Reaction of 1-(2-hydroxyphenyl)-3-phenylpropane-1,3-dione with some phosphorus halides: A simple synthesis of novel 1,2-benzoxaphosphinines

Tarik E. Ali\textsuperscript{a,b}, Mohammed A. Assiri\textsuperscript{a}, and Noha M. Hassanin\textsuperscript{b}

\textsuperscript{a}Department of Chemistry, Faculty of Science, King Khalid University, Abha, Saudi Arabia; \textsuperscript{b}Department of Chemistry, Faculty of Education, Ain Shams University, Cairo, Egypt

ABSTRACT
A simple method for design of some novel 1,2-benzoxaphosphinines 2–9, was achieved. The methodology depended on cyclization of 1-(2-hydroxy-phenyl)-3-phenylpropane-1,3-dione (1) as starting material with some phosphorus halides in dry solvent in the presence of a base. Reaction of the substrate 1 with some phosphorus halides, such as P,P-dichlorophenylphosphine, phenyl phosphonic dichloride, phenyl phosphorodichloridate, and phosphorus oxychloride in dry toluene containing triethylamine led to a predominant formation of 3-benzoyl-4-hydroxy-2\(H\)-1,2-benzoxaphosphinines 2–5, respectively. Under the same reaction conditions, the molecular structures of type 3-benzoyl-4\(H\)-1,2-benzoxaphosphinin-4-ones 6 and 7 were isolated by treatment of the substrate 1 with phosphorus pentachloride and phosphorus tribromide, respectively. In addition, the interesting 4-(1-phenyl-ethanoyl)-1,2,\(\mu\)-benzoxaphosphinines 8 and 9 were obtained by treatment of compound 1 with acetonyl and benzyl triphenylphosphonium chlorides, respectively, in dry dioxane and sodium hydride. The chemical structures of the title compounds were established by elemental analysis and spectral tools.

ARTICLE HISTORY
Received 27 May 2022

KEYWORDS
1; 2-Benzoxaphosphinine; 3-phenylpropanedione; phosphorus halides

CONTACT Tarik E. Ali tarik_elsayed1975@yahoo.com Chemistry, Faculty of Education, Ain Shams University, Gesr E-Swis, Cairo 11566, Egypt

Supplemental data for this article can be accessed online at https://doi.org/10.1080/00397911.2022.2146514

© 2022 Taylor & Francis Group, LLC
Introduction

In recent years, organophosphorus compounds have become extremely important in both organic synthetic chemistry and pharmaceutical applications. This is because of their important biological activities.\(^1\)–\(^7\) 1,2-Benzoxaphosphinin-2-oxides are phosphorus analogs of coumarins that are physiologically active \(\alpha\)-pyrone derivatives.\(^8\) These phosphorus compounds are endowed with unique biological properties such as antimicrobial, inhibitory activity against SHP-1 and potent inhibitors for pancreatic cholesterol esterase.\(^9\)–\(^12\) There are known ways to synthesize the 1,2-benzoxaphosphinine system in the literature. The main route involves treatment of 2,2,2-trihalobenzo-1,3,2-dioxaphospholes with terminal acetylenes\(^13\)–\(^20\) as well as cyclization of dialkyl[2-(5-chloro-2-hydroxyphenyl)-2-phenylethenyl]phosphine oxides under the action of thionyl chloride.\(^21\) In addition, there are other synthetic methods for construction of 1,2-benzoxaphosphinine systems. These methods depend on Knoevenagel reaction of salicylaldehydes with phosphonoacetates,\(^22\),\(^23\) and recyclization of dialkyl 2-methyl-4-oxo-4\(^H\)-chromen-3-ylphosphonate with amines.\(^8\) Moreover, some \(\omega\)-haloalkyl phosphonates can react with methyl salicylate under basic conditions to give the corresponding 1,2-benzoxaphosphorin.\(^24\)

Therefore, in the context of our ongoing studies concerning the synthesis of novel bioactive phosphorus heterocycles,\(^25\)–\(^29\) this work reports for the first time, a facile and inexpensive method for the synthesis of a novel class of 1,2-benzoxaphosphinine systems. The suggested methodology depends on cyclocondensation of 1-(2-hydroxyphenyl)-3-phenylpropane-1,3-dione (1) with some phosphorus halides in dry solvent with the presence of a base.

Results and discussion

The reaction of 1-(2-hydroxyphenyl)-3-phenylpropane-1,3-dione (1)\(^30\) with three types of phenyl phosphorus halides, namely dichlorophenylphosphine, phenyl phosphonic dichloride, and phenyl phosphorodichloridate in dry toluene containing triethylamine as a base, was studied. These reactions afforded the 3-benzoyl-4-hydroxy-2-phenyl-2\(^H\)-1,2-benzoxaphosphinine (2), 3-benzoyl-4-hydroxy-2-oxido-2-phenyl-2\(^H\)-1,2-benzoxaphosphinine (3) and 3-benzoyl-4-hydroxy-2-oxido-2-phenoxo-2\(^H\)-1,2-benzoxaphosphinine (4), respectively, in moderate yields (Scheme 1). The moderate yields due to decreasing of electrophilicity character of the phosphorus atom in the used phosphorus halides as following: PhP(Cl\(_2\))=O > PhOP(Cl\(_2\))=O > PhPCl\(_2\).\(^31\) These reactions started initially at 10 °C for 30 min then heated for 8–12 h at 80–90 °C. The plausible mechanism for these reactions was proposed by a nucleophilic attack of OH group in substrate 1 at the phosphorus atom of phosphorus dichloride reagents forming the salt A. By helping of triethylamine, the latter salt A was converted into the intermediate B. Upon heating of the mixture reaction, another nucleophilic attack was occurred by the negative charge of the activated methylene group at the phosphorus atom in the intermediate C. By releasing of the chloride anion, the intermediate C may give the cyclic intermediate D that was rearranged through keto-enol tautomerism into the isolated forms of the products 2–4 (Scheme 1). In this condensation, the formation of product 3 was selected as a
model reaction to optimize the best reaction conditions. Toluene as a nonpolar solvent was found to be an ideal solvent (72% yield) than benzene (41% yield) and THF (45% yield) since the reactants readily dissolved in it. In addition, the boiling point of toluene is high (110°C) that gives the required energy for the reactions to complete in a suitable time. The use of triethylamine as aprotic base in toluene for these reactions is effective than other bases, such as pyridine (32% yield), 1-methylpiperidine (45% yield), and DBU (48% yield), which gave low yields. Triethylamine readily scavenges the liberated hydrogen chloride forming its salt and thereby drives the reaction to be completed.

On the other hand, the product 3 was also obtained through oxidation of compound 2 by hydrogen peroxide in dry tetrahydrofuran according to the reported method and mechanism in the literature (Scheme 2).[^32][^33]

Structures of the synthesized compounds 2–4 were confirmed by elemental analysis and mass spectrometry as well as IR, ¹H-, ¹³C-, and ³¹P-NMR spectra. The infrared spectra showed absorption bands for OH stretching frequencies in the region 3390–3008 cm⁻¹. The carbonyl groups of products 2–4 exhibited absorption bands at 1660, 1687, and 1646 cm⁻¹, respectively, in a relatively low region than normal due to the effect of aromatic phenyl rings attached to them.[^34] The ¹H- and ¹³C-NMR spectra confirmed the absence of methylene group. However, the ¹H-NMR spectra displayed characteristic signals for OH groups at position 4 in the regions δ 12.15–12.92 ppm. The aromatic protons appeared in the expected regions at δ
The $^{13}$C-NMR spectra for the products 2–4 recorded all the carbon atoms at the expected values. For example, the carbonyl carbon atoms were displayed at $\delta$ 166.6–172.3 ppm. Further, the $^{31}$P-NMR spectrum of compound 3 recorded a singlet at $\delta$ 38.42 ppm. The EI mass spectra of compounds 2–4 were recorded and interpreted in support of the proposed structures.

The above-mentioned effective synthesis of novel 1,2-benzoxaphosphinine compounds motivated us to extend the scope of substrate 1 to react with other examples of phosphorus halides. Thus, reaction of substrate 1 with phosphorus oxychloride under the same reaction conditions gave 3-benzoyl-2,4-dihydroxy-2-oxido-2H-1,2-benzoxaphosphinine (5) (Scheme 3), whereas its treatment with phosphorus pentachloride led to the formation of 3-benzoyl-2,2-dichloro-4H-1,2$\lambda^5$-benzoxaphosphinin-4-one (6) (Scheme 3). The product 5 was also obtained by warming of compound 6 in aqueous sodium carbonate for 1 h (Scheme 3). Similarly, the reaction of phosphorus tribromide with
compound 1 in dry toluene containing three equivalent amounts of triethylamine produced the interesting novel 3-benzoyl-4H-1,2-benzoxaphosphinin-4-one (7) in good yield (Scheme 3). The synthesis of both products 6 and 7 is similar to the above-mentioned products 2–4. The pathways suggested the cyclocondensation of the substrate 1 with the phosphorus halides by helping of triethylamine. Moreover, the product 5 was formed by spontaneously air hydrolysis of the nonisolable intermediate F or intended hydrolysis for the product 6, followed by rearrangement through keto-enol tautomerism (Scheme 3).

Structures of the latter products 5–7 were deduced by the spectral and analytical tools. For example, the IR spectrum of compound 7 showed two characteristic carbonyl groups at 1694 (benzoyl) and 1649 (C=O) cm⁻¹. Its ¹H-NMR spectrum displayed multiplet signals for the aromatic protons between δ 7.48 and 8.10 ppm, while its ³¹P-NMR spectrum exhibited a singlet signal at δ 210.02 ppm. Moreover, its ¹³C-NMR spectrum revealed two specific signals at δ 163.1 and 177.6 ppm for the two carbonyl groups. Furthermore, its molecular ion peak M⁺ was recorded at m/z 268 in the mass spectrometry.

In the same way, the behavior of compound 1 toward two examples of the phosphonium salts was investigated. The substrate 1 was treated with acetonyl triphenylphosphonium bromide and benzyl triphenylphosphonium chloride. Both reactions were performed in dry dioxane containing sodium hydride as a base. The reaction mixtures were heated under reflux for 10-12 hours to give 4-(1-phenylethanoyl)-3-acetyl-2,2,2-triphenyl-2H-1,2λ⁵-benzoxaphosphinine (8) and 4-(1-phenylethanoyl)-2,2,2,3-tetraphenyl-2H-1,2λ⁵-benzoxaphosphinine (9), respectively (Scheme 4). Because the

![Scheme 4. Reaction of the substrate 1 with acetonyl triphenylphosphonium bromide and benzyl triphenylphosphonium chloride.](image-url)
reactants are more easily soluble in dioxane than in toluene, the yield products were higher. In addition, sodium hydride caused good yield than triethylamine. The plausible mechanism for the formation of both products 8 and 9 was predicted as removal of hydrogen halide by a nucleophilic attack of OH group in substrate 1 at the phosphorus atom of forming the nonisolable intermediate K. Then, the activated methylene -CH2P(Ph)3- in the intermediate L condensed with the carbonyl group with concomitant loss of a molecule of water through the intermediate M (Scheme 4). The IR spectra of both products 8 and 9 showed the characteristic C=O benzoyl at 1702 and 1765 cm⁻¹, respectively. Their ¹H-NMR spectra displayed the aromatic protons as multiplets in the region δ 6.97–8.18 ppm. Also, the CH₂ protons in both compounds were resonated as doublets at δ 5.72 (J = 16 Hz) and 5.22 (J = 14.6 Hz) ppm, respectively, for their homotropic effect.[35] The ¹³C-NMR spectra for both products displayed the aromatic carbons in the expected region. The CH₂ carbon atoms were observed as doublets at δ 38.3 (J = 58 Hz) and 50.0 (J = 56 Hz) ppm. The C=O benzoyl was observed around δ 159.3 ppm. The C–3 carbon atom in each product which was directly linked to phosphorus atom appeared as a doublet in the region δ 129.4–128.5 (JPC = 86–85 Hz). The ³¹P-NMR chemical shift of compound 9 appeared at δ 24.31 ppm. Finally, the mass spectra of 8 and 9 supported their formation, although they did not show the molecular ion peaks, indicating the fragile nature of these compounds. Thus, the mass spectrum of 8 showed the highest value peak at m/z 463 (M⁺–Ph, 7%), while product 9 recorded the highest peak at m/z 497 (M⁺–Ph, 12%).[36]

Experimental

The melting points were determined in an open capillary tube on a digital Stuart SMP-3 apparatus. Infrared spectra were measured on FT-IR (Nicolet IS10) spectrophotometer using KBr disks. The ¹H- and ¹³C-NMR spectra were measured on Gemini-300BB spectrometer (400 and 100 MHz), using DMSO-d₆ as a solvent and TMS (δ) as an internal standard. ³¹P-NMR spectra were measured on a Bruker (162 MHz) spectrophotometer using DMSO-d₆ as a solvent, TMS as an internal standard and 85% H₃PO₄ as an external reference. Mass spectra were recorded on direct probe controller inlet part to single quadrupole mass analyzer in (Thermo-Scientific GCMS). Elemental microanalysis was performed Perkin-Elmer 2400II at the Chemical War department, Ministry of Defense. The purity of the synthesized compounds was checked by thin-layer chromatography (TLC) and elemental microanalysis.

General method for reaction substrate 1 with phenyl phosphorus halides: Synthesis of 2-aryl-3-benzoyl-4-hydroxy-2H-1,2-benzoxaphosphinines 2–4

P,P-Dichlorophenylphosphine, phenyl phosphonic dichloride, and phenyl phosphorodichloridate (5 mmol) was added individually to a solution of compound 1 (5 mmol, 1.20 g) in dry toluene (30 mL) in the presence of triethylamine (10 mmol, 1.4 mL) as a base, under stirring for 30 min at 10 °C then heated under reflux for 8–12 h. The formed solids were filtered off, washed with water and crystallized from diluted EtOH.
3-Benzoyl-4-hydroxy-2-phenyl-2H-1,2-benzoxaphosphinine (2)

Orange solid in 59% yield; mp 226–228°C; IR (KBr), ν 3390 (OH), 3057 (C–HAr), 1660 (C–O), 1619, 1591 (C–C), 1024 (O–C); ¹H-NMR (400 MHz, DMSO-d₆) δ 7.44 (t, 1H, J = 7.6 Hz, H–6), 7.55–7.70 (m, 6H, Ph–H), 7.79 (d, 1H, J = 6.8 Hz, H–5), 8.12 (d, 1H, J = 8.0 Hz, H–5), 8.16 (d, 2H, J = 7.2 Hz, Ph–H), 12.63 (br, 1H, OH); ¹³C-NMR (100 MHz, DMSO-d₆) δ 117.3 (C–8), 119.5 (d, J = 97 Hz, C–1”), 122.1 (C–4’), 127.3 (C–4a), 128.2 (C–3’,5’), 128.5 (C–5), 129.3 (d, J = 132 Hz, C–3), 129.4 (C–2’,6’), 130.5 (C–3”,5”), 131.3 (C–1’), 132.2 (C–6), 133.2 (C–2”,6”), 133.5 (C–7), 137.3 (C–4”), 156.9 (C–8a), 159.5 (C–4), 166.6 (C=O); MS m/z (%) 346 (M⁺, 2%). Anal. Calcd for C₂₁H₁₅O₃P (346.33): C, 72.83; H, 4.37%. Found: C, 72.51; H, 4.09%.

Conclusions

In summary, we have suggested a novel method to synthesize 2-aryl-3-benzoyl-4-hydroxy-2H-1,2-benzoxaphosphinines, 3-benzoyl-4H-1,2-benzoxaphosphinin-4-ones and 4-(1-phenylethanoyl)-1,2,₅-benzoxaphosphinines. The method suggested reaction of 1-(2-hydroxyphenyl)-3-phenylpropane-1,3-dione with different examples of phosphorus halides and phosphonium salts in dry solvent in the presence of a base. This method is facile and appears to be effective to construct this novel class of phosphorus compounds that were in good purity and easily work up.

Acknowledgments

The authors extend their appreciation to the Deanship of Scientific Research at King Khalid University for funding this work through large research groups program under grant number RGP.2/8/43.

Funding

This work was supported by Deanship of Scientific Research at King Khalid University.

References

[1] Gubaidullin, A. T.; Mironov, V. F.; Burnaeva, L. M.; Litvinov, I. A.; Dobrynin, A. B.; Goryunov, E. I.; Ivkova, G. A.; Konovalova, I. V.; Maistryukova, T. A. Synthesis and Comparative Analysis of the Steric and Supramolecular Structures of Diastereomers of 4,4-Bis(Trifluoromethyl)-2-(Fluoroalkoxy)-6,7-Benzo-1,3,2,₅-Dioxaphosphepin-5-One 2-Oxides. Russ. J. Gen. Chem. 2004, 74, 6, 842–892. DOI: 10.1021/jm200587f.

[2] Mucha, A.; Kafarski, P.; Berlicki, L. Remarkable Potential of the α-Amino-Phosphonate/Phosphinate Structural Motif in Medicinal Chemistry. J. Med. Chem. 2011, 54, 5955–5980. DOI: 10.1021/jm200587f.

[3] Fañanas-Mastral, M.; Feringa, B. L. Copper-Catalyzed Synthesis of Mixed Alkyl Aryl Phosphonates. J. Am. Chem. Soc. 2014, 136, 9894–9897. DOI: 10.1021/ja505281v.

[4] Katagi, M. S.; Mamledesai, S.; Bolakatti, G.; Fernandes, J.; Ml, S.; Tari, P. Design, Synthesis, and Characterization of Novel Class of 2-Quinolon-3-Oxime Reactivators for Acetylcholinesterase Inhibited by Organophosphorus Compounds. Chem. Data Collect. 2020, 30, 100560. DOI: 10.1016/j.cdc.2020.100560.
Elkolli, M.; Chafai, N.; Chafaa, S.; Kadi, I.; Bensouici, C.; Hellal, A. New Phosphinic and Phosphonic Acids: Synthesis, Antidiabetic, anti-Alzheimer, Antioxidant Activity, DFT Study and SARS-CoV-2 Inhibition. *J. Mol. Struct.* 2022, 1268, 133701. DOI: 10.1016/j.molstruc.2022.133701.

Abd-El-Maksoud, M. A.; El-Hussieny, M.; Awad, H. M.; Mossa, A.-T. H.; Soliman, F. M. Chemistry of Phosphorus Ylides. Part 47. Synthesis of Organophosphorus and Selenium Pyrazolone Derivatives, Their Antioxidant Activity, and Cytotoxicity against MCF7 and HepG2. *Russ. J. Gen. Chem.* 2020, 90, 2356–2364. DOI: 10.1134/S1070363220120208.

Sankar, V.; Cheeran, V.; Ganesh, M. R.; Sivakumar, B. Synthesis, Antimicrobial, and Anticancer Activity of 1,2-Substituted 2,3-Dihydro-1H-Benzo[4,5]imidazo[1,2-c][1,3,2] Diazaphosphol-1-Oxides. *Pharm. Chem. J.* 2020, 54, 827–833. DOI: 10.1007/s11094-020-02282-z.

Abd-El-Maksoud, M. A.; El-Hussieny, M.; Awad, H. M.; Mossa, A.-T. H.; Soliman, F. M. Chemistry of Phosphorus Ylides. Part 47. Synthesis of Organophosphorus and Selenium Pyrazolone Derivatives, Their Antioxidant Activity, and Cytotoxicity against MCF7 and HepG2. *Russ. J. Gen. Chem.* 2020, 90, 2356–2364. DOI: 10.1134/S1070363220120208.

Abd-El-Maksoud, M. A.; El-Hussieny, M.; Awad, H. M.; Mossa, A.-T. H.; Soliman, F. M. Chemistry of Phosphorus Ylides. Part 47. Synthesis of Organophosphorus and Selenium Pyrazolone Derivatives, Their Antioxidant Activity, and Cytotoxicity against MCF7 and HepG2. *Russ. J. Gen. Chem.* 2020, 90, 2356–2364. DOI: 10.1134/S1070363220120208.

Li, X.; Zhang, D.; Pang, H.; Shen, F.; Fu, H.; Jiang, Y.; Zhao, Y. Synthesis of a Diverse Series of Phosphacoumarins with Biological Activity. *Org. Lett.* 2005, 7, 4919–4922. DOI: 10.1021/ol051871m.

Budzisz, E.; Brzezinska, E.; Malecka, M. Synthesis, Antimicrobial, and Alkylation Properties and Molecular Modelling of Coumarin Derivatives and Their Phosphonic Analogues. *Eur J. Med. Chem.* 2003, 38, 1605–1610. DOI: 10.1016/s0223-5234(03)00086-2.

Varaksina, E. N.; Tatarinov, D. A.; Cherkin, K. Y.; Nemtarev, A. V.; Mironov, V. F.; Efremov, Y. Y.; Konovalov, A. I. Reactions of Phenyleneoxytrihalophosphoranes with Acetylenes: VII. Reaction of 2,2,2-Trichloro-4-Fluoro-1,3,2\(^3\)k5-Benzodioxaphosphole with Phenylacetylene. *Russ. J. Org. Chem.* 2004, 40, 1798–1803. DOI: 10.1007/s11178-005-0102-5.

Nemtarev, A. V.; Baranov, D. S.; Mironov, V. F.; Aniskin, A. S.; Nenchev, N. M.; Musin, R. S.; Litvinov, I. A.; Konovalov, A. I. Reaction of Phenyleneoxytrihalophosphoranes with Arylacetylenes: VII. Reaction of 2,2,2-Trichloro-4-Fluoro-1,3,2\(^3\)k5-Benzodioxaphosphole with Phenylacetylene. *Russ. J. Org. Chem.* 2006, 42, 391–411. DOI: 10.1134/S1070363206030091.

Varaksina, E. N.; Tatarinov, D. A.; Cherkin, K. Y.; Nemtarev, A. V.; Mironov, V. F.; Konovalov, A. I. Synthesis and Chemical Properties of Benzo[\text{e}]1,2-Oxaphosphorinine Derivatives-Analogues of Coumarins. *Phosphorus Sulf. Silicon Relat. Element* 2008, 188, 566–570. DOI: 10.1080/10426500701764957.

Nemtarev, A. V.; Mironov, V. F.; Bogdanov, A. V.; Cherkasov, V. K.; Druzhkov, N. O.; Gubaidullin, A. T.; Aniskin, A. S.; Mironov, V. F.; Aniskin, A. S.; Makarova, Z. Y.; Mironov, V. F.; Konovalov, A. I. Synthesis and Chemical Properties of Benzo[\text{e}]1,2-Oxaphosphorinine Derivatives-Analogues of Coumarins. *Phosphorus Sulf. Silicon Relat. Element* 2013, 188, 200–204. DOI: 10.1080/10426507.2012.744009.

Nemtarev, A. V.; Mironov, V. F.; Aniskin, A. S.; Baranov, D. S.; Mironova, E. V.; Krivolapov, D. B.; Musin, R. Z.; Vasilevskii, S. F.; Druzhkov, N. O.; Cherkesov, V. K. Reaction of Arylenedioxytrihalophosphoranes with Acetylenes 11. Electronic Effect of the Substituent in Arylacetylene on the Reaction Rate. *Russ. Chem. Bull.* 2013, 62, 55–70. DOI: 10.1007/s11172-013-0008-2.
Nemtarev, A. V.; Nasibullin, I. O.; Fayzullin, R. R.; Grigor'eva, L. R.; Mironov, V. F. 2,2,2-Trichloro-4-Methoxy-1,3,2-Benzodioxaphosphole in the Reactions with Terminal Acetylenes. *Mendeleev Commun.* 2020, 30, 34–37. DOI: 10.1016/j.mencom.2020.01.011.

Nemtarev, A. V.; Mironov, V. F.; Fayzullin, R. R.; Litvinov, I. A.; Musin, R. Z. Reactions of Arylendioxytrihalophosphoranes with Acetylenes: XV.1 Reaction of 2,2,2-Tribromo-4,6-di-Tert-Butylbenzo-1,3,2-Dioxaphospholedioxaphosphole with Pent-1-Yne. *Russ. J. Gen. Chem.* 2018, 88, 2290–2295. DOI: 10.1134/S1070363218110075.

Tatarinov, D. A.; Kuznetsov, D. M.; Mironov, V. F. Intramolecular Cyclization of Dialkyl[2-(5-Chloro-2-Hydroxyphenyl)-2-Phenylethenyl]Phosphine Oxides by the Action of Thionyl Chloride. *Russ. J. Org. Chem.* 2014, 50, 544–546. DOI: 10.1134/S107042801404017.

Bojilova, A.; Nikolova, R.; Ivanov, C.; Rodios, N. A.; Terzis, A.; Raptopoulou, C. P. A. Comparative Study of the Interaction of Salicylaldehydes with Phosphonoacetates under Knoevenagel Reaction Conditions. Synthesis of 1,2-Benzoxaphosphorines and Their Dimers. *Tetrahedron* 1996, 52, 12597–12612. DOI: 10.1016/0040-4020(96)00748-X.

Hassanin, N. M.; Ali, T. E.; El-Shaaer, H. M.; Hassan, M. M.; Fouda, A. M.; Hassanin, N. M. Reaction of 2-Imino-2H-Chromene-3-Carboxamide with Some Phosphorus Esters: Synthesis of Some Novel Chromenes Containing Phosphorus Heterocycles and Phosphonate Groups and Their Antioxidant and Cytotoxicity Properties. *Synth. Commun.* 2019, 49, 2983–2994.

Hassanin, N. M.; Ali, T. E.; El-Shaaer, H. M.; Abdel-Kariem, S. M.; El-Edfawy, S. M.; Abdel-Monem, W. R. Synthesis of Some Novel Antimicrobial and Antioxidant Agents of Functionalized Pyrazolo[4',3':5,6]Pyrazolo[3,2-d][1,2]Azaphospholes and Pyrazolo[4',3':5,6]Pyrazolo[3,2-d][1,3,2]Diazaphosphinines. *Heterocycles* 2020, 100, 1902–1913. DOI: 10.3987/COM-20-14325.

Bakhotmah, D. A.; Ali, T. E. Four-Component Domino Reaction for the Synthesis of Novel 8-Methyl-9-Substituted-2,10-Diaryl-2,3-Dihydro-10H-Pyrano[3,2-c][1,2,4,3]Triazaphospholo[1,5-c]Pyrimidines. *Heterocycles* 2020, 100, 1914–1919.

Ali, T. E.; Assiri, M. A.; El-Shaaer, H. M.; Hassan, M. M.; Fouda, A. M.; Hassanin, N. M. Reaction of 2-Imino-2H-Chromene-3-Carboxamide with Some Phosphorus Esters: Synthesis of Some Novel Chromenes Containing Phosphorus Heterocycles and Phosphonate Groups and Their Antioxidant and Cytotoxicity Properties. *Synth. Commun.* 2021, 51, 2478–2497. DOI: 10.1080/00397911.2021.1939059.

Saxena, S.; Makrandi, J. K.; Grover, S. K. Synthesis of 5- and/or 7-Hydroxyflavones Using a Modified Phase Transfer-Catalysed Baker-Venkataraman Transformation. *Synthesis* 1985, 1985, 697–697. DOI: 10.1055/s-1985-31319.

Kolodiazhna, A. O.; Kolodiazhnyi, O. I. Asymmetric Electrophilic Reactions in Phosphorus Chemistry. *Symmetry* 2020, 12, 108–159. DOI: 10.3390/sym12010108.

Sarıoz, O.; Oznergiz, S.; Saracoglu, H.; Buyukgunor, O. Aminophosphines Derived from N-Phenylpipperazine and N-Ethylpipperazine: Synthesis, Oxidation Reactions, and Molybdenum Complexes. *Heteroat. Chem.* 2011, 22, 679–686. DOI: 10.1002/hc.20733.

Biricik, N.; Durap, F.; Kayan, C.; Gümüş, B.; Gürbüz, N.; Ozdemir, I.; Ang, W. H.; Fei, Z.; Scopelliti, R. Synthesis of New Aminophosphine Complexes and Their Catalytic
Activities in C–C Coupling Reactions. J. Organomet. Chem. 2008, 693, 2693–2699. DOI: 10.1016/j.jorganchem.2008.05.010.

[34] Kanduluru, A. K.; Cirandur, S. R.; Kumar, N. J.; Krishnaiah, M. Synthesis, Spectral, X-Ray Diffraction Analysis and Antimicrobial Activity of 6-Aryloxy/Trichloromethyl/Chloroethoxy -12-Oxodibenzo[d,g][1,3,2]Dioxaphosphocin-6-Oxides. Phosphorus Sulf. Silicon, Relat. Element 2001, 173, 83–104.

[35] Mistry, B. D. A Handbook of Spectroscopic Data, CHEMISTRY (UV, IR, HNMR, CNMR and Mass Spectroscopy); Oxford, Book Company: Jaipur, India, 2009.

[36] Huq, R.; Poë, A. Synthesis and Fragmentation Kinetics of Tetrakis(Triphenylphosphine) Octacarbonyltetracobalt. J. Organomet. Chem. 1982, 226, 277–288. DOI: 10.1016/S0022-328X(00)83410-5.