Heteroatom Chemistry
Volume 19, Number 3, 2008

A Convenient and Practical Method for the Synthesis of *N*-Thiophosphoryl Aldimines and Ketimines

Xinyuan Xu, Chungui Wang, Zhenghong Zhou, Zebing Zeng, Xinpeng Ma, Guofeng Zhao, and Chuchi Tang

State Key Laboratory of Elemento-Organic Chemistry, Institute of Elemento-Organic Chemistry, Nankai University, Tianjin 300071, People's Republic of China

Received 11 January 2007; revised 17 October 2007

ABSTRACT: *A convenient and practical method for the preparation of N-thiophosphoryl imines was developed through the thermal condensation of acetals with different thiophosphoramides at 120–160°C.* © 2008 Wiley Periodicals, Inc. Heteroatom Chem 19:238–244, 2008; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/hc.20412

INTRODUCTION

Asymmetric addition of imines is an important approach to the preparation of synthetic valuable nitrogen-containing compounds, such as chiral amines, 1,2-diamines, and α- or β-amino acids. Recently, significant progress has been witnessed in this area [1]. To increase the electrophilic activity of the C=N double bond of imines, electron-withdrawing groups, for example, acyl [2], sulfonyl [3], and phosphoryl [4], are often introduced on the nitrogen atom. The introduction of a phosphoryl group modulates the reactivity of the imines, and the phosphoryl group can be easily removed through acid-catalyzed hydrolysis under mild conditions [5]. Because of these advantages, *N*-phosphoryl imines have recently begun to draw much attention of synthetic chemists and have been successfully employed in a variety of asymmetric reactions [4], such as hydrogenation, alkylation, the Mannich reaction, the aza-Henry reaction, and the Strecker reaction. However, *N*-phosphoryl imines used in the aforementioned reactions are limited to diphenylphosphinoylimines. In fact, the reactivities of phosphoryl imines may be finely tuned by changing the substituents on the phosphorus atom. In addition, thiophosphoryl compounds generally possess better stability compared with the corresponding phosphoryl analogues. Thus, replacement of phosphoryl group by thiophosphoryl makes the imine synthesis and purification easier. To date, there is only one report about the synthesis of *N*-thiophosphoryl imines. In 1988, Kawashima described a simple procedure for the preparation of allylphenylphosphinoylimnes through the condensation of the corresponding allylphenylphosphinamide and aldehyde in the presence of a dehydrating agent $MgSO_4$ [6]. However, no data were available, and this methodology was proved to limit to the preparation of phosphinoylimines and inapplicable for ketimines. Therefore, it is necessary to develop a versatile protocol for the synthesis of both *N*-thiophosphory aldimines and ketimines. In this paper, a convenient and economical method for the synthesis of several types of thiophosphoryl imines is described and that will promote the wide application of these compounds

Correspondence to: Zhenghong Zhou; e-mail: z.h.zhou@nankai.edu.cn.
Contract grant sponsor: National Natural Science Foundation of China.
Contract grant number: 20472033.

as electrophiles in organic synthesis, especially in asymmetric synthesis.

RESULTS AND DISCUSSION

An earlier procedure reported by Kruglyak et al. [7a] in 1968 for the synthesis of *N*-phosphoryl imines involved the treatment of an aldoxime or ketoxime with a trivalent phosphorus derivative. Then, the rearrangement of the initially formed trivalent intermediate, phosphorous oximes, led to *N*-phosphoryl imines. This is a general protocol for the synthesis of phosphorylimines with different substituents on the phosphorus atom. However, because of the instability of trivalent phosphorus compounds, the main drawback of this reaction was its harsh reaction conditions. The reaction was most commonly carried out at ca. −40°C.

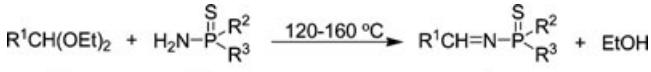
Jennings and Lovely documented a simple method for the preparation of diphenylphosphinoylimines [8]. The direct condensation of an aldehyde and *P*,*P*-diphenyl phosphinamide catalyzed by $TiCl_4/Et_3N$ led to the formation of the desired diphenylphosphinoylimine. However, the reaction suffered from a tedious workup, and the yield was only 35%–58%. Moreover, the substrate aldehyde was limited to aromatic aldehyde.

Zwierzak and coworkers reported that thermal condensation of acetals of aromatic aldehydes with diethyl phosphoramidate in the absence of solvent afforded the corresponding phosphorylimines in good yields (68%–88%) [9]. However, the reaction was unsuccessful with aliphatic acetals, and only limited to the synthesis of *O*,*O*-diethyl *N*-benzylidene phosphoramidate.

The aforementioned procedures for the preparation of phosphoryl (or phosphinoyl) imines may be helpful in the synthesis of *N*-thiophosphoryl imines. Apparently, Kruglyak's methodology is not suitable for the synthesis of these compounds because the rearrangement of the trivalent phosphorous oximes can only lead to phosphorylimines. Second, it was found that $TiCl_4/Et_3N$-catalyzed direct condensation of aldehyde with the corresponding amide is not effective in preparing such imines from thiophosphoramides. The reaction was very complicated, and the isolated yield of thiophosphorylimine was quite low. Finally, we discovered that Zwierzak's procedure is more suitable for the preparation of *N*-thiophosphoryl imines. Satisfactory results were obtained for the *N*-thiophosphoryl imines synthesis. The preliminary result has already been communicated [10].

First of all, thermal condensation of a set of acetals **2** with different thiophosphoramides **3** at 120–160°C was investigated. The results are listed in Table 1.

TABLE 1 Experimental Data of the Prepared *N*-Thiophosphoryl Aldimines **1**



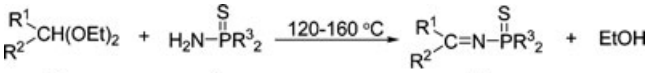
2 3 1

Compound	R^1	R^2	R^3	*Yield (%)*[a]
1a	Ph	EtO	EtO	90
1b	4-MeC_6H_4	EtO	EtO	95
1c	3-$MeOC_6H_4$	EtO	EtO	92
1d	4-$MeOC_6H_4$	EtO	EtO	94
1e	2-ClC_6H_4	EtO	EtO	95
1f	3-ClC_6H_4	EtO	EtO	93
1g	4-$F_3CC_6H_4$	EtO	EtO	83
1h	2-Furyl	EtO	EtO	98
1i	PhCH=CHCH	EtO	EtO	84
1j	EtOCH	EtO	EtO	71
1k	Ph	Ph	Ph	94
1l	4-MeC_6H_4	Ph	Ph	97
1m	4-$MeOC_6H_4$	Ph	Ph	91
1n	2-ClC_6H_4	Ph	Ph	93
1o	3-ClC_6H_4	Ph	Ph	91
1p	4-$F_3CC_6H_4$	Ph	Ph	91
1q	4-$O_2NC_6H_4$	Ph	Ph	92
1r	4-BrC_6H_4	Ph	Ph	84
1s	3-FC_6H_4	Ph	Ph	88
1t	PhCH=CHCH	Ph	Ph	83
1u	EtOCH	Ph	Ph	82
1v	Ph	PhO	PhO	80
1w	Ph	EtO	Ph	98

Compounds **1a–c**, **1e–j**, **1u**, and **1w** were purified via column chromatography. Compounds **1d**, **1j–t**, and **1v** were purified through recrystallization.
[a]Isolated yield.

As shown in Table 1, acetals of aromatic aldehydes could react smoothly with different types of thiophosphoramide (**3a**: $R^2 = R^3 = EtO$, **3b**: $R^2 = R^3 = Ph$, **3c**: $R^2 = EtO$, $R^3 = Ph$, or **3d**: $R^2 = R^3 = PhO$) to afford the corresponding imines **1** in good to excellent yield (83%–98%). The substituents R^2 and R^3 on phosphorus atom have an obvious influence on the reaction. A substantial decrease in the yield was observed for those thiophosphoramides in which R^2 and R^3 are equal to phenoxy (80%). The reaction of aliphatic acetals without α-hydrogens (nonenolizable), such as cinnamic aldehyde acetal and triethyl orthoformate, and **3** also took place smoothly to afford the expected product with a little decrease in yields (71%–84%). The reaction of aldehydes containing α-hydrogens (enolizable), such as propanal and butanal, led to the predominant formation of compounds **4** rather than the desired imines. It seems feasible that this type of compound is produced by further condensation of the initially formed imines with another molecule

TABLE 2 Experimental Data of the Prepared *N*-Thiophosphoryl Ketimines **5**

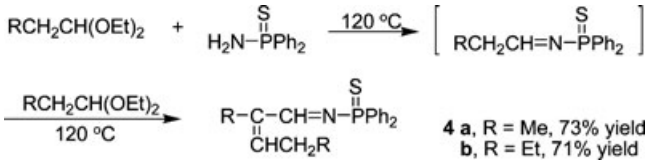


6 7 5

Compound	R^1	R^2	R^3	*Yield (%)*[a]
5a	C_6H_5	Me	EtO	97
5b	4-MeC_6H_4	Me	EtO	69
5c	4-ClC_6H_4	Me	EtO	72
5d	C_6H_5	Me	C_6H_5	91
5e	4-MeC_6H_4	Me	C_6H_5	81
5f	4-$MeOC_6H_4$	Me	C_6H_5	76
5g	4-ClC_6H_4	Me	C_6H_5	79
5h	C_6H_5	Et	C_6H_5	74

Compounds **5a–c** were purified via column chromatography. Compounds **5d–h** were purified through recrystallization.
[a]Isolated yield.

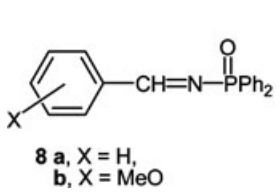
of acetal. Acceptable yields were obtained for compounds **4** employing a 2:1 molar ratio of acetals to thiophosphoramide **3**.



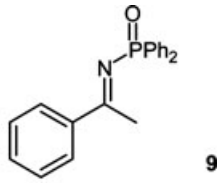
The procedure used for aromatic aldehydes was proved to be still efficient for the preparation of *N*-thiophosphoryl ketimines **5**. The results are summarized in Table 2.

As shown in Table 2, generally, there exists an obvious difference in the reactivity between acetals and ketals with respect to chemical yield of the corresponding *N*-thiophosphoryl imines. The reaction of thiophosphoramide (or thiophosphinamide) **7** and diethyl acetal of acetophenone successfully resulted in *N*-thioketimines **5** in excellent yields (97% and 91% for imine **5a** and **5d**, respectively). Although a slight decrease in the yield was noticed in substituted acetophenones and propiophenone, the corresponding *N*-thiophosphoryl ketimines were obtained in good yield (69%–81%).

In addition, this procedure also demonstrated a great advantage over Jennings' method and Kruglyak's methodology for the preparation of diphenylphosphinoylimines. For example, imines **8a, 8b**, and **9** were obtained in 75%, 80% and 64% yield, respectively, following this thermal condensation protocol. The results were obviously better than those of Jennings' method (**8a**, 58%; **8b**, 80%) [8] and Kruglyak's methodology (**9**, 42%) [11].



8 a, X = H,
b, X = MeO



9

In conclusion, a convenient and practical method for the synthesis of different types of *N*-thiophosphoryl imines was developed through thermal condensation of acetals and the corresponding thiophosphoramides. This protocol has the advantage of mild reaction conditions, ease of workup and purification, and readily availability of raw materials. Studies aimed at exploring the application of these compounds in organic synthesis and asymmetric synthesis are currently ongoing in our laboratories, and examples for the preliminary application of the thiophosphoryl imines as electrophiles are presented in [12].

EXPERIMENTAL SECTION

General

^{1}H and ^{31}P NMR spectra were recorded in $CDCl_3$ on a Varian 400 instrumental using TMS as an internal standard for ^{1}H NMR and 85% H_3PO_4 as an external standard for ^{31}P NMR. Elemental analyses were conducted on a Yanaco CHN Corder MT-3 automatic analyzer. Melting points were determined on a X-4 melting point apparatus. All temperatures were uncorrected.

Typical Procedure for the Synthesis of N-Thiophosphoryl Imines **1, 4, 5, 8**

A mixture of acetal and the corresponding phosphoramide (with a molar ratio of 1.3:1, in case of **4**, a molar ratio of 2:1 was used) was placed in a round-bottom flask equipped with a distilling apparatus. The resulting mixture was gently heated (the bath temperature was gradually raised to ca. 160°C) with stirring. The reaction was completed until ethanol was distilled off from the reaction mixture (2–6 h). After removal of the excess acetal, the crude product was purified through recrystallization or column chromatography on silica gel (200–300 meshes, gradient eluted with petroleum ether and ethyl acetate).

N-Benzylidene-O,O-diethylthiophosphoramide (**1a**). Pale yellow oil, 90% yield, ^{31}P NMR(δ, $CDCl_3$): 80.17; ^{1}H NMR(δ, $CDCl_3$): 1.26(t, 6H, $J_{H-H} = 7.2$ Hz, $2CH_3$), 4.05–4.20 (m, 4H, $2OCH_2$),

7.37–7.52 (m, 3Harom), 7.87–7.89 (m, 2Harom), 9.06 (d, 1H, $J_{P-H} = 39.3$ Hz, CH=N). Anal. Calcd for $C_{11}H_{16}NO_2PS$: C, 51.35; H, 6.27; N, 5.44; Found: C, 51.25; H, 6.32; N, 5.31.

*N-4-Methylbenzylidene-O,O-diethylthiophosphoramide (***1b***).* Pale yellow oil, 95% yield; ^{31}P NMR (δ, $CDCl_3$): 80.58; ^{1}H NMR (δ, $CDCl_3$): 1.33 (t, 6H, $J_{H-H} = 7.2$ Hz, $2CH_3$), 2.42 (s, 3H, CH_3), 4.12–4.25 (m, 4H, $2OCH_2$), 7.28 (d, 2Harom, $J_{H-H} = 8.0$ Hz), 7.85 (d, 2Harom, $J_{H-H} = 8.0$ Hz), 9.09 (d, 1H, $J_{P-H} = 39.6$ Hz, CH=N). Anal. Calcd for $C_{12}H_{18}NO_2PS$: C, 53.12; H, 6.69; N, 5.16; Found: C, 53.07; H, 6.53; N, 5.14.

*N-3-Methoxybenzylidene-O,O-diethylthiophosphoramide (***1c***).* Pale yellow oil, 92% yield; ^{31}P NMR (δ, $CDCl_3$): 80.37; ^{1}H NMR (δ, $CDCl_3$): 1.33 (t, 6H, $J_{H-H} = 7.2$ Hz, $2CH_3$), 3.84 (s, 3H, OCH_3), 4.10–4.25 (m, 4H, $2CH_2$), 7.11–7.13 (m, 1Harom), 7.36–7.50 (m, 3Harom), 9.09 (d, 1H, $J_{P-H} = 39.2$ Hz, CH=N). Anal. Calcd for $C_{12}H_{18}NO_3PS$: C, 50.16; H, 6.32; N, 4.88; Found: C, 50.06; H, 6.34; N, 4.77.

*N-4-Methoxybenzylidene-O,O-diethylthiophosphoramide (***1d***).* White solid, mp 61–62°C, 94% yield; ^{31}P NMR (δ, $CDCl_3$): 80.82; ^{1}H NMR (δ, $CDCl_3$): 1.33 (t, 6H, $J_{H-H} = 7.2$ Hz, $2CH_3$), 3.87 (s, 3H, OCH_3), 4.09–4.24 (m, 4H, $2CH_2$), 6.96–6.98 (d, 2Harom, $J_{H-H} = 8.8$ Hz), 7.91–7.93 (d, 2Harom, $J_{H-H} = 8.8$ Hz), 9.05 (d, 1H, $J_{P-H} = 39.2$ Hz, CH=N). Anal. Calcd for $C_{12}H_{18}NO_3PS$: C, 50.16; H, 6.32; N, 4.88; Found: C, 49.72; H, 6.30; N, 4.52.

*N-2-Chlorobenzylidene-O,O-diethylthiophosphoramide (***1e***).* Pale yellow oil, 95% yield; ^{31}P NMR (δ, $CDCl_3$): 79.57; ^{1}H NMR (δ, $CDCl_3$): 1.34 (t, 3H, $J_{H-H} = 7.2$ Hz, $2CH_3$), 4.12–4.28 (m, 4H, $2CH_2$), 7.31–7.50 (m, 4Harom), 9.60 (d, 1H, $J_{P-H} = 38.8$ Hz, CH=N). Anal. Calcd for $C_{11}H_{15}ClNO_2PS$: C, 45.28; H, 5.18; N, 4.80; Found: C, 45.09; H, 5.23; N, 4.67.

*N-3-Chlorobenzylidene-O,O-diethylthiophosphoramide (***1f***).* Pale yellow oil, 93% yield; ^{31}P NMR (δ, $CDCl_3$): 79.87; ^{1}H NMR (δ, $CDCl_3$): 1.33 (t, 3H, $J_{H-H} = 7.2$ Hz, $2CH_3$), 4.15–4.21 (m, 4H, $2CH_2$), 7.42–7.79 (m, 3Harom), 7.98 (s, 1Harom), 9.07 (d, 1H, $J_{P-H} = 38.4$ Hz, CH=N). Anal. Calcd for $C_{11}H_{15}ClNO_2PS$: C, 45.28; H, 5.18; N, 4.80; Found: C, 45.31; H, 5.10; N, 4.82.

*N-4-Trifluoromethylbenzylidene-O,O-diethylthiophosphoramide (***1g***).* Pale yellow oil, 83% yield. ^{31}P NMR (δ, $CDCl_3$): 79.35; ^{1}H NMR (δ, $CDCl_3$): 1.35 (t, 6H, $J_{H-H} = 7.2$ Hz, $2CH_3$), 4.15–4.28 (m, 4H, $2CH_2$), 7.74–7.76 (d, 2Harom, $J_{H-H} = 8.0$ Hz), 8.08–8.10 (d, 2Harom, $J_{H-H} = 8.0$ Hz), 9.18 (d, 1H, $J_{P-H} = 38.4$ Hz, −CH=N−). Anal. Calcd for $C_{12}H_{15}F_3NO_2PS$: C, 44.31; H, 4.65; N, 4.31; Found: C, 44.25; H, 4.71; N, 4.55.

*N-2-Furylmethylidene-O,O-diethylthiophosphoramide (***1h***).* Brown oil, 98% yield; ^{31}P NMR (δ, $CDCl_3$): 79.80; ^{1}H NMR (δ, $CDCl_3$): 1.30 (t, 6H, $J_{H-H} = 7.2$ Hz, $2CH_3$), 4.03–4.22 (m, 4H, $2CH_2$), 6.60 (m, 1Harom), 7.25 (d, 1Harom, $J_{H-H} = 3.2$ Hz), 7.69 (s, 1Harom), 8.86 (d, 1H, $J_{P-H} = 39.6$ Hz, −CH=N−). Anal. Calcd for $C_9H_{14}NO_3PS$: C, 43.27; H, 5.71; N, 5.66; Found: C, 43.32; H, 5.62; N, 5.61.

*N-3-Phenyl-2-propenylidene-O,O-diethylthiophosphoramide (***1i***).* Pale yellow oil, 84% yield; ^{31}P NMR (δ, $CDCl_3$): 79.82; ^{1}H NMR (δ, $CDCl_3$): 1.32 (t, 6H, $J_{H-H} = 7.2$ Hz, $2CH_3$), 4.06–4.21 (m, 4H, $2CH_2$), 6.97–7.04 (m, 1H, CH), 7.39–7.54 (m, 5Harom, CH), 8.85 (dd, 1H, $J_{H-H} = 9.2$ Hz, $J_{P-H} = 38.4$ Hz, −CH=N−). Anal. Calcd for $C_{13}H_{18}NO_2PS$: C, 55.11; H, 6.40; N, 4.94; Found: C, 53.06; H, 6.53; N, 5.01.

*N-Ethoxymethylidene-O,O-diethylthiophosphoramide (***1j***).* Pale yellow oil, 71%, yield; ^{31}P NMR (δ, $CDCl_3$): 75.08; ^{1}H NMR (δ, $CDCl_3$): 1.28 (t, 6H, $J_{H-H} = 7.2$ Hz, $2CH_3$), 1.30 (t, 3H, CH_3), 4.02–4.11 (m, 4H, $2CH_2$), 4.27 (q, 2H, $J_{H-H} = 7.2$ Hz, CH_2), 8.25 (d, 1H, $J_{P-H} = 19.2$ Hz, −CH=N−). Anal. Calcd for $C_7H_{16}NO_3PS$: C, 37.32; H, 7.16; N, 6.22; Found: C, 53.06; H, 6.53; N, 5.01.

*N-Benzylidene-diphenylthiophosphinamide (***1k***).* White solid, 87–89°C, 94% yield; ^{31}P NMR (δ, $CDCl_3$): 62.08; ^{1}H NMR (δ, $CDCl_3$): 7.41–7.59 (m, 9Harom), 7.99–8.80 (m, 6Harom), 9.38 (d, 1H, $J_{P-H} = 44.0$ Hz, −CH=N−). Anal. Calcd for $C_{19}H_{16}NPS$: C, 71.01; H, 5.02; N, 4.36; Found: C, 70.95; H, 4.60; N, 4.68.

*N-4-Methylbenzylidene-diphenylthiophosphinamide (***1l***).* White solid, 119–120°C, 97% yield, ^{31}P NMR (δ, $CDCl_3$): 61.82; ^{1}H NMR (δ, $CDCl_3$): 2.44 (s, 3H, CH_3), 7.32 (d, 2Harom, $J_{H-H} = 8.0$ Hz), 7.42–7.46 (m, 6Harom), 7.96 (d, 2Harom, $J_{H-H} = 8.0$ Hz), 7.98–8.04 (m, 4Harom), 9.35 (d, 1H, $J_{P-H} = 39.6$ Hz, −CH=N−). Anal. Calcd for $C_{20}H_{18}NPS$: C, 71.62; H, 5.41; N, 4.18; Found: C, 71.53; H, 5.29; N, 3.98.

*N-4-Methoxybenzylidene-diphenylthiophosphinamide (***1m***).* White solid, 139–141°C, 91% yield, ^{31}P NMR (δ, $CDCl_3$): 61.56; ^{1}H NMR (δ, $CDCl_3$): 3.89 (s, 3H, CH_3), 7.01 (d, 2Harom, $J_{H-H} = 8.8$ Hz), 7.40–7.46 (m, 6Harom), 7.98–8.04 (m, 6Harom), 9.29 (d, 1H, $J_{P-H} = 39.6$ Hz, −CH=N−). Anal. Calcd

for $C_{20}H_{18}NOPS$: C, 68.36; H, 5.16; N, 3.99; Found: C, 68.00; H, 5.27; N, 4.00.

*N-2-Chlorobenzylidene-diphenylthiophosphinamide (**1n**)*. White solid, 115–116°C, 93% yield, ^{31}P NMR (δ, $CDCl_3$): 62.07; ^1H NMR (δ, $CDCl_3$): 7.44–7.48 (m, 9Harom), 7.99–8.06 (m, 4Harom), 8.32 (dd, 1Harom, $J_{H-H} = 7.5$ and 1.5 Hz), 8.89 (d, 1H, $J_{P-H} = 38.7$ Hz, —CH=N—). Anal. Calcd for $C_{19}H_{15}ClNPS$: C, 64.13; H, 4.25; N, 3.94; Found: C, 64.17; H, 4.27; N, 3.92.

*N-3-Chlorobenzylidene-diphenylthiophosphinamide (**1o**)*. White solid, 136–138°C, 91% yield; ^{31}P NMR (δ, $CDCl_3$): 62.66; ^1H NMR (δ, $CDCl_3$): 7.44–7.56 (m, 8Harom), 7.66–8.10 (m, 6Harom), 9.35 (d, 1H, $J_{P-H} = 40.0$ Hz, —CH=N—). Anal. Calcd for $C_{19}H_{15}ClNPS$: C, 64.13; H, 4.25; N, 3.94; Found: C, 64.43; H, 4.60; N, 3.92.

*N-4-Trifluoromethylbenzylidene-diphenylthiophosphinamide (**1p**)*. White solid, 145–147°C, 91% yield; ^{31}P NMR (δ, $CDCl_3$): 61.96; ^1H NMR (δ, $CDCl_3$): 7.41–7.49 (m, 6Harom), 7.78 (d, 2Harom, $J_{H-H} = 8.1$ Hz), 7.98–8.06 (m, 4Harom), 8.18 (d, 2Harom, $J_{H-H} = 8.1$ Hz), 9.45 (d, 1H, $J_{P-H} = 38.7$ Hz, —CH=N—). Anal. Calcd for $C_{20}H_{15}F_3NPS$: C, 61.69; H, 3.88; N, 3.60; Found: C, 61.65; H, 4.09; N, 3.55.

*N-4-Nitrobenzylidene-diphenylthiophosphinamide (**1q**)*. Golden solid, 216–219°C, 92% yield; ^{31}P NMR (δ, $CDCl_3$): 62.49; ^1H NMR (δ, $CDCl_3$): 7.44–7.56 (m, 6Harom), 7.98–8.06 (m, 4Harom), 8.23 (d, 2Harom, $J_{H-H} = 8.7$ Hz), 8.36 (d, 2Harom, $J_{H-H} = 8.7$ Hz), 9.49 (d, 1H, $J_{P-H} = 39.0$ Hz, —CH=N—). Anal. Calcd for $C_{19}H_{15}N_2O_2PS$: C, 62.29; H, 4.13; N, 7.65; Found: C, 62.27; H, 3.99; N, 7.65.

*N-4-Bromobenzylidene-diphenylthiophosphinamide (**1r**)*. White solid, 127–128°C, 84% yield; ^{31}P NMR (δ, $CDCl_3$): 61.55; ^1H NMR (δ, $CDCl_3$): 7.40–7.51 (m, 6Harom), 7.66 (d, 2Harom, $J_{H-H} = 8.4$ Hz), 7.93 (d, 2Harom, $J_{H-H} = 8.4$ Hz), 7.97–8.04 (m, 4Harom), 9.35 (d, 1H, $J_{P-H} = 39.0$ Hz, —CH=N—). Anal. Calcd for $C_{19}H_{15}BrNPS$: C, 57.01; H, 3.78; N, 3.50; Found: C, 57.02; H, 3.54; N, 3.58.

*N-3-Fluorobenzylidene-diphenylthiophosphinamide (**1s**)*. White solid, 128–131°C, 88% yield; ^{31}P NMR (δ, $CDCl_3$): 61.50; ^1H NMR (δ, $CDCl_3$): 7.28–7.31 (m, 1Harom), 7.41–7.53 (m, 7Harom), 7.77–7.83 (m, 2Harom), 7.98–8.05 (m, 4Harom), 9.37 (d, 1H, $J_{P-H} = 39.0$ Hz, —CH=N—). Anal. Calcd for $C_{19}H_{15}FNPS$: C, 67.24; H, 4.46; N, 4.13; Found: C, 67.09; H, 4.25; N, 4.19.

*N-3-Phenyl-2-propenylidene-diphenylthiophosphinamide (**1t**)*. White solid, mp 101–102°C, 83% yield; ^{31}P NMR (δ, $CDCl_3$): 62.21; ^1H NMR (δ, $CDCl_3$): 7.19–7.24 (m, 1H, CH), 7.41–7.59 (m, 11Harom, CH), 7.94–8.00 (m, 4Harom), 9.15 (dd, 1H, $J_{H-H} = 9.2$ Hz, $J_{P-H} = 38.8$ Hz, —CH=N—). Anal. Calcd for $C_{21}H_{18}NPS$: C, 72.60; H, 5.22; N, 4.03; Found: C, 67.09; H, 4.25; N, 4.19.

*N-Ethoxymethylidene-diphenylthiophosphinamide (**1u**)*. White solid, mp 53–55°C, 82% yield, ^{31}P NMR (δ, $CDCl_3$): 56.04; ^1H NMR (δ, $CDCl_3$): 1.40 (t, 3H, $J_{H-H} = 7.2$ Hz, CH_3), 4.46 (q, 2H, $J_{H-H} = 7.2$ Hz, CH_2), 7.39–7.47 (m, 6Harom), 7.91–7.96 (m, 4Harom), 8.45 (d, 1H, $J_{P-H} = 20.8$ Hz, —CH=N—). Anal. Calcd for $C_{15}H_{16}NOPS$: C, 62.27; H, 5.57; N, 4.84; Found: C, 67.09; H, 4.25; N, 4.19.

*N-Benzylidene-O,O-diphenylthiophosphoramide (**1v**)*. White crystal, mp 80–89°C, 80% yield; ^{31}P NMR (δ, $CDCl_3$): 74.18; ^1H NMR (δ, $CDCl_3$): 7.18–7.65 (m, 15Harom), 9.15–9.25 (d, 1H, $J_{P-H} = 40.4$ Hz, —CH=N—). Anal. Calcd for $C_{19}H_{16}NO_2PS$: C, 64.58; H, 4.56; N, 3.96; Found: C, 64.62; H, 4.57; N, 3.89.

*N-Benzylidene-O-ethyl phenylthiophosphonamide (**1w**)*. Pale yellow oil, 98% yield; ^{31}P NMR (δ, $CDCl_3$): 87.31; ^1H NMR (δ, $CDCl_3$): 1.32 (t, 3H, $J_{H-H} = 7.2$ Hz, CH_3), 4.07–4.13 (m, 2H, $J_{H-H} = 7.2$ Hz, CH_2), 7.43–7.56 (m, 6Harom), 7.96–8.13 (m, 4Harom), 9.18–9.28 (d, 1H, $J_{P-H} = 38.8$ Hz, —CH=N—). Anal. Calcd for $C_{15}H_{16}NOPS$: C, 62.27; H, 5.57; N, 4.84; Found: C, 62.23; H, 5.61; N, 4.92.

*N-2-Methyl-2-pentenylidene-diphenylphosphinamide (**4a**)*. Pale yellow oil, 73% yield; ^{31}P NMR (δ, $CDCl_3$): 60.71; ^1H NMR (δ, $CDCl_3$): 1.07 (t, 3H, $J_{H-H} = 7.2$ Hz, CH_3), 2.01 (s, 3H, CH_3), 2.35 (quintet, 2H, $J_{H-H} = 7.2$ Hz, CH_2), 6.49 (t, 1H, $J_{H-H} = 7.2$ Hz, CH), 7.39–7.43 (m, 6Harom), 7.99–8.04 (m, 4Harom), 8.89 (d, 1H, $J_{P-H} = 39.2$ Hz, —CH=N—). Anal. Calcd for $C_{18}H_{20}NPS$: C, 68.98; H, 6.43; N, 4.47; Found: C, 68.74; H, 6.53; N, 4.32.

*N-2-Ethyl-2-hexenylidene-diphenylphosphinamide (**4b**)*. Pale yellow oil, 71% yield; ^{31}P NMR (δ, $CDCl_3$): 60.75; ^1H NMR (δ, $CDCl_3$): 0.97 (t, 3H, $J_{H-H} = 7.2$ Hz, CH_3), 1.08 (t, 3H, $J_{H-H} = 7.2$ Hz, CH_3), 2.33 (quintet, 2H, $J_{H-H} = 7.2$ Hz, CH_2), 2.54 (q, 2H, $J_{H-H} = 7.2$ Hz, CH_2), 4.20–4.28 (m, 4H, $2CH_2$), 6.46 (t, 1H, $J_{H-H} = 7.2$ Hz, CH), 7.39–7.42 (m, 6Harom), 7.96–8.01 (m, 4Harom), 8.82 (d, 1H, $J_{P-H} = 40.0$ Hz, —CH=N—). Anal. Calcd for $C_{20}H_{24}NPS$: C, 53.12; H, 6.69; N, 5.16; Found: C, 53.06; H, 6.53; N, 5.01.

*N-1-Phenylethyliden-O,O-diethylthiophosphoramide (**5a**).* Pale yellow oil, 97% yield. ^{31}P NMR (δ, $CDCl_3$): 67.38; ^{1}H NMR (δ, $CDCl_3$): 1.38 (t, 6H, $J_{H-H} = 7.2$ Hz, $2CH_3$), 2.79 (s, 3H, CH_3), 4.20–4.28 (m, 4H, $2CH_2$), 7.39–7.43 (m, 2Harom), 7.49–7.53 (m, 1Harom), 7.96–7.98 (m, 1Harom). Anal. Calcd for $C_{12}H_{18}NO_2PS$: C, 53.12; H, 6.69; N, 5.16; Found: C, 53.06; H, 6.53; N, 5.01.

*N-1-(4-Methylphenyl)ethylidene-O,O-diethylthiophosphoramide (**5b**).* Pale yellow oil, 69% yield; ^{31}P NMR (δ, $CDCl_3$): 67.49; ^{1}H NMR (δ, $CDCl_3$): 1.37 (t, 6H, $J_{H-H} = 7.2$ Hz, $2CH_3$), 2.38 (s, 3H, CH_3), 2.79 (d, 3H, $J_{P-H} = 2.0$ Hz, CH_3), 4.19–4.26 (m, 4H, $2CH_2$), 7.19 (d, $J_{H-H} = 8.0$ Hz, 2Harom), 7.85 (d, $J_{H-H} = 8.0$ Hz, 2Harom). Anal. Calcd for $C_{13}H_{20}NO_2PS$: C, 54.72; H, 7.07; N, 4.91; Found: C, 54.86; H, 7.35; N, 4.73.

*N-1-(4-Chlorophenyl)ethylidene-O,O-diethylthiophosphoramide (**5c**).* Pale yellow oil, 72% yield; ^{31}P NMR (δ, $CDCl_3$): 67.23; ^{1}H NMR (δ, $CDCl_3$): 1.37 (t, 6H, $J_{H-H} = 7.2$ Hz, $2CH_3$), 2.76 (s, 3H, CH_3), 4.17–4.29 (m, 4H, $2CH_2$), 7.37 (d, $J_{H-H} = 8.2$ Hz, 2Harom), 7.90 (d, $J_{H-H} = 8.2$ Hz, 2Harom). Anal. Calcd for $C_{12}H_{17}ClNO_2PS$: C, 47.14; H, 5.60; N, 4.58; Found: C, 46.97; H, 5.53; N, 4.54.

*N-1-Phenylethylidene-diphenylthiophosphinamide (**5d**).* White solid, 129–131°C, 91% yield; ^{31}P NMR (δ, $CDCl_3$): 46.90; ^{1}H NMR (δ, $CDCl_3$): 2.79 (s, 3H, CH_3), 7.40–7.55 (m, 9Harom), 8.01–8.08 (m, 6Harom). Anal. Calcd for $C_{20}H_{18}NPS$: C, 71.62; H, 5.41; N, 4.18; Found: C, 71.65; H, 5.47; N, 4.20.

*N-1-(4-Methylphenyl)ethylidene diphenylthiophosphinamide (**5e**).* White solid, 144–147°C, 81% yield; ^{31}P NMR (δ, $CDCl_3$): 47.53; ^{1}H NMR (δ, $CDCl_3$): 2.43 (s, 3H, CH_3), 2.77 (d, 3H, $J_{P-H} = 1.6$ Hz, CH_3), 7.27 (d, $J_{H-H} = 8.4$ Hz, 2Harom), 7.40–7.44 (m, 6Harom), 7.96 (d, $J_{H-H} = 8.4$ Hz, 2Harom), 8.01–8.06 (m, 4Harom). Anal. Calcd for $C_{21}H_{20}NPS$: C, 72.18; H, 5.77; N, 4.01; Found: C, 72.19; H, 5.90; N, 4.00.

*N-1-(4-Methoxyphenyl)ethylidene-diphenylthiophosphinamide (**5f**).* White solid, 125–128°C, 76% yield; ^{31}P NMR (δ, $CDCl_3$): 47.29; ^{1}H NMR (δ, $CDCl_3$): 2.76 (s, 3H, CH_3), 3.89 (s, 3H, OCH_3), 6.96 (d, $J_{H-H} = 8.0$ Hz, 2Harom), 7.41–7.47 (m, 6Harom), 8.02–8.08 (m, 6Harom). Anal. Calcd for $C_{21}H_{20}NOPS$: C, 69.02; H, 5.52; N, 3.83; Found: C, 68.83; H, 5.48; N, 3.96.

*N-1-(4-Chlorophenyl)ethylidene-diphenylthiophosphinamide (**5g**).* White solid, 130–132°C, 79% yield. ^{31}P NMR (δ, $CDCl_3$): 48.26; ^{1}H NMR (δ, $CDCl_3$): 2.77 (s, 3H, CH_3), 7.41–7.47 (m, 6Harom), 8.02–8.08 (m, 6Harom). Anal. Calcd for $C_{20}H_{17}ClNPS$: C, 64.95; H, 4.63; N, 3.79; Found: C, 65.02; H, 4.72; N, 3.76.

*N-1-Phenylpropylidene-diphenylthiophosphinamide (**5h**).* White solid, 126–128°C, 74% yield; ^{31}P NMR (δ, $CDCl_3$): 46.67; ^{1}H NMR (δ, $CDCl_3$): 1.04 (t, 3H, $J_{H-H} = 7.6$ Hz, CH_3), 3.41 (q, 2H, $J_{H-H} = 7.6$ Hz, CH_2), 7.42–7.55 (m, 9Harom), 7.97–8.09 (m, 6Harom). Anal. Calcd for $C_{21}H_{20}NPS$: C, 72.18; H, 5.77; N, 4.01; Found: C, 72.09; H, 5.60; N, 3.95.

*N-Benzylidene-diphenylphosphinamide (**8a**).* White solid, 124–126°C, 75% yield; ^{31}P NMR (δ, $CDCl_3$): 23.10; ^{1}H NMR (δ, $CDCl_3$): 7.19–7.38 (m, 10Harom), 7.52–7.67 (m, 3Harom), 8.03 (d, 2Harom, $J_{H-H} = 8.0$ Hz), 9.23 (d, 1H, $J_{P-H} = 20.8$ Hz, —CH=N—).

*N-4-Methoxybenzylidene-diphenylphosphinamide (**8b**).* White solid, 146–148°C, 80% yield, ^{31}P NMR (δ, $CDCl_3$): 25.87; ^{1}H NMR (δ, $CDCl_3$): 3.88 (s, 3H, OCH_3), 6.99 (d, 2Harom, $J_{H-H} = 8.8$ Hz), 7.42–7.49 (m, 6Harom), 7.90–7.95 (m, 4Harom), 7.97 (d, 2Harom, $J_{H-H} = 8.8$ Hz), 9.22 (d, 1H, $J_{P-H} = 32.4$ Hz, —CH=N—).

*N-1-Phenylethylidene-diphenylphosphinamide (**9**).* White solid, 139–140°C, 64% yield; ^{31}P NMR (δ, $CDCl_3$): 19.99; ^{1}H NMR (δ, $CDCl_3$): 2.97 (d, 3H, $J_{P-H} = 1.2$ Hz, CH_3), 7.42–7.57 (m, 9Harom), 7.96–8.10 (m, 6Harom).

REFERENCES

[1] (a) Kobayashi, S.; Ishitani, H. Chem Rev 1999, 99, 1069; (b) Vilainan, T.; Bhanthumnavin, W. Curr Org Chem 2005, 9, 1315.

[2] Speckamp, W. N.; Hiemstra, H. Tetrahedron 1985, 41, 4367.

[3] Weinreb, S. M. Top Curr Chem 1997, 190, 131.

[4] Weinreb, S. M.; Orr, R. K. Synthesis 2005, 8, 1205.

[5] Bernardi, L.; Bonini, B. F.; Capito, E.; Dessole, G.; Comes-Franchini, M.; Fochi, M.; Ricci, A. J Org Chem 2004, 69, 8168.

[6] Kawashima, T.; Kihara, T.; Inamoto, N. Chem Lett 1988, 577.

[7] (a) Kruglyak, Y. L.; Leibovskaya, G. A.; Stretenskaya, I. I.; Sheluchenko, V. V.; Martynov, I. V. Zh Obsch Khim 1968, 38, 943; (b) Kruglyak, Y. L.; Landan, M. A.; Leibovskaya, G. A.; Martynov, I. V.; Saltykova, L. I.; Sokalskii, M. A. Zh Obsch Khim 1969, 39, 215; (c) Brown, C.; Hudson, R. F.; Maron, A.; Record, K. A. F. J. Chem Soc, Chem Commun 1976, 663; (d) Hudson, R. F.; Brown, C.; Maron, A. Chem Ber

1982, 115, 2560; (e) Krzyzanowska, B.; Stec, W. J. Synthesis 1978, 521; (f) Krzyzanowska, B; Stec, W. J. Synthesis 1982, 270; (g) Lopez, L.; Barrans, J. J. Chem Soc Perkin Trans 1 1977, 1806.

[8] (a) Jennings, W. B.; Lovely, C. J. Tetrahedron Lett 1988, 29, 3725; (b) Jennings, W. B.; Lovely, C. J. Tetrahedron 1991, 47, 5561.

[9] (a) Zwierzak, A.; Osowska-Pacewicka, K. Pol J Chem 1993, 67, 2085; (b) Zwierzak, A.; Napieraj, A. Tetrahedron 1996, 52, 8789.

[10] Xu, X. Y.; Wang, C. G.; Zhou, Z. H.; Zeng, Z. B.; Ma, X. P.; Zhao, G. F.; Tang, C. C. Lett Org Chem 2006, 3, 640.

[11] Lipshutz, B. H.; Shimitzu, H. Angew Chem Int Ed 2004, 43, 2228.

[12] (a) Ma, X. P.; Xu, X. Y.; Wang, C. G.; Zhao, G. F.; Zhou, Z. H.; Tang, C. C. J Organomet Chem 2007, 692, 3685; (b) Xu, X. Y.; Wang, C. G.; Zhou, Z. H.; Tang, X. F.; He, Z. J.; Tang, C. C. Eur J Org Chem 2007, 4487.