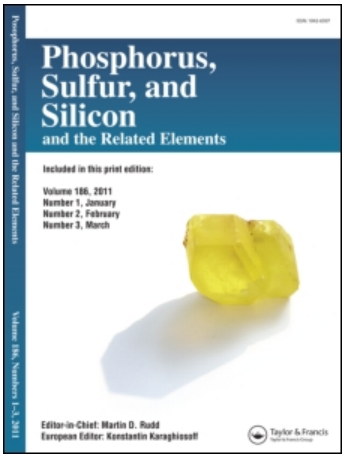

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Three-Component Reaction Between Trivalent Phosphorus, Dimethyl Acetylenedicarboxylate, and Amide Derivatives

Nader Zabarjad-Shiraz,[1] Issa Yavari,[2] Azizolah Biglari,[1] Seyed Ahmad Izadiar,[1] and Hamid-Reza Bijanzadeh[2]
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Stabilized phosphoranes were synthesized from the reaction between dimethyl acetylenedicarboxylate and amide derivatives in the presence of triphenylphosphine. Dimethylurea containing a phosphorus ylide underwent a smooth reaction in boiling toluene to produce hydantoin and oxo-oxazolidin containing stable phosphorus ylides in good yields. Phosphorus ylides derived from $(PhO)_3P$ were not stable and converted to diastereoisomeric phosphonates and phosphorimidate. The nature of the amide derivatives and type of trivalent phosphorus compounds, as well as solvents, determined the distribution of products.

Keywords β-Amidophosphonates; hydantoin; oxo-oxazolidin; stable phosphorus ylides; phosphorimidate; three-component reaction

INTRODUCTION

Organophosphorus compounds are important substrates in the study of biochemical processes.[1,2] For a long time, phosphorus analogues of amino acids, in which the carboxylic acid group is replaced with phosphonate group, $P(O)(OR)_2$, have attracted particular interest in preparing analogues of numerous natural products.[3,4] In this area, β-amido phosphonates as isosteres of β-amino acids occupy an important place and reveal diverse and interesting biological and biochemical properties.[5,6] There are several methods for synthesis of β-amidophosphonates. In most of them, nucleophilic trivalent phosphorus is attached to an electrophilic carbon.[7]

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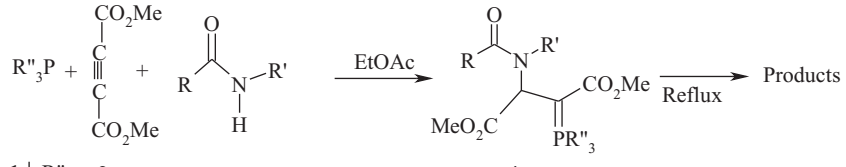
Multicomponent reactions have proven highly efficient in the assembly of diversified molecules.[8] Among the methods available for heterocyclic synthesis, the generation of 1,3-dipolar species and their trapping by suitable π systems leading to five-membered heterocycles occupies a prime position.[9] Zwitterionic species often result from the addition of nucleophiles to activated alkynes. Triphenylphosphine (Ph_3P) has been the most studied nucleophilic species.[10]

Considering these strategies and importance of multicomponent reactions in organic synthesis, as a part of our study on the development of new routes to heterocycles and organophosphorus compounds,[11] we now report on the reaction of $(PhO)_3P$ and/or Ph_3P and dimethyl acetylenedicarboxylate (DMAD, **2**) in the presence of amides and/or *N,N′*-dimethylurea to produce β-amidophosphonates, phosphonates, and stable phosphorus ylides.

RESULTS AND DISCUSSION

The reaction of **2** and *N,N′*-dimethylurea **3a** in the presence of triphenylphosphine **1a** in dried CH_2Cl_2 as solvent and at ambient temperature proceeded to produce directly hydantoin and oxo-oxazolidin containing stable phosphorus ylides **5** and **6** in good yields (Schemes 1 and 2).

Usually the solubility of phosphorus ylides in ethyl acetate is less than in methylenechloride. So for restricting the reaction, ethyl acetate was used as a solvent. The reaction was complete in EtOAc within a few hours. Precipitation of phosphoranes **4** in ethylacetate prevents the reaction proceeding to produce phosphorus ylides **5** and **6**. ^1H, ^{13}C, and ^{31}P NMR spectra of these crude products clearly showed the formation



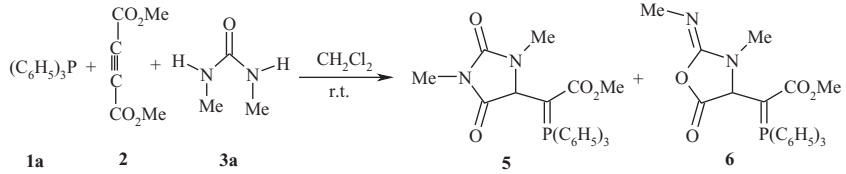
1	R"
a	Ph
b	OPh

2

3	R-	R'
a	MeNH-	CH_3
b	CH_3 -	H
c	Ph-	H
d	N	H

4

SCHEME 1



1a **2** **3a** **5** **6**

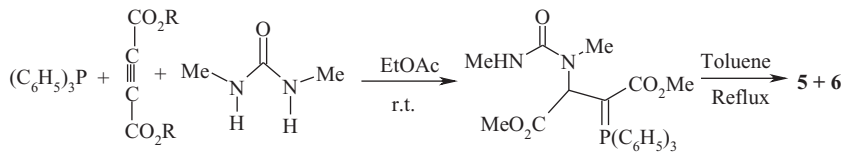
SCHEME 2

of stable phosphorus ylide **4** in good yields (Scheme 2). No product other than **4** could be detected. Phosphorane **4** undergoes a smooth reaction in boiling toluene to produce a mixture of stable phosphorus ylides **5** and **6** (Scheme 3). Ylides **5** and **6** were stable in boiling toluene.

The reaction of **2** with amides **3b–3d** in the presence of **1a** at r.t. in ethyl acetate and/or methylenechloride was complete within a few hours. ^{1}H, ^{13}C, and ^{31}P NMR spectra of these crude products showed the formation of stable phosphorus ylides **7** in good yields (Scheme 4). No other product than **7** could be detected.

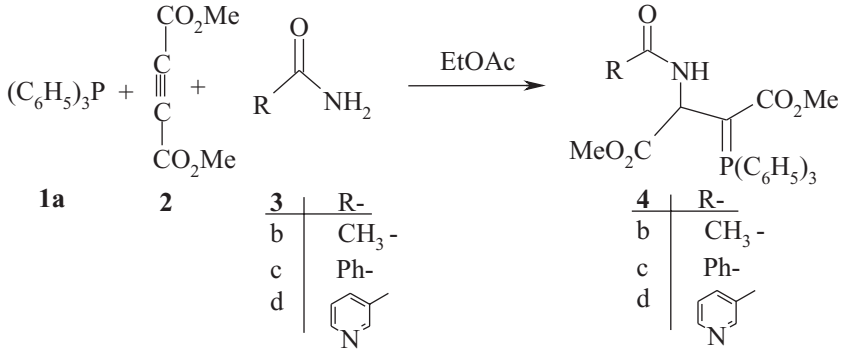
Structures of ylides **4a–4d** were deduced from their IR, ^{1}H, ^{13}C, and ^{31}P NMR spectra. The mass spectra of these compounds display molecular ion peaks. In spite of ylide **4a**, IR do not show N-H stretching absorption for **5** and **6**. ^{1}H and ^{13}C NMR of **4a** showed four peaks for NCH_3 and four peaks for OCH_3 groups. ^{1}H and ^{13}C NMR spectra of **5** and **6** show eight NCH_3 and 4 OCH_3 groups. Resonance of C=N-CH_3 protons of **6** appeared at about 2.3 ppm, which is in downfield in comparasion with resonance of C-N-CH_3 protons of **5** (see the Experimental section). These comparisions indicated that during formation of phosphoranes **5** and **6** from **4a**, H-atom of N-H have been eliminated by one of OMe groups of esters as MeOH (Scheme 3).

^{1}H, ^{13}C, and ^{31}P NMR spectra of ylides **4**, **5**, and **6** are consistent with the presence of two diastereoisomers. The ylide moiety of these compounds is strongly conjugated with the adjacent carbonyl group and rotation around the partial double bond in the (*E*) and (*Z*) geometrical isomers (Scheme 5). Rotation is slow on the NMR time scale at ambient



1a **2** **3a** **4a**

SCHEME 3



SCHEME 4

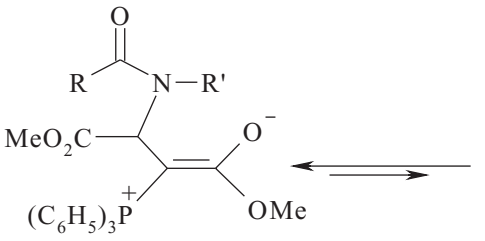
temperature. Selected ^{1}H, ^{13}C, and ^{31}P NMR chemical shifts and coupling constants in the major (M) and minor (m) geometrical isomers of compounds **4**, **5**, and **6** are shown in the Experimental section.

Phosphorus ylides **4b–4d** are stable in boiling toluene, although the ylides derived from the reaction of ureas, instead of amides, led to the production of iminophosphoranes in the same conditions.[12] In the presence of H_2O in boiling toluene, phosphorus ylides were decomposed to triphenylphosphine oxide, $Ph_3P{=}O$.

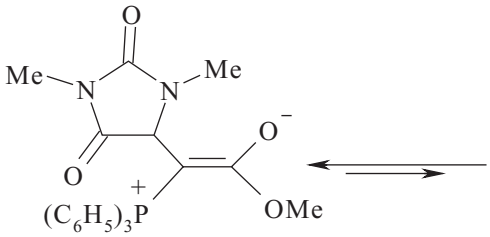
The reaction of **2** with **3a** in the presence of triphenyl phosphite **1b** at r.t. in EtOAc was complete within 1 day. ^{1}H, ^{13}C, and ^{31}P NMR spectra of these crude products clearly showed the formation of phosphonate **7** and phosphorimidate **8** in good yields (Scheme 6). The structures of **7** and **8** were deduced from their IR, ^{1}H, ^{13}C, and ^{31}P NMR spectra. The mass spectra of these compounds display molecular ion peaks.

When the reaction was carried out in EtOAc, ^{31}P NMR showed three peaks for the crude products. The peak at –11.29 ppm is proof for the formation of a phosphorimidate (**8**, $(PhO)_3P{=}N$) structure, and two peaks at 11.98 and 12.67 ppm indicate two phosphonate structures (**7**, C-P(=O)$(OPh)_2$). In dried CH_2Cl_2, the peaks of two phosphonates disappeared in ^{31}P NMR.

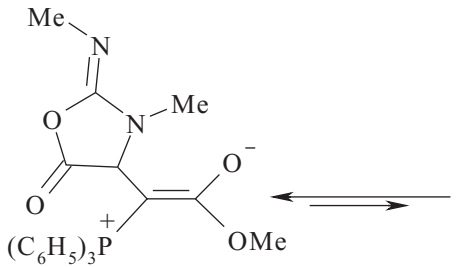
The products were isolated and their structures were elucidated from their NMR spectra. ^{1}H NMR of **8** indicates no signal for methyl groups of esters at 3–4 ppm. This is in agreement with the elimination of dimethyl fumarate and/or dimethyl maleate **18** and the formation of phosphorimidate **8**. ^{13}C and ^{31}P NMR spectra of **8** confirmed the phosphorimidate structure. The ^{1}H NMR spectra of phosphonates **7** display signals for vicinal methine protons at $\delta = 4.22$–5.62 ppm, which appear as doublet of doublets for each isomer with $^{2}J_{PH} = 23.8$, $^{3}J_{PH} = 18.0$,



(*Z*)-**4**; Major (*E*)-**4** ; Minor

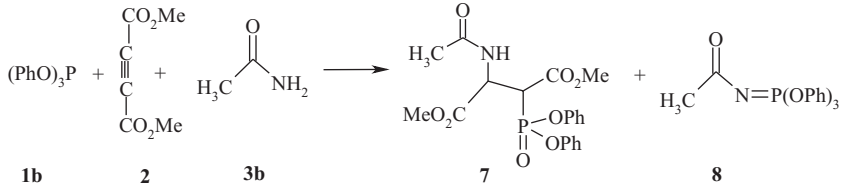


(*Z*)-**5**; Major (*E*)-**5** ; Minor



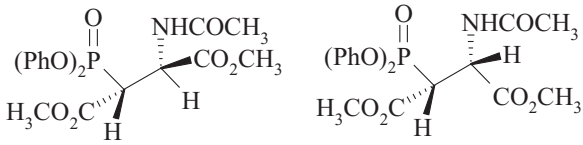
(*Z*)-**6**; Major (*E*)-**6**; Minor

SCHEME 5



1b **2** **3b** **7** **8**

SCHEME 6



7 (2*R*,3*S*) or (2*S*,3*R*) **7** (2*R*,3*R*) or (2*S*,3*S*)

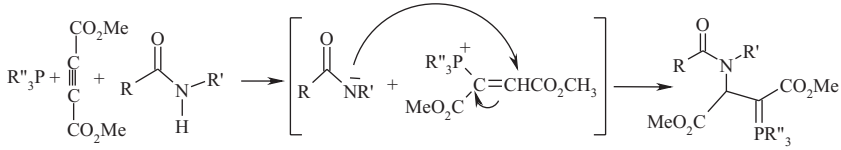
SCHEME 7

and $^{3}J_{HH} = 5.6$ Hz for (2*R*, 3*S*) or (2*S*, 3*R*)-**7** isomer, and $^{2}J_{PH} = 24.0$, $^{3}J_{PH} = 9.0$, and $^{3}J_{HH} = 3.5$ Hz for (2*R*, 3*R*) or (2*S*, 3*S*)-**7** isomer.

The presence of ^{31}P nucleus in compounds **7** contributes in the assignment of signals by coupling with ^{1}H and ^{13}C nuclei (see the Experimental section). The vicinal proton–proton coupling constant ($^{3}J_{HH}$) as a function of the torsion angle can be obtained from the Karplus equation.[13] Typically, $^{3}J_{gauche}$ varies between 1.5–6.0 Hz, and $^{3}J_{anti}$ between 10–16 Hz. The observation of $^{3}J_{HH} = 3.5$ and 5.6 Hz for vicinal protons in the two isomers of **7** indicates a gauche arrangment for this protons.

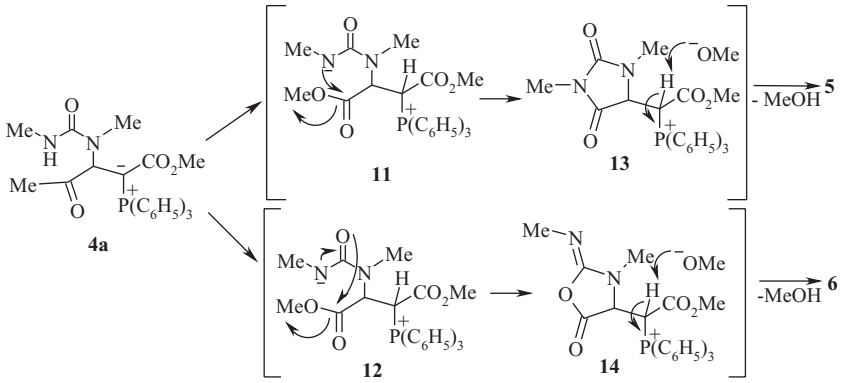
The three-bond carbon-phosphorus coupling, $^{3}J_{PC}$, depends on the configuration, and as expected, transoid couplings are larger than cisoid ones. The Karplus relation can be derived from the data for organophosphorus compounds with tetra- and pentavalent phosphorus.[14] The observation of $^{3}J_{PC} = 4$ Hz is in agreement with a cisoid arrangement of P with C=O of ester. $^{3}J_{PC} = 22$ Hz indicated transoid arrangement, which was in agreement with (2*R*,3*R*) or (2*S*, 3*S*) configuration for another isomer (Scheme 7).

Although we have not yet established the mechanism of the formation of ylides **4**, **5**, and **6,** on the basis of chemistry of trivalent phosphorus nucleophiles,[15] it is reasonable to assume that phosphorus ylides **4** resulted from the initial addition of trivalent phosphorus **1** to the acetylenic ester **2**. Subsequent protonation of the 1:1 adduct was followed by attacking the nitrogen atom of the anion of NH-acid **9** on the vinylphosphonium cations **10** to generate ylides **4** (Scheme 8).



1 **2** **3** **9** **10** **4**

SCHEME 8



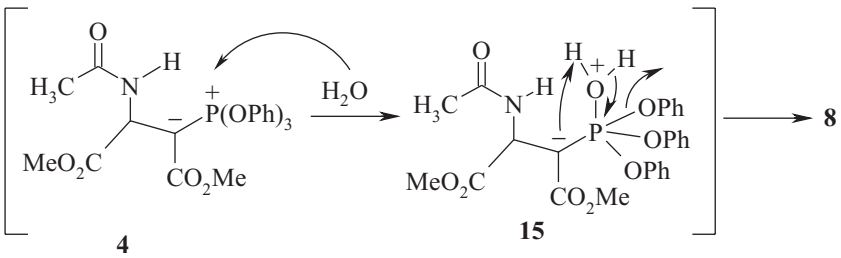
SCHEME 9

In boiling toluene or in dried CH_2Cl_2, the NH-proton of **4a** shifted to the ylinic carbon and formed the 1,6-diionic compounds **11** and **12**. These diionic intermediates underwent an intramolecular nucleophilic substitution by attacking the N^- or O^- nucleophile on the ester groups and led to the formation of intermediates **13** and **14**. Deprotonation by MeO^-, led to the formation of ylides **5** and **6** (Scheme 9).

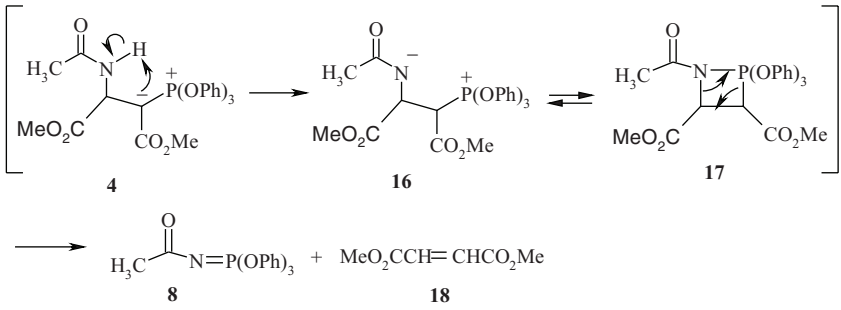
In the presence of moisture, H_2O attacked the phosphorus atom of **4** and produced intermediate **15**, which underwent PhOH elimination to form phosphonate **8** (Scheme 10).

Alternatively in dry solvent, the NH-proton of **4** shifted to the ylidic carbon and formed the betain **16**, which could be in equilibrium with azaphosphetane **17**. Formation of dimethyl fumarate and/or dimethyl maleate **18** confirmed the proposed mechanism (Scheme 11).

In conclusion, the present method features the advantages that the reaction can be performed under neutral conditions, and the starting materials and reagents can be mixed without any modifications.



SCHEME 10



SCHEME 11

Phosphorus ylides can be considered as potentially useful synthetic intermediates.

Phosphorus ylides derived from triphenylphosphites are not stable and undergo reactions to produce phosphonates and phosphorimidates. The presence or absence of H_2O plays an important role in formation of phosphonates and/or phosphorimidates.

Phosphorus ylides containing additional reactive functional groups, such as N-H, are potentially able to undergo further intramolecular reaction to produce other compounds.

Although three component reactions between trivalent phosphorus, acetylenic esters, and N-H acids are well studied, the prediction of the final product is complicated, and should be considered by attention to the solvent, temperature, presence or absence of moisture, and type of solvent, as well as the functionality of starting materials.

The procedure described here provides an acceptable method for preparation of phosphorus ylides, phosphorimidates, and phosphonates as well as some heterocycle-containing phosphoranes.

EXPERIMENTAL

Melting points were measured on an Electrothermal 9100 apparatus. Elemental analyses for C, H, and N were performed using a Heraeus CHN-O-Rapid analyzer. These data were in good agreement with the calculated values. IR spectra were measured on a Shimadzu IR 460 spectrometer. ^1H and ^{13}C NMR spectra were measured with Bruker DRX-500 Avance spectrometer at 500.1 MHz and 125.8 MHz, respectively. Mass spectra were recorded with a Finnigan-Matt 8430 mass spectrometer operating at an ionization potential of 70 eV. Triphenylphosphine, triphenylphosphite, *N,N′*-dimethylurea, DMAD, and

amides were purchased from Fluka (Buchs, Switzerland) and were used without further purification.

Typical Process for the Preparation of Dimethyl 2-(1,3-dimethyl-ureido)-3-triphenylphosphanylidene) succinate 4a

To a magnetically stirred mixture of *N,N′*-dimethylurea (0.24 g, 2 mmol) and triphenylphosphine (0.52 g, 2 mmol) in EtOAc (10 mL), a solution of DMAD (0.14 g, 2 mmol) in EtOAc (3 mL) was added dropwise. The solution was stirred at r.t. for 24 h. The solvent was removed under reduced pressure, and the solid residue was washed with cold diethyl ether (2 × 5 mL), and the product was obtained as colorless crystals. IR (KBr) (ν_{max}, cm^{-1}) 3320 (NH), 1750 (C=O), 1695 (NC=O), 1630 (C=C). Analyses: Calcd. for $C_{27}H_{29}N_2O_5P$ (492.5): C, 65.85; H, 5.94; N, 5.69%. Found: C, 65.8; H, 5.9; N, 5.8%. ^1H, ^{13}C, ^{31}P NMR data for major isomer (67%) (*Z*)-**4a**. ^1H NMR (500.1 MHz, $CDCl_3$): δ 2.61 (3H, d, $^3J_{HH}$ = 4.2 Hz, NH*CH*$_3$), 2.84 (3H, s, NCH_3), 3.08 and 3.73 (6H, 2s, 2 OCH_3), 4.21 (1H, bs, CH), 4.62 (1H, bs, NH), 7.4–7.8 (15 H, m, 3 C_6H_5). ^{13}C NMR (125.8 MHz, $CDCl_3$) δ 27.2 and 31.1 (2 NCH_3), 41.3 (d, $^1J_{PC}$ = 129 Hz, P-*C* = C), 49.1 and 52.2 (2 OCH_3), 59.2 (d, $^2J_{PC}$ = 17.6 Hz, CH), 126.7 (d, $^1J_{PC}$ = 92 Hz, P-C_{ipso}), 128.8 (d, $^3J_{PC}$ = 12 Hz, C_{meta}), 132.1 (d, $^4J_{PC}$ = 2 Hz, C_{para}), 133.5 (d, $^2J_{PC}$ = 10 Hz, C_{ortho}), 158.5 (NC=O), 160.3 (P-C = *C*), 170.1 (d, $^4J_{PC}$ = 13.0 Hz, OC=O). ^{31}P NMR (202.4 MHz, $CDCl_3$) δ 24.72 (Ph_3P^+-C).

^1H, ^{13}C, ^{31}P NMR data for minor isomer (33%) (*E*)-**4a**: ^1H NMR (500.1 MHz, $CDCl_3$): δ 2.64 (3H, d, $^3J_{HH}$ = 4.5 Hz, NH*CH*$_3$), 2.94 (3H, s, NCH_3), 3.51 and 3.69 (6H, 2s, 2 OCH_3), 4.68 (1H, d, $^3J_{PH}$ = 16 Hz, CH), 5.24 (1H, bs, NH), 7.4–7.8 (15 H, m, 3 C_6H_5). ^{13}C NMR (125.8 MHz, $CDCl_3$) δ 26.8 and 29.4 (2 NCH_3), 41.7 (d, $^1J_{PC}$ = 131 Hz, P-*C* = C), 51.9 and 52.3 (2 OCH_3), 57.9 (d, $^2J_{PC}$ = 17 Hz, CH), 126.1 (d, $^1J_{PC}$ = 92 Hz, P-C_{ipso}), 128.5 (d, $^3J_{PC}$ = 12 Hz, C_{meta}), 131.9 (d, $^4J_{PC}$ = 2 Hz, C_{para}), 133.4 (d, $^2J_{PC}$ = 10 Hz, C_{ortho}), 158.5 (NC=O), 164.0 (P-C = *C*), 173.7 (d, $^4J_{PC}$ = 17 Hz, OC=O). ^{31}P NMR (202.4 MHz, $CDCl_3$) δ 25.26 (Ph_3P^+-C).

Dimethyl 2-(Triphenylphosphonylidene)-3-acetamidosuccinate (4b)

White powder. Mp 142–144°C. IR (KBr) (ν_{max}, cm^{-1}) 3448 (N-H), 1747 (C=O), 1648 (C=O). MS (EI, 70 eV): *m*/*z* (%) = 464 (M^+, 4), 262 (100). Anal Calcd for $C_{26}H_{26}NO_5P$ (463.5): C, 67.38; H. 5.65; N, 3.02. Found: C, 67.5; H. 5.7; N, 3.1.

^{1}H, ^{13}C, and ^{31}P NMR data for the major (72%) *(Z)*-**4b**: ^{1}H NMR (500.1 MHz, $CDC1_3$) δ : 1.96 (3H, s, CH_3), 3.14 and 3.69 (6H, 2s, 2 OCH_3), 4.5.7 (1H, dd, $^{3}J_{HH} = 8.3$ Hz, $^{3}J_{PH} = 15.1$ Hz, CH), 7.40 (1H, d, $^{3}J_{HH} = 8.3$ Hz, NH), 7.57.7 (15 H, m, 3 C_6H_5). ^{13}C NMR (125.8 MHz, $CDCl_3$) δ : 23.3 (CH_3), 43.5 (d, $^{1}J_{PC} = 128$ Hz, P-*C* = C), 49.0 and 52.2 (2 OCH_3), 51.5 (d, $^{2}J_{PC} = 17.8$ Hz, CH), 126.6 (d, $^{1}J_{PC} = 92.4$ Hz, P-C_{ipso}), 128.5 (d, $^{3}j_{PC} = 12.2$ Hz, $C_{meta)}$, 132.1 (d, $^{4}J_{PC} = 2$Hz, C_{pars}), 133.8 (d, $^{2}J_{PC} = 10$ Hz, C_{ortho}), 168.7 (NC=O), 170.4 (d, $^{2}J_{PC} = 12.8$ Hz, C = *C*-O), 173.8 (d, $^{3}J_{PC} = 8$ Hz, C=O). ^{31}P NMR (202.4 MHz, $CDCl_3$) δ : 22.32 (Ph_3P^{+}-C).

^{1}H, ^{13}C, and ^{31}P NMR data for the minor (28%) (*E*)-**4b**: ^{1}H NMR (500.1 MHz, $CDCl_3$) δ 1.96 (3H, s, CH_3), 3.57 and 3.69 (6 H, 2 s, 2 OCH_3), 4.58 (1H, dd, $^{3}J_{HH} = 8.4$ Hz, NH), 7.5–7.7 (15 H, m, 3 C_6H_5). ^{13}C NMR (125.8 MHz, $CDCl_3$) δ : 23.3 (CH_3), 44.1 (d, $^{1}J_{PC} = 132$ Hz, P-*C* = C), 50.1 and 50.9 (2 OCH_3), 51.5 (d, $^{2}J_{PC} = 17.8$ Hz, CH), 126.0 (d, $^{1}J_{PC} = 93.3$ Hz, P-C_{ipso}), 128.7 (d, $^{3}J_{PC} = 12$ Hz, C_{meta}), 132.1 (d, $^{4}J_{PC} = 2$ Hz, C_{para}), 133.8 (d, $^{2}J_{PC} = 10$ Hz, C_{ortho}), 168.7 (NC=O), 170.4 (d, $^{2}J_{PC} = 12.8$ Hz, C = *C*-O), 173.8 (d, $^{3}J_{PC} = 8$ Hz, C=O). ^{31}P NMR (202.4 MHz, $CDC1_3$) δ : 22.32 (Ph_3P^{+}-C).

Dimethyl 2-(Triphenylphosphonylidene)-3-(benzamido)succinate (4c)

White powder. Mp 192–194°C IR (KBr) (ν_{max}, cm^{-1}) 3404 (N-H), 1744 (C=O), 1702 (C=O). MS (EI, 70 eV): *m/z* (%) = 525 (M^{+}, 6), 262 (100). Anal Calcd for $C_{31}H_{28}NO_5P$ (463.5): C, 70.85; H. 5.37; N, 2.67. Found: C, 70.38; H. 5.4; N, 2.7.

^{1}H, ^{13}C, and ^{31}P NMR data for the major (81%) *(Z)*-**4c**: ^{1}H NMR (500.1 MHz, $CDC1_3$) δ 3.14 and 3.68 (6H, 2s, $2OCH_3$), 4.80 (1 H, dd, $^{3}J_{HH} = 8.5$ Hz, $^{3}J_{PH} = 13.9$ Hz, CH), 8.30 (1H, d, $^{4}J_{HH} = 8.5$ Hz, NH), 7.4–7.8 (20 H, m, 4 C_6H_5).^{13}C NMR (125.8 MHz, $CDCl_3$) δ 43.3 (d, $^{1}J_{PC} = 128$ Hz, P-*C* = C), 49.0 and 52.2 (2 OCH_3), 52 (d, $^{2}J_{PC} = 17.2$ Hz, CH), 127 (d, $^{1}J_{PC} = 129$ Hz, P-C_{ipso}), 128.6 (d, $^{3}J_{PC} = 9.2$ Hz, $C_{meta)}$, 132.1 (d, $^{4}J_{PC} = 16$ Hz, C_{pars}), 133.8 (d, $^{2}J_{PC} = 10$ Hz, C_{ortho}), 166.1 (NC=O), 170.5 (d, $^{4}J_{PC} = 12.8$ Hz, C = *C*-O), 173.8 (d, $^{3}J_{PC} = 8$ Hz, C=O). ^{31}P NMR (202.4 MHz, $CDCl_3$) δ 21.66 (Ph_3P^{+}-C).

^{1}H, ^{13}C and ^{31}P NMR data for the minor (19%) (*E*)-**4c**.^{1}H NMR (500.1 MHz, $CDCl_3$) δ 3.60 and 3.7 (6 H, 2s, 2 OCH_3), 4.81 (1 H, dd, $^{3}J_{HH} = 6.1$ Hz, NH), 7.4–7.8 (20 H, m, 4 C_6H_5). ^{13}C NMR (125.8 MHz, $CDCl_3$) δ 44.1 (CH_3), 44.1 (d, $^{1}J_{PC} = 132$ Hz, P-*C* = C), 50.2 and 51.4 (2 OCH_3), 50.9 (d, $^{2}J_{PC} = 16$ Hz, CH), 126.3 (d, $^{1}J_{PC} = 67.3$ Hz, P-C_{ipso}), 128.5 (d, $^{3}J_{PC} = 12.6$ Hz, C_{meta}), 132.1 (d, $^{4}J_{PC} = 15.9$ Hz, C_{para}), 133.8 (d, $^{2}J_{PC}$

= 10 Hz, C_{ortho}), 166.1 (NC=O), 170.4 (d, $^2J_{PC}$ = 12.8 Hz, C = *C*-O), 173.8 (d, $^3J_{PC}$ = 8 Hz, C=O). ^{31}P NMR (202.4 MHz, $CDC1_3$) δ : 22.32 (Ph_3P^+-C).

Dimethyl 2-(Triphenylphosphonylidene)-3-(nicotinamido)succinate (4d)

White powder. Mp 175–177°C. IR (KBr) (ν_{max}, cm^{-1}) 3367 (N-H), 1698 (C=O), 1620 (C=O). MS (EI, 70 eV): *m*/*z* (%) = 526 (M^+, 4), 262 (100). Anal Calcd for $C_{31}H_{28}NO_5P$ (526.5): C, 68.43; H. 5.17; N, 5.32. Found: C, 68.3; H. 5.2; N, 5.4.

^{1}H, ^{13}C, and ^{31}P NMR data for the major (75%) *(Z)*-**4d**: ^{1}H NMR (500.1 MHz, $CDC1_3$) δ 3.13 and 3.68 (6 H, 2 s, 2 OCH_3), 4.74 (1 H, dd, $^3J_{HH}$ = 8.9 Hz, $^3J_{PH}$ = 14 Hz, CH), 7.30 (1H, d, $^4J_{HH}$ = 9 Hz, NH), 7.5–7.7 (20 H, m, 4 C_6H_5). ^{13}C NMR (125.8 MHz, $CDCl_3$) δ 43.1 (d, $^1J_{PC}$ = 128 Hz, P-*C* = C), 49.1 and 52.3 (2 OCH_3), 52.2 (d, $^2J_{PC}$ = 18.5 Hz, CH), 150.5 (d, $^1J_{PC}$ = 443 Hz, P-C_{ipso}), 164.3 (d, $^3J_{PC}$ = 12.6 Hz, C_{meta}), 170.6 (d, $^4J_{PC}$ = 12.6 Hz, C_{pars}), 173.5 (d, $^2J_{PC}$ = 7 Hz, C_{ortho}), 123.2 (NC=O), 128.7 (d, $^4J_{PC}$ = 12.2 Hz, C = *C*-O), 133.8 (d, $^3J_{PC}$ = 9.8 Hz, C=O). ^{31}P NMR (202.4 MHz, $CDCl_3$) δ : 21.66 (Ph_3P^+-C).

^{1}H, ^{13}C, and ^{31}P NMR data for the minor (25%) (*E*)-**10c**: ^{1}H NMR (500.1 MHz, $CDCl_3$) δ 3.58 and 3.68 (6 H, 2s, 2 OCH_3), 4.75 (1 H, dd, $^3J_{HH}$ = 8.7 Hz, $^3J_{PH}$ = 13.3 Hz, CH), 7.26 (1 H, d, $^3J_{HH}$ = 8.7 Hz, NH), 7.5–7.7 (20 H, m, 4 C_6H_5). ^{13}C NMR (125.8 MHz, $CDCl_3$) δ 44.1 (d, $^1J_{PC}$ = 132 Hz, P-*C* = C), 50.2 and 51.3 (2 OCH_3), 52.2 (d, $^2J_{PC}$ = 18.5 Hz, CH), 150 (d, $^1J_{PC}$ = 4.7 Hz, P-C_{ipso}), 164.2 (d, $^3J_{PC}$ = 12.2 Hz, C_{meta}), 170.6 (d, $^4J_{PC}$ = 12.6 Hz, C_{para}), 173.5 (d, $^2J_{PC}$ = 7 Hz, C_{ortho}), 123.2 (NC=O), 128.7 (d, $^2J_{PC}$ = 12.2 Hz, C = *C*-O), 133.8 (d, $^3J_{PC}$ = 9.8 Hz, C=O). ^{31}P NMR (202.4 MHz, $CDC1_3$) δ 22.32 (Ph_3P^+-C).

The Typical Processes for the Preparation of 5 and 6

In the first method, to a magnetically stirred mixture of **3a** (0.24 g, 2 mmol) and **1a** (0.52 g, 2 mmol) in dried methylene chloride (10 mL), a solution of DMAD (0.14 g, 2 mmol) in methylene chloride (2 mL) was added dropwise. The solution was stirred at room temperature for 24 h. The solvent was removed under reduced pressure, the solid residue was washed with cold diethyl ether (2 × 5 mL), and the products were obtained as a white powder.

In the second method, a magnetically stirred mixture of phosphorane **4a** (0.49 g, 1 mmol) in toluene (30 mL) was refluxed for 12 h. The solvent was removed under reduced pressure, the solid residue was washed

with cold diethyl ether (2 × 5 mL), and the product was obtained as a white powder. In both methods the ratio of **5**:**6** was 55:45.

Methyl 1,3-Dimethyl-2,5-dioxo-imidazolidine-4-yl)triphenylphosphanilidene)acetate 5

White powder. IR (KBr) (ν_{max}, cm^{-1}): 1749 and 1690 (C=O), 1628 (C=C). Analyses: Calcd. for $C_{25}H_{23}N_2O_4P$ (446.40): C, 67.26; H, 5.19; N, 6.27%. Found: C, 67.3; H, 5.2; N, 6.3%. ^1H, ^{13}C, ^{31}P NMR data for major isomer (73%) (*Z*)-**5**: ^1H NMR (500.1 MHz, $CDCl_3$): δ 2.94 and 2.98 (6 H, 2s, 2 NCH_3), 3.15 (3 H, s, OCH_3), 3.46 (1H, d, $^3J_{PH}$ = 35.2 Hz, CH), 7.4–7.8 (15 H, m, 3 C_6H_5). ^{13}C NMR (125.8 MHz, $CDCl_3$) δ 24.2 and 26.6 (2 NCH_3), 35.3 (d, $^1J_{PC}$ = 130 Hz, P-*C* = C), 49.5 (CH_3), 61.7 (d, $^2J_{PC}$ = 17 Hz, CH), 125.8 (d, $^1J_{PC}$ = 92 Hz, P-C_{ipso}), 128.5 (d, $^3J_{PC}$ = 12 Hz, C_{meta}), 132.1 (d, $^4J_{PC}$ = 2 Hz, C_{para}), 133.7 (d, $^2J_{PC}$ = 10 Hz, C_{ortho}), 156.8 (N(C=O)N), 168.6 (d, $^2J_{PC}$ = 13 Hz, P-C = *C*), 176.0 (d, $^3J_{PC}$ = 5 Hz, NC=O). ^{31}P NMR (202.4 MHz, $CDCl_3$) δ 20.95 (Ph_3P^+-C).

^1H, ^{13}C, ^{31}P NMR data for minor isomer (27%) (*E*)-**5**. ^1H NMR (500.1 MHz, $CDCl_3$) δ 2.95 and 3.01 (6 H, 2s, 2 NCH_3), 3.12 (3 H, s, OCH_3), 3.52 (1 H, d, $^3J_{PH}$ = 35.8 Hz, CH), 7.4–7.8 (15 H, m, 3 C_6H_5). ^{13}C NMR (125.8 MHz, $CDCl_3$) δ 24.2 and 27.1 (2 NCH_3), 36.7 (d, $^1J_{PC}$ = 127 Hz, P-*C* = C), 50.5 (CH_3), 62.8 (d, $^2J_{PC}$ = 18 Hz, CH), 126.7 (d, $^1J_{PC}$ = 92 Hz, P-C_{ipso}), 129.0 (d, $^3J_{PC}$ = 12 Hz, C_{meta}), 132.1 (d, $^4J_{PC}$ = 2 Hz, C_{para}), 133.7 (d, $^2J_{PC}$ = 10 Hz, C_{ortho}), 156.8 (N(C=O)N), 170.3 (d, $^2J_{PC}$ = 17 Hz, P-C = *C*), 175.8 (d, $^3J_{PC}$ = 5 Hz, NC=O). ^{31}P NMR (202.4 MHz, $CDCl_3$) δ 20.24 (Ph_3P^+-C).

Methyl (3-Methyl-2-methylimino-4-oxo-oxazolidin-5-yl)-(triphenylphosphanilidene)acetate 6

IR (KBr) (ν_{max}, cm^{-1}): 1749 and 1690 (C=O), 1628 (C=C). Analyses: Calcd. for $C_{25}H_{23}N_2O_4P$ (446.40): C, 67.26; H, 5.19; N, 6.27%. Found: C, 67.3; H, 5.2; N, 6.3%. ^1H, ^{13}C, ^{31}P NMR data for major isomer (70%) (*Z*)-**6**: ^1H NMR (500.1 MHz, $CDCl_3$): δ 2.23 and 2.79 (6 H, 2 s, 2 NCH_3), 3.42 (3 H, s, OCH_3), 5.62 (1 H, d, $^3J_{PH}$ = 30.6 Hz, CH), 7.4–7.8 (15 H, m, 3 C_6H_5). ^{13}C NMR (125.8 MHz, $CDCl_3$) δ 24.6 and 26.8 (2 NCH_3), 37.8 (d, $^1J_{PC}$ = 138 Hz, P-*C* = C), 50.1 (CH_3), 63.0 (d, $^2J_{PC}$ = 12 Hz, CH), 125.8 (d, $^1J_{PC}$ = 92 Hz, P-C_{ipso}), 128.9 (d, $^3J_{PC}$ = 12 Hz, C_{meta}), 132.1 (d, $^4J_{PC}$ = 2 Hz, C_{para}), 133.7 (d, $^2J_{PC}$ = 10 Hz, C_{ortho}), 155.3 (C=N), 171.3 (d, $^2J_{PC}$ = 13 Hz, P-C = *C*), 174.5 (d, $^4J_{PC}$ = 2 Hz, OC=O). ^{31}P NMR (202.4 MHz, $CDCl_3$) δ 23.51 (Ph_3P^+-C).

^1H, ^{13}C, ^{31}P NMR data for minor isomer (30%) (*E*)-**6**: ^1H NMR (500.1 MHz, $CDCl_3$) δ 2.23 and 2.77 (6 H, 2 s, 2 NCH_3), 3.56 (3 H, s, OCH_3),

3.47 (1 H, d, $^3J_{PH} = 31.0$ Hz, CH), 7.4–7.8 (15 H, m, 3 C_6H_5). ^{13}C NMR (125.8 MHz, $CDCl_3$) δ 24.7 and 26.9 (2 NCH_3), 36.7 (d, $^1J_{PC} = 127$ Hz, P-*C* = C), 50.5 (CH_3), 62.2 (d, $^2J_{PC} = 11$ Hz, CH), 126.7 (d, $^1J_{PC} = 92$ Hz, P-C_{ipso}), 128.9 (d, $^3J_{PC} = 12$ Hz, C_{meta}), 132.3 (d, $^4J_{PC} = 2$ Hz, C_{para}), 133.8 (d, $^2J_{PC} = 10$ Hz, C_{ortho}), 155.1 (C=N), 171.4 (d, $^2J_{PC} = 17$ Hz, P-C = *C*), 174.4 (d, $^4J_{PC} = 2$ Hz, OC=O). ^{31}P NMR (202.4 MHz, $CDCl_3$) δ 22.77 (Ph_3P^+-C).

The Procedure for the Preparation of 7 and 8

A magnetically stirred mixture of **3b** (0.24 g, 2 mmol) and **1b** (0.52 g, 2 mmol) in EtOAc (10 mL) was added dropwise to a solution of DMAD (0.14 g, 2 mmol) in EtOAc. The solution was stirred at room temperature for 24 h. The solvent was removed under reduced pressure, the solid residue was washed with cold diethyl ether (2 × 5 mL), and the product, (2S,3R) or (2R,3S)-(**7**), was obtained as white powder. The residue of filtrate on silicagel column was washed by 1:1 ethyl acetae:diethyl ether, was separated to (2S,3S) or (2R, 3R)-**7** and **8**. When the reaction was carried out in dried methylene chloride, only phosphorimidate **8** was isolated as a white powder.

(2S,3R) or (2R,3S)-Dimethyl 2-Acetamido-3-(diphenoxyphosphoryl)succinate (7)

IR (KBr) (ν_{max}, cm^{-1}) 3302 (NH), 1738 (C=O), 1630 (C=C), 1284 (P=O). MS (EI, 70 eV): m/z (%) = 453 (M^+, 5), 233 (100). Anal Calcd for $C_{20}H_{22}NO_8P$ (435.4): C, 55.18; H. 5.09; N, 3.22. Found: C, 55.2; H. 5.1; N, 3.2. ^1H NMR (500.1 MHz, $CDCl_3$) δ: 1.91 (3 H, s, O = C-CH_3), 3.67 and 3.74 (6 H, 2 s, 2 OCH_3), 4.22 (1 H, dd, $^2J_{PH} = 23.8$ Hz, $^3J_{HH} = 5.6$ Hz, CH-P), 5.26 (1 H, ddd, $^3J_{PH} = 18$ Hz, $^3J_{HH} = 5.6$ Hz, $^3J_{NH} = 7.9$ Hz, N-CH), 6.78 (1H, d, $^3J_{HH} = 7.9$Hz, NH), 7.1–7.3 (10 H, m, 2 OPh). ^{13}C NMR (125.8 MHz, $CDCl_3$)δ: 22.9 (O = C-*C*H_3), 47.0 (d, $^1J_{PC} = 138$ Hz, P-C), 51.1 (d, $^2J_{PC} = 4$ Hz, N-CH), 53.1 and 53.2 (2 OCH_3), 120.3 (d, $^3J_{PC} = 4$ Hz, C_{ortho}) 120.5 (d, $^3J_{PC} = 4$ Hz, C_{ortho}), 125.5 and 125.7 (2 C_{para}), 129.8 and 129.9 (2 C_{meta}), 149.9 (d, $^2J_{PC} = 9.0$ Hz, $C_{ipso)}$, 150.2 (d, $^2J_{PC} = 9$ Hz, C_{ipso}), 166.6 (d, $^3J_{PC} = 4$ Hz, NCH-*C* = O), 169.7 (d, $^2J_{PC} = 7$ Hz, P-CH-*C* = O), 170.4 (N-C=O). ^{31}P NMR (202.4 MHz, $CDCl_3$) δ : 12.67 (C-P(= O)$(OPh)_2$.

(2R, 3R) or (2S, 3S)-Dimethyl 2-Acetamido-3-(diphenoxyphosphoryl)succinate (7)

IR (KBr) (ν_{max}, cm^{-1}) 3359 (NH), 1739 (C=O), 1668 (C=C), 1280 (P=O). ^1H NMR (500.1 MHz, $CDCl_3$) δ 1.97 (3H, s, O = C-CH_3), 3.68

and 3.76 (6 H, 2 s, 2 OCH_3), 4.34 (1 H, dd, $^2J_{PH}$ = 24.0 Hz, $^3J_{HH}$ = 3.5 Hz, CH-P), 5.62 (1 H, ddd, $^3J_{PH}$ = 9.0 Hz, $^3J_{HH}$ = 3.5 Hz, $^3J_{NH}$ = 9 Hz, N-CH), 6.80 (1 H, d, $^3J_{HH}$ = 9 Hz, NH), 7.1–7.3 (10 H, m, 2 OPh). ^{13}C NMR (125.8 MHz, $CDCl_3$) δ 23.1 (O = C-CH_3) 47.9 (d, $^1J_{PC}$ = 138 Hz, P-C), 49.0 (d, $^2J_{PC}$ = 3.9 Hz, N-CH), 53.6 and 53.9 (2 OCH_3), 120.8 (d, $^3J_{PC}$ = 4 Hz, C_{ortho}) 120.9 (d, $^3J_{PC}$ = 4 Hz, C_{ortho}), 126.2 and 126.3 (2 C_{para}), 130.3 and 130.4 (2 Cmeta), 149.8 (d, $^2J_{PC}$ = 9 Hz, $C_{ipso)}$, 150.3 (d, $^2J_{PC}$ = 9 Hz, C_{ipso}), 166.8 (d, $^3J_{PC}$ = 22 Hz, NCH-C = O), 168.3 (PCH-C = O), 171.7 (N-C=O). ^{31}P NMR (202.4 MHz, $CDCl_3$) δ 11.98 (C-P(= O)$(OPh)_2$.

Triphenyl Acetylphosphorimidate (8)

White powder. IR (KBr) (ν_{max}, cm^{-1}) 1590 (P=N), 1666 (C=C). MS (EI, 70 eV): m/z (%) = 367 (M^+, 8), 310 (100). Anal Calcd for $C_{20}H_{18}NO_4P$ (367.4): C, 65.39; H. 4.94; N, 3.81. Found: C, 65.3; H. 5.1; N, 3.7. ^{1}H NMR (500.1 MHz, $CDCl_3$) δ: 2.21 (3 H, s, O = C-CH_3), 7.1–7.6 (15 H, m, 3 OPh) ^{13}C NMR (125.8 MHz, $CDCl_3$) δ 23.3 (CH_3), 120.6 (d, $^3J_{PC}$ = 5 Hz, C_{ortho}), 125.4 (C_{para}) 129.9 (C_{meta}) 151.3 (d, $^2J_{PC}$ = 7 Hz, $C_{ipso)}$, 176.2 (C=O). ^{31}P NMR (202.4 MHz, $CDCl_3$) δ: -11.29 ($(PhO)_3P$=N).

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