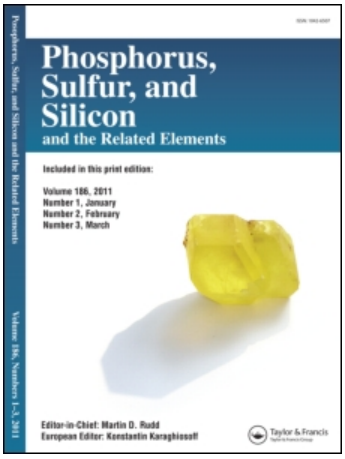


Phosphorus, Sulfur, and Silicon and the Related Elements
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713618290

Synthesis, Structure and Biological Activity of Some New Aroylurea Derivatives Containing 1,3,4-Thiadiazole

Xin-Jian Song[ab]; Xiao-Hong Tan[b]
[a] Key Laboratory of Biological Resources Protection and Utilization of Hubei Province, Enshi, Hubei, P. R. China [b] School of Chemical and Environmental Engineering, Hubei Institute for Nationalities, Enshi, Hubei, P. R. China

To cite this Article Song, Xin-Jian and Tan, Xiao-Hong(2008) 'Synthesis, Structure and Biological Activity of Some New Aroylurea Derivatives Containing 1,3,4-Thiadiazole', Phosphorus, Sulfur, and Silicon and the Related Elements, 183: 7, 1755 — 1765
To link to this Article: DOI: 10.1080/10426500701734323
URL: http://dx.doi.org/10.1080/10426500701734323

Phosphorus, Sulfur, and Silicon, 183:1755–1765, 2008

ISSN: 1042-6507 print / 1563-5325 online
DOI: 10.1080/10426500701734323

Taylor & Francis
Taylor & Francis Group

Synthesis, Structure and Biological Activity of Some New Aroylurea Derivatives Containing 1,3,4-Thiadiazole

Xin-Jian Song[1,2] and Xiao-Hong Tan[2]
[1]Key Laboratory of Biological Resources Protection and Utilization of Hubei Province. Enshi, Hubei, P. R. China
[2]School of Chemical and Environmental Engineering, Hubei Institute for Nationalities. Enshi, Hubei, P. R. China

In an extensive search for biologically active aroylurea compounds as plant growth regulators, a series of new N-aroyl-N′-[5-(E)-styryl-1,3,4-thiadiazol-2-yl]ureas have been designed and synthesized. Their structures were characterized by IR, ^{1}H NMR, MS, elemental analysis, and single-crystal X-ray diffraction techniques. The preliminary bioassay showed that some of the title compounds exhibited good plant-growth regulating activity.

Keywords 1,3,4-thiadiazole; aroylurea; crystal structure; plant growth regulating activity

INTRODUCTION

Over the last few decades, many efforts have been devoted to the research on aroylurea derivatives because they are known to possess diverse biological activities, such as insecticidal, fungicidal, herbicidal and plant-growth regulating activities.[1—4] Some of them have been widely used in agriculture. The important and multiple biological and pharmacological properties of 1,3,4-thiadiazole derivatives have also attracted considerable attention.[5—9] Therefore, we think it worthwhile to investigate the aroylurea derivatives containing 1,3,4-thiadiazole. Moreover, it has been reported that trans-6-styrylpurine has high cytokinin activity[10,11] among purine derivatives, demonstrating the

Received 29 August 2007; accepted 5 September 2007.
We acknowledge financial support from the Natural Science Foundation of Hubei Province, China (2007ABA001), and the Scientific Research Project for Excellent Young & Middle-aged Talent of Hubei Provincial Department of Education (grant No. Q200729001).
Address correspondence to Xin-Jian Song, School of Chemical and Environmental Engineering, Hubei Institute for Nationalities, Enshi, Hubei 445000, P. R. China. E-mail: whxjsong@yahoo.com.cn

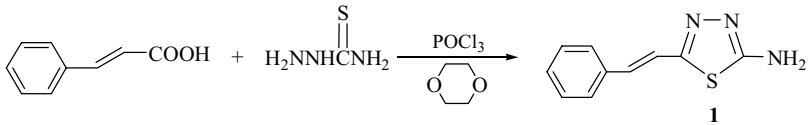
amino group is not essential for the promotion of all kinds of cytokinin effects; whereas cis-6-styrylpurine is only weakly active.[11,12] Based upon this point, the trans-styryl group could be assumed as bioactive substructure for plant-growth regulating activity.

In view of these, and as a continuation of our search for biologically active compounds, we synthesized a series of *N*-aroyl-*N*′-[5-(*E*)-styryl-1,3,4-thiadiazol-2-yl]urea for evaluating their plant-growth regulating activities, focusing mainly on the auxin activity and cytokinin activity.

RESULTS AND DISCUSSION

Synthesis and Characterization

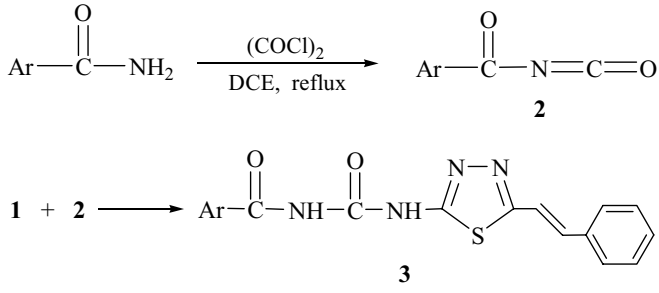
2-Amino-5-(*E*)-styryl-1,3,4-thiadiazole **1** was synthesized through the dehydration-cyclization of trans-cinnamic acid and thiosemicarbazide in the presence of phosphorous oxychloride, which was used as effective dehydrating agent (Scheme 1). Thus, the amino-substituted 1,3,4-thiadiazole heterocycle was conveniently prepared by one-step procedure; meanwhile, the trans-styryl group was simply introduced to 1,3,4-thiadiazole ring at 5-position. The required aroyl isocyanates **2** were obtained by treating substituted benzamide with an excess of oxalyl chloride in anhydrous 1,2-dichloroethane (DCE), was used without further purification after removing the remaining oxalyl chloride by distillation under reduced pressure, then reacted directly with 2-amino-5-styryl-1,3,4-thiadiazole to prepare the corresponding aroylureas (Scheme 2). This general method involves the advantages of readily available starting material, simple operation and good yield.



1

SCHEME 1

The structures of the title compounds **3a**–**3j** were confirmed by IR, ^{1}H NMR, elemental analysis, and mass spectroscopy. The IR spectra showed the existence of the two secondary amino groups (two broadened bands in the region of 3300–3100 cm^{-1}) and two carbonyl groups (two strong and sharp peaks in the range of 1725–1660 cm^{-1}), which are typical for the aroylurea structure. NMR spectra exhibited two broad singlet peaks at $\delta = 11.80$–12.30 and 11.55–11.75 ppm characteristic of two



Ar = C_6H_5 (a); 2-ClC_6H_4 (b); 3-ClC_6H_4 (c); 4-ClC_6H_4 (d); 2-BrC_6H_4 (e); 4-BrC_6H_4 (f); 2-$CH_3C_6H_4$ (g); 3-$CH_3C_6H_4$ (h); 4-$CH_3C_6H_4$ (i); 4-$CH_3OC_6H_4$ (j)

SCHEME 2

N–H groups, whichever signal was located downfield could be assigned to the N—H group bonded to thiadiazole ring owing to the occurrence of intramolecular hydrogen bonding together with the strong electron-drawing effect of the thiadiazole heterocycle. The vinyl protons were sandwiched among so many aromatic hydrogens that their signals were indecipherable. However, the signals from vinyl protons in intermediate **1** were distinguishable, appearing at δ 7.34 and 7.06 ppm as doublet with $J = 16.4$ Hz, which suggested that the styryl moiety assumes a trans-configuration, as further proved by X-ray diffraction analysis (see Figure 1). In addition, the EI mass spectra gave the anticipated molecular ion peaks. It is apparent that all the spectroscopic data for the title compounds are in accordance with their structures.

Crystal Structure Analysis

The crystallographic data for **3i** are summarized in Table I, and the selected bond lengths and angles are listed in Table II. The molecular

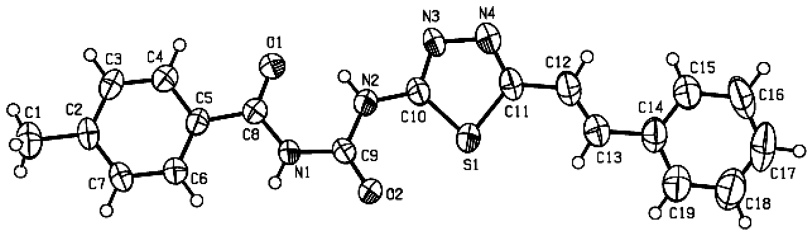


FIGURE 1 Molecular structure of compound **3i** with the atomic labeling.

TABLE I Crystallographic Data and Parameters for 3i

Empirical formula	$C_{19}H_{16}N_4O_2S$	
Formula weight	364.42	
Crystal system	Triclinic	
Space group	$P\bar{1}$	
Unit cell dimensions	$a = 6.8929(8)$ Å	$\alpha = 81.328(2)^\circ$
	$b = 10.8007(13)$ Å	$\beta = 77.906(2)^\circ$
	$c = 12.4114(15)$ Å	$\gamma = 73.700(2)^\circ$
Volume	863.01(18) Å^3	
Z	2	
Density (calculated)	1.402 Mg·m^{-3}	
Absorption coefficient	0.209 mm^{-1}	
$F(000)$	380	
θ range for data collection	1.69 to 20.81°	
Index ranges	$-6 \le h \le 6$, $-10 \le k \le 10$, $-12 \le l \le 12$	
Reflections collected	3750	
Independent reflections	1796 [$R_{int} = 0.0304$]	
Data/restraints/parameters	1796/0/237	
Goodness-of-fit on F^2	1.053	
Final R indices [$I > 2\sigma(I)$]	$R_1 = 0.0509$, $wR_2 = 0.1160$	
R indices (all data)	$R_1 = 0.0689$, $wR_2 = 0.1358$	
Large diff. peak and hole	0.180 and −0.180 e·Å^{-3}	

structure and the packing diagram of **3i** are depicted in Figures 1 and 2, respectively.

In the molecule of **3i**, all of the C—N distances (Table II) are between the normal C=N double bond (1.27 Å) and C—N single bond

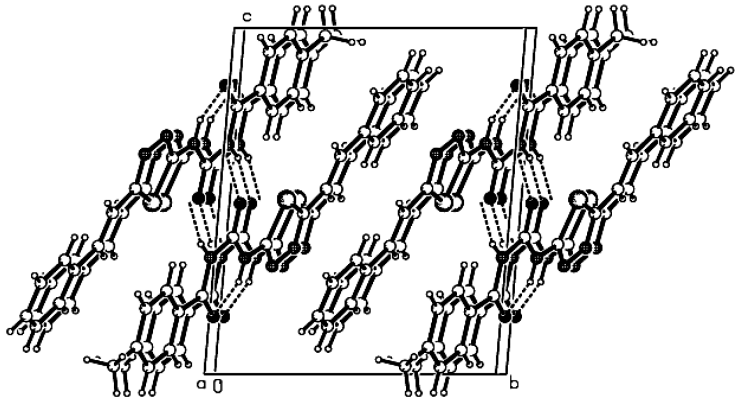


FIGURE 2 Packing diagram of compound **3i** approximately along a axis, showing the H-bonding (dashed lines) and π -π stacking interactions.

TABLE II Selected Bond Lengths (Å) and Bond Angles (°) for 3i

	Bond lengths		
C(1)–C(2)	1.512(6)	S(1)–C(10)	1.724(4)
C(5)–C(8)	1.483(6)	S(1)–C(11)	1.740(4)
O(1)–C(8)	1.226(5)	N(3)–C(10)	1.308(5)
O(2)–C(9)	1.218(4)	N(3)–N(4)	1.374(5)
N(1)–C(8)	1.372(5)	N(4)–C(11)	1.293(5)
N(1)–C(9)	1.397(5)	C(11)–C(12)	1.460(6)
N(2)–C(9)	1.344(5)	C(12)–C(13)	1.293(6)
N(2)–C(10)	1.364(5)	C(13)–C(14)	1.463(6)
	Bond angles		
O(1)–C(8)–N(1)	119.9(4)	N(3)–C(10)–S(1)	114.6(3)
O(1)–C(8)–C(5)	121.3(4)	C(10)–S(1)–C(11)	86.2(2)
N(1)–C(8)–C(5)	118.8(4)	C(10)–N(3)–N(4)	112.1(3)
C(8)–N(1)–C(9)	127.8(3)	C(11)–N(4)–N(3)	112.8(4)
O(2)–C(9)–N(1)	121.6(4)	N(4)–C(11)–S(1)	114.3(3)
O(2)–C(9)–N(2)	123.1(4)	N(4)–C(11)–C(12)	121.0(4)
N(2)–C(9)–N(1)	115.3(4)	C(12)–C(11)–S(1)	124.7(4)
C(9)–N(2)–C(10)	125.6(3)	C(11)–C(12)–C(13)	127.6(5)
N(2)–C(10)–S(1)	125.6(3)	C(12)–C(13)–C(14)	127.7(5)
N(3)–C(10)–N(2)	119.8(4)	C(13)–C(14)–C(15)	123.4(5)

(1.47 Å), indicating all the N atoms are characterized by sp^2 hybridization in part. The whole molecule is nearly coplanar except for the methyl H atoms, the dihedral angles formed by the thiadiazole ring with the methylbenzene and vinylbenzene moieties being only 7.7(2)° and 9.9(2)°, respectively.

The X-ray diffraction analysis revealed that the urea linkage unit O(1)—C(8)—N(1)—C(9)—N(2)—H(2) adopts the most stable conformation due to the presence of an intramolecular N–H···O hydrogen bond to give a planar six-membered ring. As shown in Figure 2 and Table III, intermolecular N–H···O hydrogen bonds link pairs of neighboring molecules into centrosymmetric dimers, which can be described as graph-set motifs of $R_2^2(8)$.[13] In addition, intermolecular π-π stacking interactions between thiadiazole and vinylbenzene rings were also observed. Obviously, these various non-covalent inter- and intramolecular

TABLE III Hydrogen-Bonding Geometry (Å, °) for Compound 3i

D–H···A	d(D–H)	d(H···A)	d(D···A)	∠D–H···A	Symmetry code
N(1)–H(1)···O(2)	0.86	2.15	2.986(4)	163	$-x+1, -y, -z+1$
N(2)–H(2)···O(1)	0.86	1.86	2.556(4)	137	

TABLE IV The Plant Growth Regulating Activities of Compounds 3a–3j

Compd.	Auxin activity (%)	Cytokinin activity (%)
3a	21.3	25.2
3b	19.5	32.7
3c	15.8	35.4
3d	17.3	45.1
3e	22.8	16.6
3f	16.4	37.9
3g	14.0	29.1
3h	10.5	47.5
3i	24.6	39.2
3j	15.1	27.6
IAA	28.7	
KT		51.5

interactions, such as hydrogen-bonding and π-π stacking, played a fundamental role in forming a three-dimensional supramolecular organization in the solid state.

Plant-Growth Regulating Activities

The plant-growth regulating activities of compounds **3a**–**3j** were evaluated according to a previously reported method.[14] The auxin activity was tested in terms of the elongation of wheat coleoptile, where β-indolylacetic acid (called IAA for short) was used as reference compound for comparison; while the cytokinin activity was investigated by means of cucumber cotyledon enlargement bioassay, in which kinetin (KT) was used as reference compound. All investigated compounds were tested at the concentration of 10 ppm. The data for the bioassays are outlined in Table IV. It is evident from the results that all title compounds displayed moderate-to-good cytokinin activity and an auxin activity to some extent. The substituents in aromatic phenyl ring had some effects on activity. Excitingly, compounds **3d** and **3h** exhibited considerably high cytokinin activity towards cucumber cotyledon, giving promotive percentages of 45.1 and 47.5%, respectively, but remained less active than kinetin. Overall, we would conclude that the aroylurea group, besides the 1,3,4-thiadiazole heterocycle and attached trans-styryl group, could exert beneficial effects on such good biological activity.

EXPERIMENTAL

All chemicals used for the preparations were of analytical grade. Solvents were dried by standard methods and distilled prior to use.

^{1}H NMR spectra were obtained on a Varian Mercury Plus-400 MHz Spectrometer with TMS as internal standard and DMSO-d_6 as the solvent. IR spectra were recorded in the range 4000–400 cm^{-1} on a Nicolet NEXUS 470 FT-IR spectrophotometer, using KBr pellets. Elemental analysis was performed by a Vario EL III analyzer. MS spectra were recorded with a Finnigan Trace MS 2000 organic mass spectrometer using the electron ionization (EI) method. Melting points were measured with an X-4 microscopic melting-point apparatus and uncorrected.

Synthesis of 2-Amino-5-(*E*)-styryl-1,3,4-thiadiazole 1

To a mixture of trans-cinnamic acid (14.82 g, 0.1 mol), thiosemicarbazide (9.11 g, 0.1 mol) and 100 mL of 1,4-dioxane was dropwise added phosphorous oxychloride (15.33 g, 0.1 mol) with stirring. The resulting slurry was heated slowly to gentle reflux with rapid evolution of hydrogen chloride gas, and the refluxing continued for about 3.5 h until the gas evolution ceased. The dioxane was evaporated off under reduced pressure and then 80 mL of cold water was added to the residue. The pH of the solution was adjusted to 8.0–9.0 with 40% sodium hydroxide, and a solid precipitate formed. The solid precipitate was filtered off, washed with water, air dried, and then recrystallized from ethanol to give 2-amino-5-(*E*)-styryl-1,3,4-thiadiazole **1** in 74% yield as pale yellow solid. M.p. 235–236°C; ^{1}H NMR (400 MHz, DMSO-d_6): δ7.64 (d, 2H, $J = 7.2$ Hz, Ar-H), 7.43 (s, 1H, NH_2), 7.39 (t, 2H, $J = 7.4$ Hz, Ar-H), 7.34 (d, 1H, $J = 16.4$ Hz, CH=), 7.31 (t, 1H, $J = 7.2$ Hz, Ar-H), 7.06 (d, 1H, $J = 16.4$ Hz, CH=); Anal. calcd for $C_{10}H_9N_3S$: C 59.09; H 4.46; N 20.67. Found: C 58.93; H 4.58; N 20.86.

General Synthetic Procedure for Target Compounds 3

To a stirred suspension of substituted benzamide (10 mmol) in 8 mL of anhydrous 1,2-dichloroethane (DCE), 10 mL of fresh distilled oxalyl chloride was added with cooling on a ice-bath and stirring. The reaction mixture was stirred for 3 h, while maintaining the temperature within 45–55°C; it was then refluxed under N_2 until the evolution of hydrogen chloride gas ceased. The solvent and the remaining oxalyl chloride was removed by distillation at reduced pressure, the crude aroyl isocyanate **2** was thus obtained without further isolation. Then the solution of intermediate **1** (1.83 g, 9 mmol) in 30 mL of dry acetonitrile was added dropwise to the corresponding aroyl isocyanate **2**. The mixture was stirred for 3–4 h at room temperature. The progress of the reactions was monitored by TLC. The solvent was removed by evaporation under

reduced pressure, and the residue was recrystallized from ethanol/DMF to afford white crystals **3a**–**3j** with m.p. >300°C.

Compound 3a

Yield: 81%; ^{1}H NMR (400 MHz, DMSO-d_6): δ 12.10 (s, 1H, NH), 11.65 (s, 1H, NH), 7.32–8.06 (m, 12H, Ar-H and CH=CH); IR (KBr, ν in cm^{-1}): 3233, 3138 (N–H), 1713, 1670 (C=O), 1635 (C=C), 1595 (C=N), 966 (trans CH=CH); Anal. calcd for $C_{18}H_{14}N_4O_2S$: C 61.70; H 4.03; N 15.99. Found: C 61.54; H 4.15; N 16.07; EI-MS (%): m/z 350 (M^+, 68), 228 (100), 202 (96), 121 (45), 105 (80).

Compound 3b

Yield: 69%; ^{1}H NMR (400 MHz, DMSO-d_6): δ 11.80 (s, 1H, NH), 11.74 (s, 1H, NH), 7.35–7.74 (m, 11H, Ar-H and CH=CH); IR (KBr, ν in cm^{-1}): 3241, 3155 (N–H), 1725, 1679 (C=O), 1636 (C=C), 1593 (C=N), 962 (trans CH=CH); Anal. calcd for $C_{18}H_{13}ClN_4O_2S$: C 56.18; H 3.40; N 14.56. Found: C 56.06; H 3.31; N 14.28; EI-MS (%): m/z 384 (M^+, 4), 349 (3), 228 (100), 202 (57), 155 (17), 139 (74), 111(32).

Compound 3c

Yield: 74%; ^{1}H NMR (400 MHz, DMSO-d_6): δ 12.04 (s, 1H, NH), 11.72 (s, 1H, NH), 7.37–8.09 (m, 11H, Ar-H and CH=CH); IR (KBr, ν in cm^{-1}): 3236, 3142 (N–H), 1717, 1697 (C=O), 1635 (C=C), 1591 (C=N), 969 (trans CH=CH); Anal. calcd for $C_{18}H_{13}ClN_4O_2S$: C 56.18; H 3.40; N 14.56. Found: C 56.39; H 3.52; N 14.70; EI-MS (%): m/z 384 (M^+, 3), 228 (80), 202 (100), 155 (19), 139 (85), 111(46).

Compound 3d

Yield: 77%; ^{1}H NMR (400 MHz, DMSO-d_6): δ 12.09 (s, 1H, NH), 11.71 (s, 1H, NH), 7.37–8.06 (m, 11H, Ar–H and CH=CH); IR (KBr, ν in cm^{-1}): 3230, 3133 (N–H), 1698, 1682 (C=O), 1637 (C=C), 1596 (C=N), 971 (trans CH=CH); Anal. calcd for $C_{18}H_{13}ClN_4O_2S$: C 56.18; H 3.40; N 14.56. Found: C 56.34; H 3.27; N 14.45; EI-MS (%): m/z 384 (M^+, 5), 228 (31), 202 (100), 155 (6), 139 (48), 111(49).

Compound 3e

Yield: 70%; ^{1}H NMR (400 MHz, DMSO-d_6): δ 11.81 (s, 1H, NH), 11.74 (s, 1H, NH), 7.37–7.76 (m, 11H, Ar-H and CH=CH); IR (KBr, ν in cm^{-1}): 3243, 3145 (N–H), 1724, 1678 (C=O), 1639 (C=C), 1587 (C=N), 962 (trans CH=CH); Anal. calcd for $C_{18}H_{13}BrN_4O_2S$: C 50.36; H 3.05; N 13.05. Found: C 50.23; H 3.16; N 13.19; EI-MS (%): m/z 428 (M^+, 3), 228 (100), 202 (53), 199 (23), 183 (59), 155(27).

Compound 3f

Yield: 75%; ^{1}H NMR (400 MHz, DMSO-d_6): δ 12.09 (s, 1H, NH), 11.71 (s, 1H, NH), 7.35–7.98 (m, 11H, Ar-H and CH=CH); IR (KBr, ν in cm^{-1}): 3210, 3147 (N–H), 1697, 1681 (C=O), 1628 (C=C), 1589 (C=N), 959 (trans CH=CH); Anal. calcd for $C_{18}H_{13}BrN_4O_2S$: C 50.36; H 3.05; N 13.05. Found: C 50.45; H 2.91; N 13.22; EI-MS (%): m/z 428 (M^+, 7), 228 (46), 202 (100), 199 (12), 183 (71), 155(58).

Compound 3g

Yield: 68%; ^{1}H NMR (400 MHz, DMSO-d_6): δ 12.02 (s, 1H, NH), 11.61 (s, 1H, NH), 7.31–7.74 (m, 11H, Ar-H and CH=CH), 2.44 (s, 3H, CH_3); IR (KBr, ν in cm^{-1}): 3220, 3111 (N–H), 1699, 1686 (C=O), 1631 (C=C), 1590 (C=N), 957 (trans CH=CH); Anal. calcd for $C_{19}H_{16}N_4O_2S$: C 62.62; H 4.43; N 15.37. Found: C 62.74; H 4.30; N 15.21; EI-MS (%): m/z 364 (M^+, 9), 228 (64), 202 (100), 135 (15), 119(76), 91(71).

Compound 3h

Yield: 73%; ^{1}H NMR (400 MHz, DMSO-d_6): δ 12.18 (s, 1H, NH), 11.61 (s, 1H, NH), 7.37–7.88 (m, 11H, Ar–H and CH=CH), 2.41 (s, 3H, CH_3); IR (KBr, ν in cm^{-1}): 3245, 3144 (N–H), 1705, 1673 (C=O), 1633 (C=C), 1589 (C=N), 962 (trans CH=CH); Anal. calcd for $C_{19}H_{16}N_4O_2S$: C 62.62; H 4.43; N 15.37. Found: C 62.49; H 4.52; N 15.56; EI-MS (%): m/z 364 (M^+, 4), 228 (43), 202 (100), 135 (6), 119(62), 91(48).

Compound 3i

Yield: 76%; ^{1}H NMR (400 MHz, DMSO-d_6): δ 12.22 (s, 1H, NH), 11.59 (s, 1H, NH), 7.37–7.97 (m, 11H, Ar–H and CH=CH), 2.42 (s, 3H, CH_3); IR (KBr, ν in cm^{-1}): 3276, 3146 (N–H), 1693, 1661 (C=O), 1634 (C=C), 1590 (C=N), 958 (trans CH=CH); Anal. calcd for $C_{19}H_{16}N_4O_2S$: C 62.62; H 4.43; N 15.37. Found: C 62.50; H 4.29; N 15.28; EI-MS (%): m/z 364 (M^+, 4), 228 (59), 202 (94), 135 (14), 119(100), 91(60).

Compound 3j

Yield: 79%; ^{1}H NMR (400 MHz, DMSO-d_6): δ 12.30 (s, 1H, NH), 11.55 (s, 1H, NH), 7.09–8.09 (m, 11H, Ar–H and CH=CH), 3.87 (s, 3H, OCH_3); IR (KBr, ν in cm^{-1}): 3290, 3139 (N–H), 1691, 1670 (C=O), 1630 (C=C), 1589 (C=N), 958 (trans CH=CH); Anal. calcd for $C_{19}H_{16}N_4O_3S$: C 59.99; H 4.24; N 14.73. Found: C 60.14; H 4.07; N 14.85; EI-MS (%): m/z 380 (M^+, 3), 228 (42), 202 (85), 151 (11), 135 (100), 107(12).

X-Ray Crystallography of Compound 3i

A colorless single crystal of compound **3i** with dimensions of 0.20 × 0.01 × 0.01 mm^3 was selected and mounted on a BRUKER SMART APEX-CCD diffractometer equipped with a graphite-monochromated Mo $K\alpha$ ($\lambda = 0.71073$ Å) radiation. The intensity data were collected by using a ψ-ω scan mode at 298(2) K. Absorption correction was not applied. The structure was solved by direct methods with SHELXS-97[15] and expanded using Fourier difference techniques. All non-hydrogen atoms were refined anisotropically, and the hydrogen atoms were added according to theoretical models. Structural refinement was carried out by full-matrix least-squares techniques on F^2 with SHELXL-97.[16] The θ_{max} for data collection is only 21 degrees, maybe indicating the diffracting power of the crystal was weak due to small crystal size.

SUPPLEMENTARY MATERIAL

Crystallographic data for **3i** have been deposited with the Cambridge Crystallographic Data Center (Deposition No. CCDC-656228). These data can be obtained free of charge by contacting the CCDC, 12 Union Road, Cambridge CB2 1EZ, UK (fax: +44-1223-336033; e-mail: deposit@ccdc.cam.ac.uk).

REFERENCES

[1] N. P. Hajjar and N. P. Casida, *Science*, **200**, 1499 (1978).
[2] L. Chen, Q. M. Wang, R. Q. Huang, C. H. Mao, J. Shang, and F. C. Bi, *J. Agric. Food Chem.*, **53,** 38 (2005).
[3] A. Abad, C. Agullo, A. C. Cunat, R. Jimenez, and C. Vilanova, *J. Agric. Food Chem.*, **52,** 4675 (2004).
[4] X. J. Song, S. Wang, X. H. Tan, Z. Y. Wang, and Y. G. Wang, *Chinese J. Org. Chem.*, **27,** 72 (2007).
[5] X. J. Zou, L. H. Lai, and G. Y. Jin, *J. Agric. Food Chem.*, **50,** 3757 (2002).
[6] X. J. Song, X. H. Tan, and Y. G. Wang, *Phosphorus Sulfur Silicon*, **182,** 1907 (2007).
[7] C. J. Chen, B. A. Song, S. Yang, G. F. Xu, P. S. Bhadury, L. H. Jin, D. Y. Hu, Q. Z. Li, F. Liu, W. Xue, P. Lu, and Z. Chen, *Bioorg. Med. Chem.*, **15,** 3981 (2007).
[8] T. M. Abdel-Rahman, *Phosphorus Sulfur Silicon*, **181,** 1737 (2006).
[9] S. Talath and A. K. Gadad, *Eur. J. Med. Chem.*, **41,** 918 (2006).
[10] T. R. Henderson, C. Frihart, N. L. Leonard, R. Y. Schmitz, and F. Skoog, *Phytochemistry*, **14,** 1687 (1975).
[11] S. Nishikawa, Z. Kumazawa, H. Mizutani, and N. Kashimura, *Agric. Biol. Chem.*, **50,** 1089 (1986).
[12] S. Koyama, Z. Kumazawa, N. Kashimura, and R. Nishida, *Agric. Biol. Chem.*, **49,** 1859 (1985).

[13] J. Bernstein, R. E. Davis, L. Shimoni, and N. L. Chang, Angew. *Chem. Int. Ed. Engl.*, **34,** 1555 (1995).
[14] Y. G. Wang, Y. X. Gong, X. Y. Zhao, W. F. Ye, and S. Wang, *Chinese J. Org. Chem.*, **23,** 195 (2003).
[15] G. M. Sheldrick, *SHELXS-97: Program for the Solution of Crystal Structure*. University of Göttingen, Germany, 1997.
[16] G. M. Sheldrick, *SHELXL-97: Program for the Refinement of Crystal Structure.* University of Göttingen, Germany, 1997.