Green Chemistry

Accepted Manuscript

ROYAL SOCIETY OF CHEMISTRY

www.rsc.org/greenchem

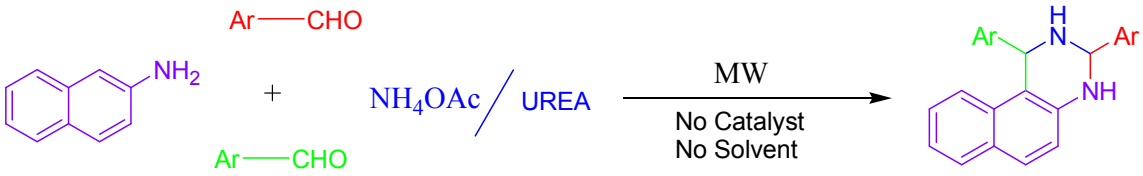
Graphical Abstract:

Catalyst- and solvent-free, pot, atom and step economic synthesis of tetrahydroquinazolines by an aza-Diels–Alder reaction strategy

Debajyoti Bhuyan[a], Rupam Sarma[b], Yuvaraj Dommaraju[a], Dipak Prajapati[a,*]

[a]*Medicinal Chemistry Division, CSIR-North-East Institute of Science & Technology, Jorhat, Assam 785006, India*

[b]*Department of Chemistry, Nalbari College, Nalbari, Assam 781335, India*



2,4-Disubstituted tetrahydroquinazolines can be readily obtained via a four-component aza-Diels–Alder reaction inside a microwave reactor. The methodology developed is simple, catalyst- and solvent-free and can be tuned to get dihydroquinazoline derivatives.

Journal Name

RSCPublishing

COMMUNICATION

Catalyst- and solvent-free, pot, atom and step economic synthesis of tetrahydroquinazolines by an aza-Diels–Alder reaction strategy

Cite this: DOI: 10.1039/x0xx00000x

Received ooth January 2012,
Accepted ooth January 2012

DOI: 10.1039/x0xx00000x

www.rsc.org/

Debajyoti Bhuyan[a], Rupam Sarma[b], Yuvaraj Dommaraju[a], Dipak Prajapati[a,*]

A pot, atom and step economic (PASE) synthesis of tetrahydroquinazolines has been achieved via microwave-assisted four-component catalyst- and solvent-free aza-Diels–Alder reaction strategy. The key step of the methodology is the in situ generation of both the diene and the dienophile and their subsequent reaction to give the desired product.

Introduction

The concept of pot, atom and step economy (PASE), first conceived by Clarke and co-workers,[1] provides a new line of approach towards developing environmentally friendly synthetic technologies. The formulation of the PASE concept is based on the introduction of the idea of pot economy and combining it with the already known ideas of atom and step economy. An atom economic procedure takes into consideration the number of atoms of all the reagents that constitutes the desired product, thereby regulating the waste generated in terms of participating atoms.[2] On the other hand, a step economic procedure regulates the efficiency of a procedure by minimising the number of steps required to synthesize the target molecule.[3] A method is considered pot economic if successive reaction steps can be carried out in one reaction vessel without the requirement of workup and isolation of the intermediate species.[4] The beauty of the PASE concept is that it brings together divergent aspects of green chemistry within a single umbrella so that one can plan, execute and monitor organic synthesis in a way that leads to minimal waste generation.

The hetero Diels–Alder reaction has become a powerful and widely used strategy for the construction of N-containing 6-membered heterocyclic units as it ensures 100% atom economy.[5] A number of synthetic groups have craftily employed the aza-Diels–Alder (ADA) reaction to construct substructures of biological and pharmaceutical significance.[6] For example, synthesis of microfungal alkaloid (±)-lapatin B and other alkaloid-type polycycles has been achieved via the aza-Diels–Alder reaction strategy.[7] Numerous asymmetric and nonasymmetric ADA methods has been developed to prepare N-heterocycles such as pyridine,[8] pyrimidine[9] and quinoline.[10] Moreover, nitrogen containing tetracyclic[11] and tricyclic[12] compounds can also be obtained by employing the ADA reaction. Despite being highly efficient, majority of the reported ADA techniques either requires catalyst, ligand, co-catalyst, additive or inert atmosphere for the transformation to take place or the pre-requisite to synthesize the diene and/or dienophile. In such a scenario, development of catalyst- and solvent-free ADA reaction, with the added flavour of in situ generation of both the diene and dienophile will provide an intriguing and green alternative to conventional approach.

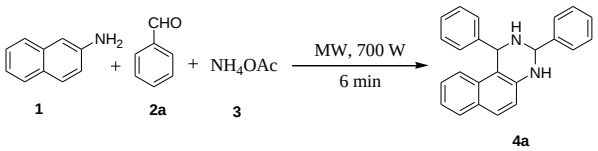
Quinazolines are an important class of heterocyclic compounds because of their presence in various alkaloids[13] and development of quinazoline based drugs such as gefitinib(Iressa) and erlotinib(Tarceva). Quinazoline and its hydrated derivatives have also shown diverse biological and therapeutic properties such as selective inhibitor of the tyrosine kinase activity of the epidermal growth factor receptor (EGFR)[14], anticancer, antitubercular, antibacterial, and antiviral activity.[15] Because of such desirable properties, recent years have witnessed a sharp increase in interest towards development of quinazoline derivatives.[16] Although a range of attractive protocols for assembling the quinazoline core are available, simple, rapid and eco-friendly methods are significantly less and involves considerable synthetic challenge.

Over the past decade, microwave assisted organic synthesis (MAOS)[17] has blossomed into a popular branch of synthetic organic chemistry as it offers fundamental advantages like conservation of energy and time while performing the organic transformation.[18] Very recently, we have developed microwave-promoted aza-Diels–Alder reaction for the synthesis of various aza-heterocycles.[19] We have also demonstrated that dihydroquinazolines can be efficiently synthesized via a eco-friendly procedure under microwave irradiation.[20] In the context of our interest towards developing environmentally benign synthetic methodologies,[19-21] we describe in this paper a microwave-promoted four-component catalyst- and solvent-free synthesis of tetrahydroquinazolines.

Results and Discussion

Initial studies were carried out by taking 2-naphthylamine **1a**, benzaldehyde **2a** and ammonium acetate **3** as model substrates. In a typical experiment, a mixture of **1a**, 2.2 equiv of **2a** and 1.2 equiv of **3** were irradiated inside a microwave reactor in absence of any other

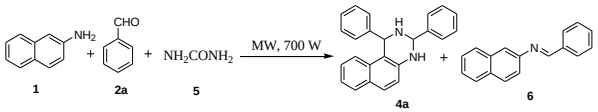
catalyst or additives to obtain a 2,4-diaryltetrahydroquinazoline derivative **4a** as major product with a small amount of the corresponding Schiff base as minor product (Scheme 1).



Scheme 1

To optimise the conditions, the effects of solvent, reaction time and microwave power were monitored. Optimisation studies revealed that best results can be obtained when the reactants are irradiated at 700 W for 6 min under neat condition (See Table S1, ESI). Enhancement of the reaction rate under neat conditions compared to different solvents was quite encouraging as no solvent is often considered the best solvent for carrying out organic reactions. Except for lower molecular weight alcohols, which showed partial conversion, no other solvents were found to be compatible for this reaction.

In a recent report, we have shown that urea can also be employed as an alternative source of ammonia under microwave conditions.[20] Therefore, we became interested to explore the possibility of employing urea as ammonia source for our current transformation. For this purpose, a four component reaction was carried out between 1 equiv of **1a**, 2.2 equiv of **2a** and 1 equiv of urea under identical experimental conditions (Scheme 2). To our delight, the same 2,4-diaryltetrahydroquinazoline derivative **4a** was obtained, albeit with much lower yield. Schiff base **6** was, instead, obtained as main product, which can be separated by silica gel column chromatography. Alternation in reaction conditions did not result in increase in yield of the tetrahydroquinazoline product (See Table S2, ESI).

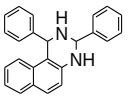
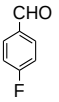
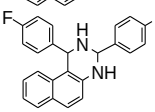
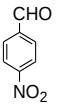
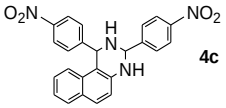
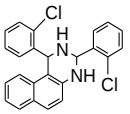
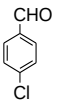
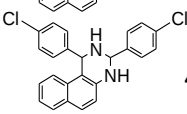
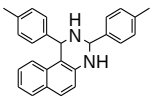
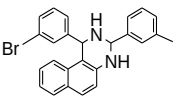
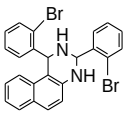
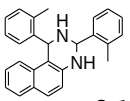
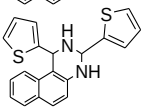
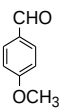
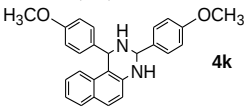
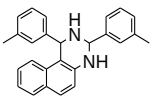
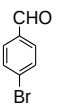
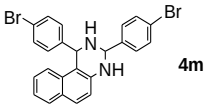


Scheme 2

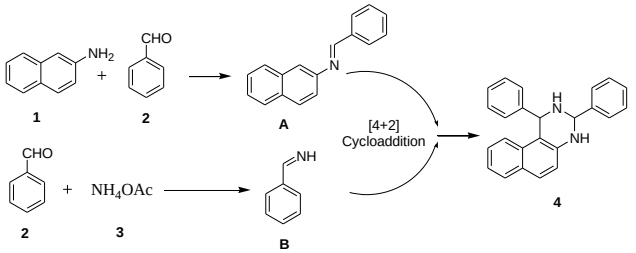
In the next step, the feasibility of the reaction scheme was explored by employing various aryl aldehydes and the results are summarized in table 1. It was observed that the nature of the substituent present in the aromatic ring of the aldehydes do not have any significant impact over the yield of the reaction. Aryl aldehydes with both electron-donating as well as withdrawing substituent participated in the reaction smoothly with comparable yields. In all cases, replacement of ammonium acetate with urea resulted in formation of the same product, with much lower yield. Aliphatic aldehydes did not participate in the reaction when either ammonium acetate or urea was used as the ammonia source. Although conclusive evidence has not yet been obtained, the difference in reactivity of ammonium acetate and urea may arise because of their differential ability to release ammonia and form the aldimine intermediate. Ammonium acetate readily forms the highly reactive aldimine intermediate which is trapped by the stable Schiff base to form the quinazoline. The reluctance of urea to form the reactive aldimine results in poor yield of the desired quinazoline with generation of the Schiff base as major product.

Although mechanistic studies are not performed, formation of the observed product can be rationalized via an aza-Diels−Alder pathway as shown in Scheme 3. Initially naphthylamine **1** and aryl aldehyde **2** reacts to form a Schiff base **A**. It is proposed that there is simultaneous release of ammonia by either ammonium acetate or urea under microwave condition which forms a reactive aldimine **B** with the second molecule of the aldehyde. This reactive aldimine then undergoes instantaneous [4 + 2] cycloaddition with the diene system of the Schiff base to generate the 2,4-diaryltetrahydroquinazoline **4**.

Table 1 Synthesis of tetrahydroquinoline derivatives **4** under MW condition[a]

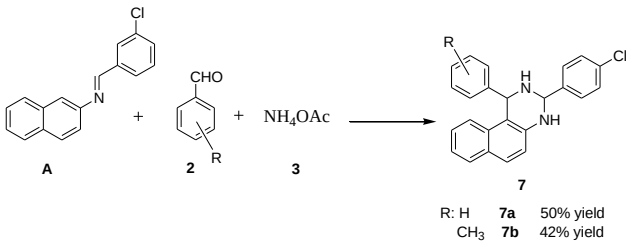
Entry	Amm. Acetate/Urea	Aldehyde	Product	% Yield[b]
1	NH_4OAc		 **4a**	82
2	Urea			30
3	NH_4OAc		 **4b**	80
4	Urea			32
5	NH_4OAc		 **4c**	78
6	Urea			20
7	NH_4OAc		 **4d**	85
8	Urea			28
9	NH_4OAc		 **4e**	82
10	Urea			25
11	NH_4OAc		 **4f**	79
12	Urea			27
13	NH_4OAc		 **4g**	83
14	Urea			28
15	NH_4OAc		 **4h**	85
16	Urea			30
17	NH_4OAc		 **4i**	77
18	Urea			25
19	NH_4OAc		 **4j**	78
20	Urea			29
21	NH_4OAc		 **4k**	80
22	Urea			20
23	NH_4OAc		 **4l**	80
24	Urea			24
25	NH_4OAc		 **4m**	82
26	Urea			30

[a]2-naphthyl amine (1 mmol), aldehyde (2.2 mmol), ammonium acetate (1.2 mmol) were mixed and irradiated at 700 watt for 6 min in absence of any solvent in a microwave reactor. [b]isolated yield.



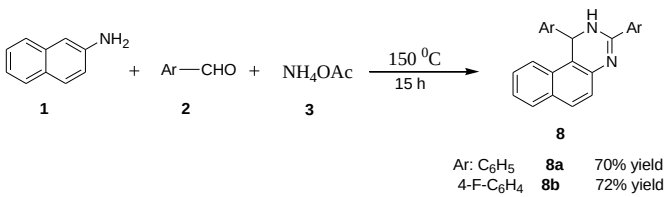
Scheme 3 Proposed mechanism for formation of 2,4-diaryltetrahydroquinazoline derivative

To verify our proposed mechanism, a three component crossed reaction was carried out by reacting a pre-formed Schiff base **A** with an aldehyde and ammonium acetate (Scheme 4). As expected, the 2,4-diaryltetrahydroquinazoline derivative **7** was obtained in 42-50% yield. This shows that the experimental results are highly consistent with the proposed mechanism.



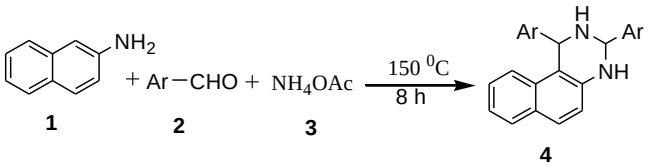
Scheme 4

Most recently, Kappe and co-workers[22] have experimentally shown that contrary to the common notion, most microwave-irradiated chemical transformations can be rationalized by considering them as pure thermal phenomenon. In other words, existence of genuine non-thermal microwave effect is not possible. This also meant that a transformation that is successful under microwave heating must be feasible under conventional heating too. Therefore, it was decided to study our reaction under thermal condition without indulging in the detailed study of effect of temperature. Gratifyingly, the desired 2,4-diaryltetrahydro-quinazoline **4a** was obtained in 75 % yield when a mixture of 2-naphthylamine **1a**, 2.2 equiv. of benzaldehyde **2a** and 1.2 equiv. of ammonium acetate **3** were heated on a preheated oil bath at 150 ^{0}C for 8 h. Generalisation of the reaction was carried out to examine the scope of the method under thermal condition and the results are listed in Table 2. Thermal heating was also found to be effective and good yields were obtained in all cases. However, little amount of Schiff base remained unreacted which can be separated by column chromatography. As column chromatography is not considered as 100% green method of separation, alternative methods for separation of products was also tried. It was found that the product can be separated in reasonably good yield by crystallisation from methanol-water mixture. It may be proposed that the crystallization technique can be suitably implemented for large scale implementation of this procedure.



Scheme 5

Table 2 Synthesis of tetrahydroquinoline derivatives **4** under thermal condition[a]

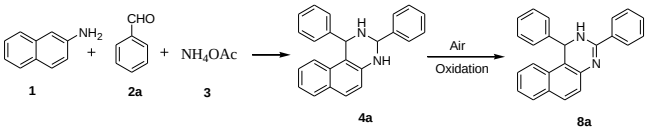


Entry	Aldehyde	Product	% Yield[b]
1	C_6H_5-CHO	**4a**	75
2	4-F-C_6H_4-CHO	**4b**	77
3	4-NO_2-C_6H_4-CHO	**4c**	70
4	2-Cl-C_6H_4-CHO	**4d**	70
5	4-Cl-C_6H_4-CHO	**4e**	71
6	4-CH_3-C_6H_4-CHO	**4f**	68
7	3-Br-C_6H_4-CHO	**4g**	70
8	2-Br-C_6H_4-CHO	**4h**	72
9	2-CH_3-C_6H_4-CHO	**4i**	70
10	2-Thiophenaldehyde	**4j**	65
11	4-OCH_3-C_6H_4-CHO	**4k**	68
12	3-CH_3-C_6H_4-CHO	**4l**	72
13	4-Br-C_6H_4-CHO	**4m**	72

[a]2-naphthyl amine (1 mmol), aldehyde (2.2 mmol), ammonium acetate (1.2 mmol) were mixed and heated in absence of any solvent on a preheated oil bath at 150 ^{0}C for 8 h. [b]isolated yield.

Quite interestingly, when the reaction was allowed for a longer period of time, we observed formation of a new product along with the expected tetrahydroquinazoline product. Spectoscopic analysis confirmed this new product to be a 1,2-dihydroquinazoline derivative **8** (Scheme 5).

After careful optimization, it was found that the reactants can be directly converted to the 1,2-dihydroquinazoline derivative after 15 h of conventional heating. Further increase in reaction time led to decomposition of the product, thereby resulting in lower yield of the reaction. We envisioned that the dihydroquinazoline **8** may form by initial formation of the tetrahydro compound **4** followed by its air oxidation (Scheme 6). The oxidation of the tetrahydroquinazoline to the corresponding dihydro compound simply by prolonging the reaction time is quite exciting as this is a difficult proposition under conventional circumstances. However, the reaction was unfruitful when ammonium acetate was replaced by urea. Only the Schiff base from naphthylamine and aryl aldehyde was obtained and no cyclized product was detected.



Scheme 6

Conclusions

In conclusion, we have developed an efficient aza-Diels–Alder reaction for the construction of 2,4-diaryltetrahydroquinazoline derivatives. The reaction is feasible under both microwave and thermal conditions and can be tuned by varying the time to obtain dihydroquinazoline derivatives under thermal heating. The cascade nature of the transformation as well as in-situ generation of both the diene and dienophile and their subsequent cycloaddition makes this methodology pot, atom and step economic. Urea is also shown as a nitrogen source under microwave conditions and can be exploited further for preparation of six membered aza heterocycles. Overall, this one-pot four-component method is simple, rapid and efficient, and provides an alternative for the construction of tetrahydroquinazolines in absence of harmful organic solvent and additives.

Acknowledgements

We thank CSIR, New Delhi for financial support to this work under Network Project. DB thanks UGC, NERO, for the award of a teacher fellowship and YD thanks UGC, New Delhi for the award of a research fellowship. We also thank the Director, NEIST, Jorhat for his keen interest and constant encouragement. We would also like to thank an anonymous referee for his insightful comments and suggestions.

Notes and references

[a]*Medicinal Chemistry Division, CSIR-North-East Institute of Science & Technology, Jorhat, Assam 785006, India*

[b]*Department of Chemistry, Nalbari College, Nalbari, Assam 781335, India*

*Corresponding author. Tel.: +91 376 2370121; fax: +91 376 2370011

E-mail address: dr_dprajapati2003@yahoo.co.uk

Electronic Supplementary Information (ESI) available: detailed experimental procedure, compound characterisation data and NMR spectra. See DOI: 10.1039/c000000x/

1. Paul A. Clarke, Soraia Santos and William H. C. Martin, *Green Chem*., 2007, **9**, 438–440.
2. (a) B. M. Trost, *Science*, 1991, **254**, 1471–1477; (b) B. M. Trost, *Angew. Chem. Int. Ed.*, 1995, *34*, 259–281.
3. (a) P. A. Wender, F. C. Bi, G. G. Gamber, F. Gosselin, R. D. Hubbard, M. J. C. Scanio, R. Sun, T. J. Williams and L. Zhang, *Pure Appl. Chem.*, 2002, **74**, 25–31; (b) P. A. Wender, S. T. Handy and D. L. Wright, *Chem. Ind. (London)*, 1997, 765–769; (c) P. A. Wender and B. L. Miller, *Organic Synthesis: Theory and Applications*, ed. T. Hudlicky, JAI, Greenwich, 1993, vol. 2, pp 27–66.
4. P. Prasanna, S. Perumal and J. C. Menendez, *Green Chem.*, 2013, **15**, 1292–1299.
5. (a) Kagan, H. B. *Comprehensive Organic Chemistry*; Pergamon Press: Oxford, 1992; Vol. 8; (b) Boger, D. L. and Weinreb, S. M. *Hetero Diels−Alder Methodology in Organic Synthesis*; Academic Press: San Diego, CA, 1987; Chapter 2; (c) Danishefsky, S. J. and De Ninno, M. P. *Angew. Chem. Int. Ed.*, 1987, **26**, 15–23; (d) Corey, E. J. *Angew. Chem. Int. Ed.*, **2002**, 41, 1650–1667. (e) Jørgensen, K. A., *Eur. J. Org. Chem.*, **2004**, 2093–2102.
6. (a) G. Masson, C. Lalli, M. Benohoud and G. Dagousset, *Chem. Soc. Rev.*, 2013, **42**, 902–923; (b) M. G. Memeo and P. Quadrelli, *Chem. Eur. J.*, 2012, **18**, 12554–12582.
7. (a) D. Leca, F. Gaggini, J. Cassayre and O. Loiseleur, *J. Org. Chem.*, 2007, **72**, 4284-4287; (b) Z. Chen, B. Wang, Z. Wang, G. Zhu and J. Sun, *Angew. Chem. Int. Ed.*, 2013, **52**, 2027–2031.
8. (a) J. Itoh, K. Fuchibe and T. Akiyama, *Angew. Chem., Int. Ed.*, 2006, **45**, 4796–4798; (b) P. J. Alaimo, R. III O'Brien, A. W Johnson, S.R. Slauson, J. M. O'Brien, E.L. Tyson, A-L. Marshall, C.E. Ottinger, J. G. Chacon, L. Wallace, C.Y. Paulino and S. Connell, *Org. Lett.*, 2008, **10**, 5111–5114; (c) U. Costantino, F. Fringuelli, M. Orru, M. Nocchetti, O. Piermatti and F. Pizzo, *Eur. J. Org. Chem.*, 2009, 1214–1220; (d) L. Di Bari, S. Guillarme, J. Hanan, A. P. Henderson, J. A. K. Howard, G. Pescitelli, M. R. Probert, P. Salvadori and A. Whiting, *Eur. J. Org. Chem.*, 2007, 5771–5779; (e) U. K. Tambar, S. K. Lee and J. L. Leighton, *J. Am. Chem. Soc.*, 2010, **132**, 10248–10250; (f) D. Shang, J. Xin, Y. Liu, X. Zhou, X. Liu and X. Feng, *J. Org. Chem.*, 2008, **73**, 630–637.
9. (a) M. C. Elliott and M. S. Long, *Org. Biomol. Chem.*, 2004, **2**, 2003–2011; (b) M. C. Elliott, E. Kruiswijk and D. J. Willock, *Tetrahedron*, 2001, **57**, 10139–10146; (c) M. C. Elliott and E. Kruiswijk, *J. Chem. Soc. Perkin Trans.*, 1999, **1**, 3157–3166.
10. (a) M. Xie, X. Chen, Y. Zhu, B. Gao, L. Lin, X. Liu and X. Feng, *Angew. Chem. Int. Ed.*, 2010, **49**, 3799–3802; (b) S. Feuillastre, V. Pellet and O. Piva, *Synthesis*, 2012, **44**, 2431–2435.
11. (a) S. Fustero, P. Bello, J. Miro, M. Sanchez-Rosello, M. A. Maestro, J. Gonzalezd and C. del Pozo, *Chem. Commun.*, 2013, **49**, 1336–1338; (b) M. P. Lalonde, M. A. McGowan, N. S. Rajapaksa and E. N. Jacobsen, *J. Am. Chem. Soc.*, 2013, **135**, 1891−1894.
12. J.–L. Li, S.–L. Zhou, B. Han, L. Wua and Y.–C. Chen, *Chem. Commun.*, 2010, **46**, 2665–2667.
13. (a) J. P. Michael, *Nat. Prod. Rep.*, 2004, **21**, 650–668. (b) Ji-F. Liu, M. Kaselj, Y. Isome, J. Chapnick, B. Zhang, G. Bi, Daniel Yohannes, L. Yu, and C. M. Baldino *J. Org. Chem.*, 2005, **70**, 10488–10493; (c) J. P. Michael, *Nat. Prod. Rep.*, 2008, **25**, 166–187; (d) C. Wattanapiromsakul, P. I. Forster and P. G. Waterman, *Phytochemistry*, 2003, **64**, 609–615; (e) Z.-Z. Ma, Y. Hano, T. Nomura and Y.-J. Chen, *Heterocycles*, 1997, **46**, 541–546; (f) S. Yoshida, T. Aoyagi, S. Harada, N. Matsuda, T. Ikeda, H. Naganawa, M. Hamada and T. Takeuchi, *J. Antibiot.*, 1991, **44**, 111–112; (g) Y. Deng, R. Xu and Y. Ye, *J. Chin. Pharm. Sci.*, 2000, **9**, 116–118.
14. P. A. Ple, T. P. Green, L. F. Hennequin, J. Curwen, M. Fennell, J. Allen, C. Lambert-van der Brempt and G. Costello, *J. Med. Chem.*, 2004, **47**, 871–887.
15. (a) C. S. Genther and C. C. Smith, *J. Med. Chem.*, 1977, **20**, 237–243; (b) L. A. Doyle and D. D. Ross, *Oncogene*, 2003, **22**, 7340–7358; (c) E. A. Henderson, V. Bavetsias, D. S. Theti, S.

C. Wilson, R. Clauss and A. L. Jackman, *Bioorg. Med. Chem.*, 2006, **14**, 5020–5042; (d) T.-C. Chien, C.-S. Chen, F.-H. Yu and J.-W. Chern, *Chem. Pharm. Bull.*, 2004, **52**, 1422–1426; (e) J. Kunes, J. Bazant, M. Pour, K. Waisser, M. Slosarek and J. Janota, *Farmaco*, 2000, **55**, 725–729; (f) E. L. Ellsworth, T. P. Tran, H. D. H. Showalter, J. P. Sanchez, B. M. Watson, M. A. Stier, J. M. Domagala, S. J. Gracheck, E. T. Joannides, M. A. Shapiro, S. A. Dunham, D. L. Hanna, M. D. Huband, J. W. Gage, J. C. Bronstein, J. Y. Liu, D. Q. Nguyen, and R. Singh, *J. Med. Chem.*, 2006, **49**, 6435–6438; (g) P. Verhaeghe, N. Azas, M. Gasquet, S. Hutter, C. Ducros,M. Laget, S. Rault, P. Rathelot and P. Vanelle, *Bioorg. Med. Chem. Lett.*, 2008, **18**, 396–401.

16. For selected examples, see: (a) Y. Lv, Y. Li, T. Xiong, W. Pu, H. Zhang, K. Sun, Q. Liu and Q. Zhang *Chem. Commun.*, 2013, **49**, 6439–6441; (b) X. Su, C. Chen, Y. Wang, J. Chen, Z. Louac and M. Li, *Chem. Commun.*, 2013, **49**, 6752–6754; (c) J. Ma, B. Han, J. Song, J. Hu, W. Lu and D. Yang, *Green Chem.*, 2013, **15**, 1485–1489; (d) J. Zhang, D. Zhu, C. Yu, C. Wan and Z. Wang, *Org. Lett.*, 2010, **12**, 2841; (e) Y. Kabri, A. Gellis and P. Vanelle, *Green. Chem.*, 2009, **11**, 201–208; (f) F. Portela-Cubillo, J. S. Scott and J. C. Walton, *J. Org. Chem.*, 2009, **74**, 4934–4942; (g) J. R. Li, X.Chen, D. X. Shi, S. L. Ma, Q. Li, Q. Zhang and J. H. Tang, *Org. Lett.*, 2009, **11**, 1193–1196.
17. For reviews on MAOS, see: (a) J. D. Moseley and C. O. Kappe, *Green Chem.*, 2011, **13**, 794–806; (b) P. Lidstrom, J. Tierney, B. Wathey and J. Westman, *Tetrahedron*, 2001, **57**, 9225–9283.
18. (a) J. Hamelin, J.-P. Bazureau and F. T. Boullet, In *Microwaves in Organic Chemisry*, 1st ed.; A. Loupy, Ed. Wiley-VCH: Weinheim, 2003; Chapter 8, p 253. (b) de la Hoz, A., Diaz-Ortiz, A. and Moreno, A. *Chem. Soc. Rev.*, 2005, **34**, 164–178. (c) Kappe, C. O. *Chem. Soc. Rev.*, 2008, **37**, 1127–1139; (d) Loupy, A., Ed. *Microwaves in Organic Synthesis*, 2nd ed.; Wiley-VCH: Weinheim, 2006; (e) R. S. Varma, *Green Chem.*, 1999, **1**, 43–55. (f) Jeselnik, M., Varma, R. S., Polanca, S. and Kocevar, M. *Chem. Commun.*, 2001, 1716–1717.
19. (a) M. M. Sarmah, R. Sarma, D. Prajapati and W. Hu, *Tetrahedron Lett.*, 2013, **54**, 267–271; (a) R. Sarma, M. M. Sarmah and D. Prajapati, *J. Org. Chem.*, 2012, **77**, 2018–2023; (c) D. Bhuyan, R. Sarma and D. Prajapati, *Tetrahedron Lett.*, 2012, **53**, 6460–6463.
20. R. Sarma and D. Prajapati, *Green Chem.*, 2011, **13**, 718–722.
21. (a) R. Sarma and D. Prajapati, *Synlett*, 2008, 3001–3005; (b) R. Sarma, M. M. Sarmah, K. C. Lekhok and D. Prajapati, *Synlett*, 2010, 2847–2852; (c) D. Prajapari, R. Sarma, D. Bhuyan and W. Hu, *Synlett*, 2011, 627–630; (d) D. Prajapati, D. Bhuyan, M. Gohain and W. Hu, *Mol. Divers.*, 2010, **15** 257–261; (e) D. Prajapati, M. Gohain and A. J. Thakur, *Bioorg. Med. Chem. Lett.*, 2006, **16**, 3537–3540.
22. C. O. Kappe, B. Pieber, and D. Dallinger, *Angew. Chem. Int. Ed.*, 2013, **52**, 1088–1094 and references cited therein.