Cycloaddition Reactions of *N*-Benzotriazolylketene as a Heteroarylketene: A Practical Approach to the Synthesis of Novel Azetidinones

Fatemeh Zigheimat,[a] Mohammad Reza Islami,*[a] Farahnaz Nourmohammadian[b]

[a] Department of Chemistry, Shahid Bahonar University of Kerman, 76169, Kerman, Iran
Fax +98(341)3222033; E-mail: mrislami@uk.ac.ir

[b] Department of Organic Colorants, Institute for Color Science and Technology, 654-16765, Tehran, Iran

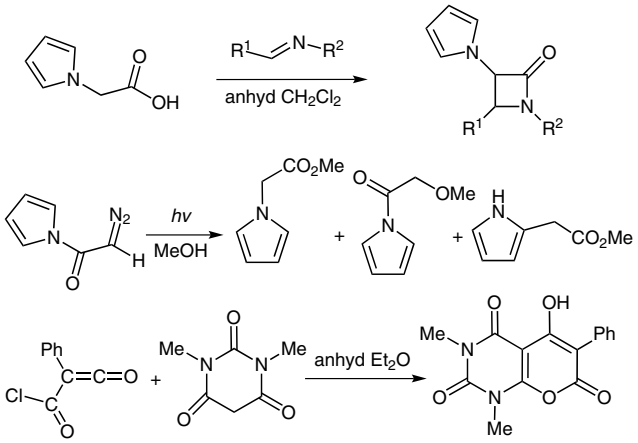
Received: 01.10.2013; Accepted after revision: 14.10.2013

Abstract: A series of novel functionalized azetidinones containing the benzotriazole moiety were synthesized stereoselectively by a reaction of benzotriazolylacetic acid, aromatic amines, and Mukaiyama's reagent in the presence of triethylamine in dichloromethane at ambient temperature. This transformation generates a four-membered lactam and presumably proceeds via in situ generation of benzotriazolylketene as a heteroarylketene. In contrast to the products obtained from the reaction of pyrrolylketene with imines in which *cis*-azetidinones were formed as major products, the generated benzotriazolylyketene reacted with imines forming the *trans*-lactams as major products.

Key words: ketenes, Schiff bases, *N*-benzotriazolylketene, [2π+2π] cycloaddition, azetidinones

β-Lactams (azetidinones) are an important class of antibiotics,[1–6] and in recent years their clinical use has expanded significantly.[7–13] The β-lactam ring plays an important role in medical treatment of infection by inhibiting the synthesis of the peptidoglycan layer of bacterial cell walls.[12] Since Staudinger prepared the first synthetic β-lactam,[13] there have been numerous reports in the literature regarding the synthesis and application of such compounds.[14–17] One of the most important methods for the synthesis of β-lactams is the use of ketenes. Ketenes are an important class of compounds in the synthesis of four- and six-membered rings.[18–22] Ketenes are remarkable for the variety of ways in which they can be prepared[23–25] and also for the range of useful products from their reactions with unsaturated compounds.[26,27] They have long been known for their unique reactivity in [2+2]-cycloaddition reactions.[28–30]

Benzotriazoles such as 1-alkylbenzotriazoles[31] and nitro derivatives are interesting due to their biological activities as herbicides.[32–34] Furthermore, benzotriazoles connected to acylonitriles showed interesting activity against the mycobacterium turberculosis.[35] However, benzotriazoles directly substituted with a β-lactam ring have received little attention[36] probably due to the lack of convenient methods for their preparation. Recently, one of the focuses in our research group has been to develop the synthesis of new heterocyclic compounds by the reaction of ketenes with imines,[14] 1,3-dicarbonyl compounds, such as dimedone and barbituric acid derivatives[37] (Scheme 1). In this present work we have synthesized new β-lactams including a benzotriazole moiety in a stereoselective manner by producing the corresponding ketene and trapping it by different Schiff bases. Herein we wish to report our results.



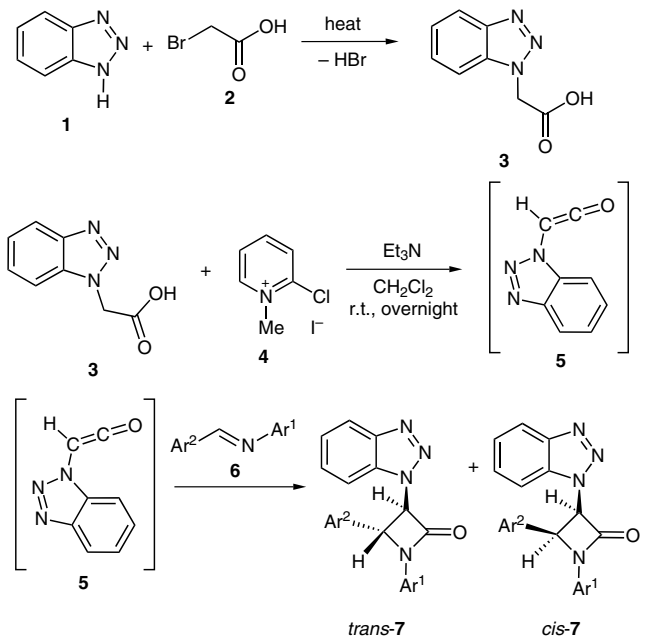
Scheme 1 Reaction of ketenes with imines, methanol, and 1,3-dimethylbarbituric acid

Firstly, we tried to prepare benzotriazolyl acetic acid as a precursor by known procedures. Although our literature survey showed there are several procedures for achieving this goal, several of these methods suffered from drawbacks such as prolonged reaction times, esoteric starting materials, the need for catalysts such as copper(II) bronze, the use of an organic solvent such as xylene, cumbersome apparatus, microwave conditions, and in some cases benzotriazolylmethyl cyanide was required as a precursor.[38–40] Therefore, in order to modify and simplify the synthesis, benzotriazole (**1**) was mixed with 2-bromoacetic acid (**2**), heated until the mixture melted and heating was continued for 60 minutes. Upon cooling to room temperature the desired product **3** was formed as a solid and, after recrystallization from water, was used in the following reactions.

As shown in Scheme 2, treatment of imines **6** with *N*-benzotriazolylketene **5** generated in situ from benzotriazolyl acetic acid (**3**) and 2-chloro-1-methylpyridinium iodide (**4**) in the presence of Et_3N gave products which were characterized as β-lactams **7** on the basis of spectroscopic analysis. In contrast to the obtained products from the reaction of pyrrolylketene with imines in which *cis*-azetidi-

SYNLETT 2014, 25, 0229–0232
Advanced online publication: 02.12.2013
DOI: 10.1055/s-0033-1340280; Art ID: ST-2013-D0927-L

nones were formed as major products,[14] ketene **5** reacted with imines **6**, forming the *trans*-lactams **7a**–**e** as major products (Table 1).



Scheme 2 β-Lactams from Benzotriazolylketene

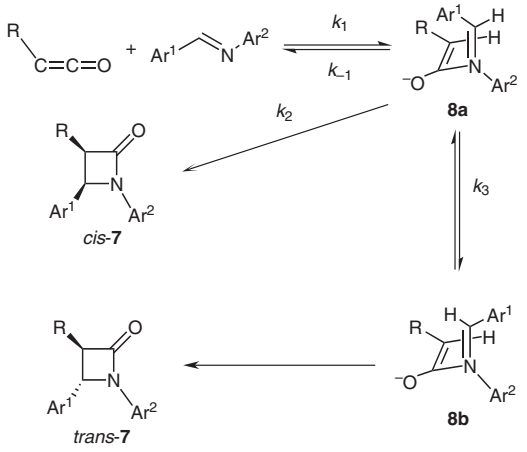
Table 1 β-Lactams **7** from Benzotriazolylketene **5** and Imines **6**

Product	Ar^1	Ar^2	Yield (%) *cis*[a]	Yield (%) *trans*[a]
7a	Ph	Ph	1	23
7b	4-BrC_6H_4	Ph	1	35
7c	4-ClC_6H_4	Ph	1	38
7d	4-MeC_6H_4	Ph	20	46
7e	4-$MeOC_6H_4$	Ph	11	40

[a] Isolated yield of pure product.

The structures of products fully characterized by IR, ^{1}H NMR, and ^{13}C NMR spectroscopy (see Supporting Information) along with elemental analysis data. The IR spectra of these compounds showed absorption bands due to the carbonyl group at 1752–1774 cm^{-1}. ^{1}H NMR spectroscopy is generally used for distinguishing between *cis*- and *trans*-β-lactam isomers using H–H coupling constants, as the *J* value is smaller (2.0–2.5 Hz) in a *trans*-β-lactam than in a *cis*-β-lactam (5.0–6.0 Hz). The ^{1}H NMR spectrum of *trans*-**7a** exhibited signals corresponding to the vicinal methine protons at δ = 5.87 and 5.54 ppm which appear as two doublets ($^3J_{HH}$ = 2.4 Hz). The aromatic protons appeared as a multiplet at δ = 7.45–7.07 ppm. The ^{1}H-decoupled ^{13}C NMR spectrum of *trans*-**7a** showed 17 distinct resonances in agreement with the suggested structure; partial assignment of these resonances is given in the experimental section. Characteristic ^{13}C NMR signals were observed corresponding to the carbonyl carbon at δ = 159.70 ppm and signals at δ = 71.42 and 62.88 ppm corresponding to methine carbons. The ^{1}H NMR and ^{13}C NMR of *cis*-**7a** were similar to those of *trans*-**7a** except for the coupling constant of the vicinal methine protons ($^3J_{HH}$ = 5.4 Hz). The ^{1}H NMR and ^{13}C NMR spectroscopic data of *trans*- and *cis*-isomers of compounds **7b**–**e** are presented in the experimental section.

A plausible mechanistic pathway that best explains the formation of these isomers is shown in Scheme 3. It is generally accepted,[15,41,42] that the stereochemistry in the ketene–imine cycloaddition involves initial attack of the imine onto the ketene with formation of intermediate **8a** which undergoes competitive ring closure to the *cis*-β-lactam **7**, with isomerization to the less crowded intermediate **8b** and ring closure to *trans*-β-lactam **7**.



Scheme 3 Plausible mechanism for the stereoselective formation of β-lactams

The difference between stereochemistry of products from pyrrolylketene[14] and products from benzotriazolylketene may be attributed to differences in steric effects in the mechanistic pathways leading to the different products.[15] The nitrogen of the imine attacks the ketene forming initial intermediate **8a**. Since the benzotriazole ring is larger than pyrrole ring k_3 is enhanced relative to k_2 so the *trans*-β-lactams **7** are favored.

In conclusion, the present work describes the synthesis of a series of novel β-lactams containing the benzotriazole moiety in a stereoselective manner via reaction of benzotriazolylacetic acid, aromatic amine, and 2-chloro-1-methylpyridinium iodide in the presence of triethylamine in dichloromethane at ambient temperature. This transformation generates a four-membered lactam and presumably proceeds via in situ generation of benzotriazolylketene and its [2+2]-cycloaddition reaction with Schiff bases. It is worthy of note that, in contrast to the products obtained from the reaction of pyrrolylketene with imines, in the present work *trans*-β-lactams were isolated as the main products.

Modified Procedure for the Synthesis of 2-(1*H*-1,2,3-Benzotriazol-1-yl) Acetic Acid 3

In a 100 mL round-bottomed flask were placed 2-bromoacetic acid (1.4 g, 10 mmol) and benzotriazole (0.6 g, 5 mmol). The mixture was heated until it melted, and then heating was continued for 60 min. On cooling, the product formed as a white solid that was recrystallized from H_2O (0.5 g, 58% yield).

Typical Procedure for the Preparation of Compounds 7a–e

Benzotriazolylacetic acid (**3**, 0.18 g, 1.0 mmol) was mixed with 2-chloro-*N*-methylpyridinium iodide (**4**, 0.30 g, 1.2 mmol) and dry Et_3N (0.50 mL, 3.6 mmol) in anhydrous CH_2Cl_2 (20 mL) under a nitrogen atmosphere at ambient temperature. The suspension was stirred for 5 min, and then a solution of *N*-benzylideneaniline (0.2 g, 1.1 mmol) in dry CH_2C1_2 (5 mL) was added, and the reaction mixture was stirred overnight. The brown solution was washed with 8% aq HCl and then with H_2O. The organic layer was dried over Na_2SO_4, filtered, and the solvent was removed under reduced pressure. The products were purified by column chromatography using *n*-hexane–EtOAc 5:3(v/v) as eluent. The *trans*- and *cis*-3-(1*H*-1,2,3-benzotriazol-1-yl)-1,4-diphenyl-2-azetanones (*trans*- and *cis*-**7a**) were isolated as the major and minor products, respectively.

Analytical Data

3-(1*H*-1,2,3-Benzotriazol-1-yl)-1,4-diphenyl-2-azetanone (*trans*-7a)

White solid; yield: 80 mg (23%); mp 158–159 °C. IR (KBr): ν_{max} = 1774 (C=O) cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 8.06 (d, 1 H, $^3J_{H-H}$ = 8.3 Hz, Ar), 7.45–7.07 (m, 13 H, Ar), 5.87 (d, 1 H, $^3J_{H-H}$ = 2.4 Hz), 5.54 (d, 1 H, $^3J_{H-H}$ = 2.4 Hz) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 159.70 (C=O), 146.28, 136.54, 134.90, 132.49 (4 C), 129.66, 129.60, 129.41, 128.49, 126.13, 125.22, 124.66, 120.55, 117.81, 109.30, 71.42, 62.88 (12 C–H) ppm. Anal. Calcd (%) for $C_{21}H_{16}N_4O$ (340.39): C, 74.10; H, 4.74; N, 16.46. Found: C, 73.85; H, 5.13; N, 16.33.

3-(1*H*-1,2,3-Benzotriazol-1-yl)-1,4-diphenyl-2-azetanone (*cis*-7a)

Yellow solid; yield: 4 mg (1%); mp 191–193 °C. IR (KBr): ν_{max} = 1774 (C=O) cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 7.77 (d, 1 H, $^3J_{H-H}$ = 9.8 Hz, Ar), 7.46–6.87 (m, 13 H, Ar), 6.52 (d, 1 H, $^3J_{H-H}$ = 5.4 Hz), 5.66 (d, 1 H, $^3J_{H-H}$ = 5.4 Hz) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 158.97 (C=O), 145.69, 136.97, 132.71, 130.96 (4 C), 129.44, 128.79, 128.29, 127.62, 126.62, 125.30, 123.93, 119.99, 117.60, 109.85, 66.85, 61.57 (12 C–H) ppm. Anal. Calcd (%) for $C_{21}H_{16}N_4O$ (340.39): C, 74.10; H, 4.74; N, 16.46. Found: C, 73.97; H, 5.10; N, 16.65.

3-(1*H*-1,2,3-Benzotriazol-1-yl)-1-(4-bromophenyl)-4-phenyl-2-azetanone (*trans*-7b)

Light yellow solid; yield: 150 mg (35%); mp 188–189 °C. IR (KBr): ν_{max} = 1754 (C=O) cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 8.05 (d, 1 H, $^3J_{H-H}$ = 8.3 Hz, Ar), 7.47–7.19 (m, 12 H, Ar), 5.84 (d, 1 H, $^3J_{H-H}$ = 2.4 Hz), 5.54 (d, 1 H, $^3J_{H-H}$ = 2.4 Hz) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 159.68 (C=O), 146.23, 135.50, 134.44, 132.53, 118.13 (5 C), 132.46, 129.81, 129.77, 128.56, 126.11, 124.72, 120.58, 119.32, 109.16, 71.46, 63.06 (11 C–H) ppm. Anal. Calcd (%) for $C_{21}H_{15}BrN_4O$ (419.28): C, 60.16; H, 3.61; N, 13.36. Found: C, 60.55; H, 3.56; N, 12.99.

3-(1*H*-1,2,3-Benzotriazol-1-yl)-1-(4-bromophenyl)-4-phenyl-2-azetanone (*cis*-7b)

Pale yellow solid; yield: 4 mg (1%); mp 176–178 °C (dec.). IR (KBr): ν_{max} = 1754 (C=O) cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 7.77 (d, 1 H, $^3J_{H-H}$ = 8.4 Hz, Ar), 7.42–6.88 (m, 12 H, Ar), 6.51 (d, 1 H, $^3J_{H-H}$ = 5.4 Hz), 5.64 (d, 1 H, $^3J_{H-H}$ = 5.4 Hz) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 158.94 (C=O), 145.64, 135.89, 132.65, 130.46, 119.15 (5 C), 132.49, 131.72, 128.99, 128.39, 127.74, 126.59, 124.03, 120.06, 109.59, 66.95, 61.69 (11 C–H) ppm. Anal. Calcd (%) for $C_{21}H_{15}BrN_4O$ (429.28): C, 60.16; H, 3.61; N, 13.36. Found: C, 60.49; H, 3.47; N, 13.15.

3-(1*H*-1,2,3-Benzotriazol-1-yl)-1-(4-chlorophenyl)-4-phenyl-2-azetanone (*trans*-7c)

Pale yellow solid; yield: 140 mg (38%); mp 189–190 °C (dec.). IR (KBr): ν_{max} = 1773 (C=O) cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 8.04 (d, 1 H, $^3J_{H-H}$=8.4 Hz, Ar), 7.43–7.18 (m, 12 H, Ar), 5.84 (d, 1 H, $^3J_{H-H}$ = 2.4 Hz), 5.54 (d, 1 H, $^3J_{H-H}$ = 2.4 Hz) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 159.65 (C=O), 146.23, 135.05, 134.50, 132.55, 130.44 (5 C), 129.79, 129.75, 129.52, 128.54, 126.12, 124.70, 120.56, 119.01, 109.18, 71.44, 63.09 (11 C–H) ppm. Anal. Calcd (%) for $C_{21}H_{15}ClN_4O$ (374.83): C, 67.29; H, 4.03; N, 14.95. Found: C, 67.29; H, 3.93; N, 14.71.

3-(1*H*-1,2,3-Benzotriazol-1-yl)-1-(4-chlorophenyl)-4-phenyl-2-azetanone (*cis*-7c)

Pale yellow solid; yield: 5 mg (1%); mp 218–220 °C (dec.). IR (KBr): ν_{max} = 1773 (C=O) cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 7.77 (d, 1 H, $^3J_{H-H}$ = 9.2 Hz, Ar), 7.40–6.87 (m, 12 H, Ar), 6.51 (d, 1 H, $^3J_{H-H}$ = 5.4 Hz), 5.64 (d, 1 H, $^3J_{H-H}$ = 5.4 Hz) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 158.91 (C=O), 145.63, 135.42, 132.64, 130.49, 128.79 (5 C), 129.56, 129.00, 128.39, 127.75, 126.59, 124.05, 120.05, 118.82, 109.59, 66.92, 61.71 (11 C–H) ppm. Anal. Calcd (%) for $C_{21}H_{15}ClN_4O$ (374.83): C, 67.29; H, 4.03; N, 14.95. Found: C, 67.33; H, 4.28; N, 14.80.

3-(1*H*-1,2,3-Benzotriazol-1-yl)-1-(4-methylphenyl)-4-phenyl-2-azetanone (*trans*-7d)

Yellow solid; yield: 160 mg (46%); mp 160–161 °C. IR (KBr): ν_{max} = 1752 (C=O) cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 8.05 (d, 1 H, $^3J_{H-H}$ = 8.3 Hz, Ar), 7.44–7.18 (m, 8 H, Ar), 7.23 (d, 2 H, $^3J_{H-H}$ = 8.3 Hz, Ar), 7.05 (d, 2 H, $^3J_{H-H}$ = 8.3 Hz, Ar), 5.85 (d, 1 H, $^3J_{H-H}$ = 2.3 Hz), 5.50 (d, 1 H, $^3J_{H-H}$ = 2.3 Hz), 2.24 (s, 3 H, Me) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 159.39 (C=O), 146.30, 135.02, 135.00, 134.10, 132.46 (5 C), 129.89, 129.60, 129.53, 128.45, 126.15, 124.62, 120.51, 117.75, 109.35, 71.45, 62.82 (11 C–H), 21.00 (Me) ppm. Anal. Calcd (%) for $C_{22}H_{18}N_4O$ (354.41): C, 74.56; H, 5.12; N, 15.81. Found: C, 74.77; H, 5.10; N, 15.75.

3-(1*H*-1,2,3-Benzotriazol-1-yl)-1-(4-methylphenyl)-4-phenyl-2-azetanone (*cis*-7d)

Yellow solid; yield: 70 mg (20%); mp 176–178 °C. IR (KBr): ν_{max} = 1752 (C=O) cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 7.76 (d, 1 H, $^3J_{H-H}$ = 8.4 Hz, Ar), 7.41 (d, 2 H, $^3J_{H-H}$ = 8.3Hz, Ar), 7.35–7.00 (m, 5 H, Ar), 7.09 (d, 2 H, $^3J_{H-H}$ = 8.3 Hz, Ar), 6.87–6.86 (m, 3 H, Ar), 6.50 (d, 1 H, $^3J_{H-H}$ = 5.4 Hz), 5.63 (d, 1 H, $^3J_{H-H}$ = 5.4 Hz), 2.26 (s, 3 H, Me) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 158.71 (C=O), 145.68, 135.08, 134.56, 132.73, 131.11 (5 C), 129.91, 128.71, 128.24, 127.58, 126.64, 123.90, 119.94, 117.52, 109.90, 66.84, 61.51 (11 C–H), 21.02 (Me) ppm. Anal. Calcd (%) for $C_{22}H_{18}N_4O$ (354.41): C, 74.56; H, 5.12; N, 15.81. Found: C, 74.89; H, 5.17; N, 15.87.

3-(1*H*-1,2,3-Benzotriazol-1-yl)-1-(4-methoxyphenyl)-4-phenyl-2-azetanone (*trans*-7e)

Pale yellow solid; yield: 150 mg (40%); mp 168 °C. IR (KBr): ν_{max} = 1760 (C=O) cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 8.04 (d, 1 H, $^3J_{H-H}$ = 8.3 Hz, Ar), 7.44–7.32 (m, 8 H, Ar), 7.28 (d, 2 H, $^3J_{H-H}$ = 9.0 Hz, Ar), 6.78 (d, 2 H, $^3J_{H-H}$ = 9.0 Hz, Ar), 5.85 (d, 1 H, $^3J_{H-H}$ = 2.3 Hz), 5.49 (d, 1 H, $^3J_{H-H}$ = 2.3 Hz), 3.69 (s, 3 H, OMe) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 159.09 (C=O), 156.95, 146.29, 134.96, 132.48, 129.96 (5 C), 129.61, 129.56, 128.44, 126.19, 124.62, 120.50, 119.20, 114.60, 109.36, 71.45, 62.96 (11 C–H), 55.49 (OMe) ppm. Anal. Calcd for $C_{22}H_{18}N_4O_2$ (370.41): C, 71.34; H, 4.90; N, 15.13. Found: C, 71.39; H, 5.00; N, 15.48.

3-(1*H*-1,2,3-Benzotriazol-1-yl)-1-(4-methoxyphenyl)-4-phenyl-2-azetanone (*cis*-7e)

Yellow solid; yield: 40 mg (11%); mp 158–160 °C. IR (KBr): ν_{max} = 1760 (C=O) cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$): δ = 7.75 (d, 1 H,

$^3J_{H–H}$ = 8.4 Hz, Ar), 7.43–7.41 (m, 1 H, Ar), 7.38 (d, 2 H, $^3J_{H–H}$ = 9.0 Hz, Ar), 7.29–7.00 (m, 5 H, Ar), 6.88–6.86 (m, 2 H, Ar), 6.81 (d, 2 H, $^3J_{H–H}$ = 9.0 Hz, Ar), 6.50 (d, 1 H, $^3J_{H–H}$ = 5.3 Hz), 5.62 (d, 1 H, $^3J_{H–H}$ = 5.3 Hz), 3.72 (s, 3 H, OMe) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 158.36 (C=O), 156.97, 145.66, 132.73, 131.11, 130.46 (5 C), 128.74, 128.25, 127.59, 126.67, 123.91, 119.93, 118.92, 114.59, 109.89, 66.87, 61.62 (11 C–H), 55.52 (OMe) ppm. Anal. Calcd (%) for $C_{22}H_{18}N_4O_2$ (370.41): C, 71.34; H, 4.90; N, 15.13. Found: C, 71.50; H, 5.05; N, 15.51.

Acknowledgment

The authors express appreciation to the Shahid Bahonar University of Kerman Faculty Research committee funds for its support of this investigation.

Supporting Information for this article is available online at http://www.thieme-connect.com/ejournals/toc/synlett.

References

(1) Elander, R. P. *Appl. Microbiol. Biotechnol.* **2003**, *61*, 385.
(2) Pichichero, M. E. *Pediatrics* **2005**, *115*, 1048.
(3) Fisher, J. F.; Meroueh, S. O.; Mobashery, S. *Chem. Rev.* **2005**, *105*, 395.
(4) Kasten, B.; Reski, R. *J. Plant Physiol.* **1997**, *150*, 137.
(5) Nangia, A.; Biradha, K.; Desiraju, G. R. *J. Chem. Soc., Perkin Trans. 2* **1996**, 943.
(6) Cohen, N. C. *J. Med. Chem.* **1983**, *26*, 259.
(7) O'Boyle, N. M.; Carr, M.; Greene, L. M.; Bergin, O.; Nathwani, S. M.; McCabe, T.; Lloyd, D. G.; Zisterer, D. M.; Meegan, M. J. *J. Med. Chem.* **2010**, *53*, 8569.
(8) O'Boyle, N. M.; Greene, L. M.; Bergin, O.; Jean-Baptiste, F.; McCabe, T.; Lloyd, D. G.; Zisterer, D. M.; Meegan, M. J. *Bioorg. Med. Chem.* **2011**, *19*, 2306.
(9) Hengzhuang, W.; Ciofu, O.; Yang, L.; Wu, H.; Song, Z.; Oliver, A.; Høiby, N. *Antimicrob. Agents Chemother.* **2013**, *57*, 196.
(10) Herzberg, O.; Moult, J. *Science* **1987**, *236*, 694.
(11) Nichol, K. A.; Zhanel, G. G.; Hoban, D. J. *Antimicrob. Agents Chemother.* **2002**, *46*, 3261.
(12) Tipper, D. J. *Rev. Infect. Dis.* **1979**, *1*, 39.
(13) Staudinger, H. *Justus Liebigs Ann. Chem.* **1907**, *356*, 51.
(14) Islami, M. R.; Allen, A. D.; Vukovic, S.; Tidwell, T. T. *Org. Lett.* **2011**, *13*, 494.
(15) Jiao, L.; Liang, Y.; Xu, J. *J. Am. Chem. Soc.* **2006**, *128*, 6060.
(16) Lee, S. H. *Bull. Korean Chem. Soc.* **2013**, *34*, 121.
(17) Tidwell, T. T. *Angew. Chem. Int. Ed.* **2008**, *47*, 1016.
(18) Leung-Toung, R.; Tidwell, T. T. *J. Am. Chem. Soc.* **1990**, *112*, 1042.
(19) Sharma, A. K.; Mahajan, M. P. *Tetrahedron* **1997**, *53*, 13841.
(20) Bandyopadhyay, D.; Cruz, J.; Banik, B. K. *Tetrahedron* **2012**, *68*, 10686.
(21) Liu, R.; Tidwell, T. T. *Can. J. Chem.* **1995**, *73*, 1818.
(22) Allen, A. D.; Tidwell, T. T. *Eur. J. Org. Chem.* **2012**, 1081.
(23) Penn, J. H.; Owens, W. H. *J. Am. Chem. Soc.* **1993**, *115*, 82.
(24) Baigrie, L. M.; Seikaly, H. R.; Tidwell, T. T. *J. Am. Chem. Soc.* **1985**, *107*, 5391.
(25) Leung-Toung, R.; Wentrup, C. *J. Org. Chem.* **1992**, *57*, 4850.
(26) Alonso, E.; López-Ortiz, F.; del Pozo, C.; Peralta, E.; Macías, A.; González, J. *J. Org. Chem.* **2001**, *66*, 6333.
(27) Bennett, D. M.; Okamoto, I.; Danheiser, R. L. *Org. Lett.* **1999**, *1*, 641.
(28) Brady, W. T.; Saidi, K. *J. Org. Chem.* **1979**, *44*, 733.
(29) Montaigne, R.; Ghosez, L. *Angew. Chem., Int. Ed. Engl.* **1968**, *7*, 221.
(30) Brady, W. T.; Saidi, K. *J. Org. Chem.* **1980**, *45*, 727.
(31) Katritzky, A. R.; Wu, J.; Kuzmierkiewicz, W.; Rachwal, S. *Liebigs Ann. Chem.* **1994**, 1.
(32) Eugene, D. R.; Vernon, K. R. US 4,240,822, **1980**.
(33) Eugene, D. R.; Vernon, K. R. US 4,086,242, **1978**.
(34) Suma, B. V.; Natesh, N. N.; Madhavan, V. *J. Chem. Pharm. Res.* **2011**, *3*, 375.
(35) Sanna, P.; Carta, A.; Rahbar Nikookar, M. E. *Eur. J. Med. Chem.* **2000**, *35*, 535.
(36) Sharma, S. D.; Saluja, A.; Bhaduri, S. *Indian J. Chem., Sect. B.: Org. Chem. Incl. Med. Chem.* **2000**, *39*, 156.
(37) Sheibani, H.; Islami, M. R.; Khabazzadeh, H.; Saidi, K. *Tetrahedron* **2004**, *60*, 5931.
(38) Pellicciari, R.; Fringuelli, R.; Natalini, B.; Brucato, L.; Contessa, A. R. *Arch. Pharm.* **1985**, *318*, 393.
(39) Gupton, J. T.; Hicks, F. A.; Smith, S. Q.; Main, A. D.; Petrich, S. A.; Wilkinson, D. R.; Sikorski, J. A.; Katritzky, A. R. *Tetrahedron* **1993**, *49*, 10205.
(40) Khalafi-Nezhad, A.; Zare, A.; Parhami, A.; Soltani Rad, M. N.; Nejabat, G. R. *J. Iran. Chem. Soc.* **2007**, *4*, 271.
(41) Fu, N.; Tidwell, T. T. *Tetrahedron* **2008**, *64*, 10465.
(42) Cossio, F. P.; Ugalde, J. M.; Lopez, X.; Lecea, B.; Palomo, C. *J. Am. Chem. Soc.* **1993**, *115*, 995.

