi, T.; Pyun, S.-J.; Lee, Y.-T. and Baik, T.-G. 1998. Palladium-catalyzed arylation of α-allenic alcohols with hypervalent iodonium salts: Synthesis of epoxides and diol cyclic carbonates. Tetrahedron Lett. 39: 2127–2130.

Khusainova, N.G. and Pudovik, A.N. 1987. Phosphorylated allenes. Methods of synthesis and properties. Russ. Chem. Rev. 56: 564–578.

Krause, N. and Hoffmann-Röder, A. 2004. Synthesis of allenes with organometallic reagents. Tetrahedron 60: 11671–11694.

Krause, N.; Aksin-Artok, Ö.; Asikainen, M.; Breker, V.; Deutsch, C.; Erdsack, J.; Fan, H.-T.; Gockel, B.; Minkler, S.; Poonoth, M.; Sawama, Yo.; Sawama, Yu.; Sun, T.; Volz, F. and Winter, C. 2012. Combined coinage metal catalysis for the synthesis of bioactive molecules. *J. Organomet. Chem*. 704: 1–8.

Krause, N.; Hoffmann-Röder, A. and Canisius, J. 2002. From amino acids to dihydrofurans: Functionalized allenes in modern organic synthesis. Synthesis 12: 1759–1774.

Kumar, B. and Kumara Swamy, K.C. 2008. The reaction of allenes with phosphorus(III) compounds bearing a P-NH-(t-Bu) group: Isolation of both enantiomers in crystalline form from an achiral system. Tetrahedron Lett. 49: 7135–7138.

Kumar, B.; Chakravarty, M.; Kumar, S.; Sajna, K. and Swamy, K. 2009. Allenylphosphonates with a 1,3,2-dioxaphosphorinane ring: Synthesis, structures, stability and utility. *J. Chem. Sci*. 121: 23–36.

Landor, P.D. The Chemistry of the Allenes; Landor, S.R., Ed.; Academic Press: New York, NY, USA, 1982; Volume 1, pp. 174–178.

Li, J.; Kong, W.; Fu, C. and Ma, S. 2009. An efficient CuCN-catalyzed synthesis of optically active 2,3-allenols from optically active 1-substituted 4-chloro-2-butyn-1-ols. *J. Org. Chem*. 74: 5104–5106.

Li, J.; Zhou, C.; Fu, C. and Ma, S. 2009. Studies on Cu(I)-catalyzed synthesis of simple 3-substituted 1,2-allenes and optically active 2-substituted secondary 2,3-allenols. Tetrahedron 65: 3695–3703.

Ma, S. 2007. Recent advances in the chemistry of allenes. Aldrichim. Acta 40: 91–102.

Ma, S. 2009. Electrophilic addition and cyclization reactions of allenes. Acc. Chem. Res. 42: 1679–1688.

Ma, S. and Gao, W. 2000. Efficient synthesis of 4-(2-alkenyl)-2,5-dihydrofurans via $PdCl_2$-catalyzed coupling-cyclization reaction of 2,3-allenols with allylic halides. Tetrahedron Lett. 41: 8933–8936.

Ma, S. and Gao, W. 2002. Efficient Synthesis of 4-(2'-alkenyl)-2,5-dihydrofurans and 5,6-dihydro-2*H*-pyrans via the Pd-catalyzed cyclizative coupling reaction of 2,3- or 3,4-allenols with allylic halides. *J. Org. Chem*. 67: 6104–6112.

Ma, S.; Hou, H.; Zhao, S. and Wang, G. 2002. Efficient synthesis of optically active 2,3-allenols via the simple CuBr-mediated reaction of optically active propargylic alcohols with paraformaldehyde. Synthesis 1643–1645.

Macomber, R.S. 1977. Phosphorus-containing products from propargyl alcohols and phosphorus trihalides. 5. A stereochemical investigation of the formation and cyclization of allenic phosphonic acids. Preparation of 4-substituted 1,2-oxaphosphol-3-enes. *J. Am. Chem.* Soc. 99: 3072–3075.

Mark, V. The Uncatalyzed Rearrangements of Tervalent Phosphorus Esters in Selective Organic Transformations; Thyagarajan, B.S., Ed.; John Wiley & Sons: New York, NY, USA, 1970; pp. 319–437.

Marshall, J.A. and Pinney, K.G. 1993. Stereoselective synthesis of 2,5-dihydrofurans by sequential SN2' cleavage of alkynyloxiranes and silver(I)-catalyzed cyclization of the allenylcarbinol products. *J. Org. Chem*. 58: 7180–7184.

Marshall, J.A. and Sehon, C.A. 1995. Synthesis of furans and 2,5-dihydrofurans by Ag(I)-catalyzed isomerization of allenones, akynyl allylic alcohols, and allenyl carbinols. *J. Org. Chem*. 60: 5966–5968.

Marshall, J.A. and Tang, Y. 1993. Allene-directed diastereoselection. Additions to chiral allenyl aldehydes and ketones. J. Org. Chem. 58: 3233–3234.

Marshall, J.A.; Yu, R.H. and Perkins, J.F. 1995. Diastereo- and enantioselective synthesis of allenylcarbinols through SE2' addition of transient nonracemic propargylic stannanes to aldehydes. *J. Org. Chem*. 60: 5550–5555.

Miyashita, M.; Yoshikoshi, A. and Griecolb, P.A. 1977. Pyridinium p-toluenesulfonate. A mild and efficient catalyst for the tetrahydropyranylation of alcohols. *J. Org. Chem*. 42: 3772-3774.

Nicolaou, K.C.; Maligres, P.; Shin, J.; de Leon, E. and Rideout, D. 1990. DNA-cleavage and antitumor activity of designed molecules with conjugated phosphine oxide-allene-ene-yne functionalities. *J. Am. Chem. Soc.* 112: 7825–7826.

Nikam, S.S.; Chu, K.H. and Wang, K.K. 1986. The cyclization of trimethylsilyl-substituted α-allenic alcohols to 3-(trimethylsilyl)-2,5-dihydrofurans and their facile autoxidation to 3-(trimethylsilyl)furans or 4-(trimethylsilyl)-2(5*H*)-furanones. *J. Org. Chem*. 51: 745–747.

Olsson, L.-I. and Claesson, A. 1979. Synthesis of 2,5-dihydrofurans and 5,6-dihydro-2*H*-pyrans by silver(I)-catalyzed cyclization of allenic alcohols. Synthesis 743–745.

Oroshnik, W.; Mebane, A. and Karmas, G. 1953. Synthesis of polyenes. III. Prototropic rearrangements in β-ionols and related compounds. *J. Am. Chem. Soc.* 75: 1050–1058.

Phadtare, S. and Zemlicka, J. 1989. Nucleic acid derived allenols: Unusual analogues of nucleosides with antiretroviral activity. *J. Am. Chem. Soc*. 111: 5925–5931.

Pinho e Melo, T.M.V.D. 2009. Allenes as dipolarophiles and 1,3-dipole precursors: Synthesis of carbocyclic and heterocyclic compounds. Curr. Org. Chem. 13: 1406–1431.

Poonoth, M. and Krause, N. 2011. Cycloisomerization of bifunctionalized Allenes: Synthesis of 3(2H)-furanones in water. *J. Org. Chem*. 76: 1934–1936.

Robertson, D.N. 1960. Adducts of tert-alcohols containing an ethynyl group with dihydropyran. Potentially useful intermediates. *J. Org. Chem*. 25: 931-932.

Saalfrank, R.W. and Lurz, C.-J. Methoden der Organischen Chemie (Houben Weyl); Kropf, H., Scheumann, E., Eds.; Thieme: Stuttgart, Gremany, 1993; pp. 2959–3102. (In German).

Saalfrank, R.W.; Haubner, M.; Deutscher, C.; Bauer, U. 1999. Yne-allenes from 1-bromoallenes and trimethylstannylacetylenes via palladium-mediated C–C coupling reactions. *Eur. J. Org. Chem*. 2367–2372.

Schmittel, M.; Steffen, J.-P.; Maywald, M.; Engels, B.; Helten, H. and Musch, P. 2001. Ring size effects in the C^2–C^6 biradical cyclisation of enyne–allenes and the relevance for neocarzinostatin. *J. Chem. Soc. Perkin Trans.* 2 1331-1339.

Srinivas, V.; Sajna, K.V. and Kumara Swamy, K.C. 2011. $Zn(OTf)_2$ catalyzed addition-cyclization reaction of allenylphosphine oxides with propargyl alcohol-unexpected formation of 2,5-dimethylenetetrahydrofurans and 2-substituted furans. Tetrahedron Lett. 52: 5323–5326.

Trost, B.M. and Pinkerton, A.B. 1999. A Ruthenium-catalyzed alkylative cycloetherification. *J. Am. Chem. Soc*. 121: 10842–10843.

Uemura, K.; Shiraishi, D.; Noziri, M. and Inoue, Y. 1999. Preparation of cyclic carbonates from alkadienols, CO_2, and aryl or vinylic halides catalyzed by a palladium complex. Bull. Chem. Soc. Jpn. 72: 1063–1069.

Ye, J.; Li, S.; Chen, B.; Fan, W.; Kuang, J.; Liu, J.; Liu, Y.; Miao, B.; Wan, B. and Wang, Y. 2012. Catalytic asymmetric synthesis of optically active allenes from terminal alkynes. Org. Lett. 14: 1346–1349.

Yoneda, E.; Kaneko, T.; Zhang, S.-W.; Onitsuka, K. and Takahashi, S. 2000. Ruthenium-catalyzed cyclic carbonylation of allenyl alcohols. Selective synthesis of γ- and δ-lactones. Org. Lett. 2: 441–443.

Zimmer, R.; Dinesh, C.U.; Nadanan, E. and Hhan, F.A. 2000. Palladium-catalyzed reactions of allenes. Chem. Rev. 100: 3067–3125.

How to cite this article:

Christov. VC *et al*, Bifunctionalized allenes. Part XVII. Synthesis of 2,5-Dihydro-1,2-Oxaphospholes and 4-Phosphoryl-3,6-Dihydro-2*H*-Pyrans by Electrophilic Cyclization and Coinage Metal-Catalyzed Cycloisomerization of Phosphorylated β-Hydroxyallenes. *International Journal of Recent Scientific Research Vol. 6, Issue, 6, pp.4526-4537, June, 2015*

****