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# Highly regioselective 6-exo-dig iodo/bromo cyclizations of functionalized 5-amino propargyl pyrimidinones: an efficient synthesis of functionalized pteridines†

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The manuscript describes the highly regioselective 6-exo-dig jodo/bromo cyclization of functionalized Npropagyl-amino-pyrimidinones under ambient conditions. The cyclization afforded functionalized pteridines in excellent yields. The optimized procedures are mild, operationally simple and working successfully with different substrates. The synthesis of functionalized pteridines is of great significance because of their potential pharmacological profile.

#### Introduction

Bicyclic pyrimidinones, condensed with other heterocyclic systems at different positions, have been extensively explored and evaluated for a wide range of biological properties.1 Pteridines are shown to be highly biologically active in every element of the growth and development of living things, including the treatment of cancer, heart disease, neurotransmitter generation, and amino acid metabolism.2-4 Moreover, a number of prevalent diseases including inflammatory disorders, autoimmune processes, neurological diseases, and birth defects have been attributed to the problems in the synthesis, nutritional availability, and/or metabolism of these compounds.3-14 Functionalized pteridines have also been explored for the treatment of fibroproliferative disorders, hepatitis C,15,16 and vascular disorders, etc. 12,17-21

A group of heterocyclic compounds known as pteridine, pyrazino[2,3-d] pyrimidines are composed up of condensed pyrimidine/pyrimidinone and pyrazine rings.22 Most naturally produced pteridines referred to as pterins (II) or generally named as 2-amino-4(3H)pteridone belong to a family of nitrogen heterocyclic compounds. The term "pteridine" refers to pyrazino[2,3-d] pyrimidine nucleus structurally, with the numbering of the ring system shown below in (I).23,24 The process of condensation of 4,5-diamino pyrimidine-2,6-dione with various dicarbonyl compounds has been exploited to

The synthesis of such functionalized pteridines with a variety of substitutions at different locations becomes crucial due to their potential pharmacological profile.30 As part of our ongoing interest in heterocyclic chemistry, we have previously looked into the synthesis of tricyclic pyrimidinones condensed benzodiazepines,31,32 pyrimidino[thiazenes],33 condensed lactams and thiazole condensed benzodiazepines34-36 among other compounds. The present manuscript describes the synthesis of functionalized 1,2,4,5-tetrasubstituted pyrimidinones and their 6-exo dig halocyclization to yield a variety of functionalized pteridines. The current approach has a number of benefits, including high yield, simplicity, and the provision of functionalized pteridines that can be converted into various heterocyclic systems (Fig. 2).

#### Results & discussion

The functionalized 5-amino pyrimidinones, 1a-h were prepared by the reaction of phthloylglycine, B with functionalized 1,3diazabuta-1,3-dienes, A and their subsequent amino deprotection reactions of C using hydrazine hydrate and ethanol (Scheme 1). $^{37}$ 

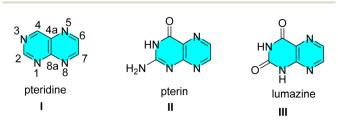


Fig. 1 Structures of pteridines.

synthesize pteridines of class III known as lumazines (Fig. 1).23,25-29

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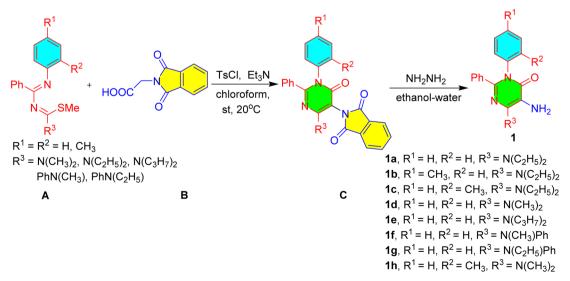
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Fig. 2 Biological applications of some pteridines.

These functionalized 5-amino pyrimidinones, **1a-h** were explored in 6-*exo dig* halocyclization reactions to yield 4-oxo-2,3-diaryl-pteridin-8-ium halide, **4a-k** in excellent yields. The synthetic methodology involved the initial mono-tosylation of functionalized 5-amino pyrimidinones, **1a-h** using tosyl chloride and mild base as triethylamine to yield *N*-(4-diaryl/alkylamino-6-oxo-1,2-diaryl-1,6-dihydro-pyrimidin-5-yl)-4-methylbenzenesulfonamides, **2a-h**. These mono-aryl-sulphonated 5-

amino pyrimidinones, **2a-h** were explored in monopropargylation to provide a series of *N*-propargyl-*N*-(4-dialkyl/aryl-amino-6-oxo-1,2-diaryl-1,6-dihydro-pyrimidin-5-yl)-aryl sulfonamides, **3a-h** in excellent yields (77–92% yield, Scheme 2).

These functionalized pyrimidinones, **3a-h** were explored in 6-*exo-dig* halocyclization reactions. The reaction resulted in the formation of 4-oxo-2,3-diaryl-pteridin-8-ium halide, **4a-k** in good



Scheme 1 Synthesis of starting materials, 5-amino-pyrimidinones.

Paper

$$\begin{array}{c} R^1 \\ R^2 \\ R^3 \cdot N_{R^3} \\ 1a\text{-h} \\ R^3 = \text{CH}_3, \text{C}_2\text{H}_5, \text{C}_3\text{H}_7, \text{Ph} \end{array}$$

Scheme 2 Synthesis of N-propagyl-N-(4-dialkyl/aryl-amino-6-oxo-1,2-diaryl-1,6-dihydro-pyrimidin-5-yl)-arylsulfonamides, 3a-h.

to excellent yields. Different solvents such as DCM, toluene, acetonitrile, etc., and different halogenated agents such as NCS, NBS, Br<sub>2</sub>, I<sub>2</sub>, etc were attempted for better yield and selectivity in the synthesis of functionalized 4-oxo-2,3-diaryl-pteridin-8-ium halide, 4a-k. The results are summarized in Table 1. It has been found that the iodocyclization occurs efficiently using I<sub>2</sub> (3 eq.) in DCM (20 mL) and the reaction gave poor yield in other tested solvents such as acetonitrile and toluene. The 6-exo-dig halocyclizations of functionalized pyrimidinones using alternate iodocyclization agents such as NIS afforded undesired products (Table 1, entry 1). The iodocyclization reactions also occurred efficiently in the absence of base (Table 1; entries 8-14). Next, we optimized the reaction conditions for 6-exo-dig bromo cyclizations using different brominating agents such as NBS, Br2, etc. The 6-exo-dig bromocyclization afforded 4-oxo-2, 3-diarylpteridin-8-ium bromide in good yields using Br<sub>2</sub> (3 eq.) in DCM

(20 mL) (Table 1, entries 6, and 12–15). The 6-exo-dig bromocyclization led to poor yields of product when a higher amount of bromine (4 to 6 eq.) was used during haloaminations. The 6-exo-dig bromocyclizations were inefficient and undesired products were found when NBS was used as a halogen source under different reaction conditions (Table 1, entries 4 and 5). Moreover, the chloro-amination reactions were unsuccessful using *N*-bromosuccinamide (NCS) was used as a halogen source in attempted 6-exo-dig chloroamination reactions (Table 1, entry 3).

**3g**,  $R^1 = H$ ,  $R^2 = H$ ,  $N(R^3)_2 = N(C_2H_5)Ph$ , **82% 3h**,  $R^1 = H$ ,  $R^2 = CH_3$ ,  $R^3 = CH_3$ , **90%** 

We next investigated these 6-exo-dig halocyclization reactions using a variety of functionalized pyrimidinones. Different pyrimidinones, **3a-h** with a variety of substituents such as dimethyl, diethyl, dipropyl, etc. at the C-4 position were studied in these halocyclization reactions. The reactions resulted in the formation of 4-oxo-2,3-diaryl-pteridin-8-ium halide **4a-k** in good to excellent yields (Table 2, entries 1–11). The various

Table 1 Optimization of the reaction conditions for 6-exo-dig halocyclizations

S. no	Pyrimidinone	Reaction con	nditions				
		Reagent	Eq.	Base (5 eq.)	Solvent (20 mL)	Reaction time <sup>b</sup>	Yields <sup>a</sup> (%)
1	3a	NIS	4	$K_2CO_3$	DCM	_	_
2	$3a^c$	$I_2$	3	$K_2CO_3$	DCM	20 min	86
3	3a	NCS	4	$K_2CO_3$	DCM	_	_
4	3a	NBS	4	$K_2CO_3$	DCM	_	_
5	3a	NBS	4	NaH	DCM	_	_
6	3a	$\mathrm{Br}_2$	2.5	$K_2CO_3$	DCM	20 min	79
7	3a	$I_2$	4.5	t-BuOK	THF	_	_
8	$3a^c$	$\overline{\mathbf{I}_2}$	3	_	DCM	20 min	89
9	3a	$I_2$	3.5	_	Toluene	3 h	55
10	3a	$I_2$	3.5	_	THF	1 h	50
11	3a	$I_2$	3.5	_	Acetonitrile	1.5 h	40
12	3a	Br <sub>2</sub>	3	_	DCM	20 min	84
13	3a	$\mathrm{Br}_2$	3	_	Toluene	3 h	53
14	3a	$\mathrm{Br}_2$	3	_	THF	3 h	49
15	3a	$\mathrm{Br}_2$	3	_	Acetonitrile	3 h	35

<sup>&</sup>lt;sup>a</sup> Isolated yields after purification. <sup>b</sup> Reaction time. <sup>c</sup> Dry DCM used as a solvent.

Table 2 6-exo-dig haloamination reactions of functionalized pyrimidinones, 3a-h

$$\begin{array}{c}
R^1 \\
R^2 \\
N \\
N \\
N
\end{array}$$

$$\begin{array}{c}
X_2, K_2CO_3 \\
DCM, st. \\
X = I, Br
\end{array}$$

$$\begin{array}{c}
X_3 \\
N \\
X = I, Br
\end{array}$$

$$\begin{array}{c}
X_3 \\
X = I, Br
\end{array}$$

$$\begin{array}{c}
X_4 \\
X = I, Br
\end{array}$$

S. no	$R^1$	$\mathbb{R}^2$	$\mathbb{R}^3$	X	Substrate <sup>b</sup>	Product <sup>c</sup>	Yield <sup>a</sup> (%)
1	Н	Н	$C_2H_5$	I	3 <b>a</b>	4a	89
2	$CH_3$	Н	$C_2H_5$	I	3 <b>b</b>	4b	87
3	Н	$CH_3$	$C_2H_5$	I	3 <b>c</b>	4c	88
4	Н	Н	$CH_3$	I	3 <b>d</b>	4d	90
5	Н	Н	$C_3 H_7$	I	3e	4e	71
6	Н	H	CH <sub>3</sub> & Ph	I	3f	4f	84
7	Н	H	C <sub>2</sub> H <sub>5</sub> & Ph	I	3g	4g	82
8	Н	$CH_3$	$CH_3$	Br	3h	4h	86
9	Н	Н	$CH_3$	Br	3d	4i	85
10	Н	H	$C_2H_5$	Br	3a	4j	84
11	$CH_3$	H	$C_2H_5$	Br	3 <b>b</b>	4k	82

<sup>&</sup>lt;sup>a</sup> Isolated yields after purification. <sup>b</sup> Reaction time 20 min. <sup>c</sup> Starting substrates (3a-g) taken = 500 mg, 0.870-1.000 mmoles.

substituents at the C-1 or C-2 position did not change the yield of the product of these halocyclization reactions (Table 2; entries 1–11). The 6-exo-dig halocyclization reactions tolerate

a variety of steric bulk at the C-4 position (Table 2; entries 3–7). Functionalized pyrimidinones with a dimethyl or diethyl amino group at the C-4 position resulted in efficient 6-exo-dig

Scheme 3 Mechanism for the formation of hexahydropteridin-8-ium derivatives, 4a-k.

cyclizations (Table 2; entries 1-4 and 8-11). With dipropyl amine at its C-4 position, the halo amination of 3e took a relatively longer reaction time and yielded 4e with a slightly lower yield (Table 2; entry 5). With a hindered secondary amine (N-aryl methyl/ethyl amine) at the C-4 position, the 2,3-dialkyl-5-propynylsulfanyl-3H-pyrimidin-4-ones, 3f & 3g effectively accomplished 6-endo-dig cyclization reactions to provide 4f, g in good yields (Table 2; entries 6 and 7). These experimental findings demonstrate that the various sterically hindered amines at the C-4 position are successfully tolerated by the 6-exo-dig haloamination reactions of pyrimidinones, 3a-h. (Table 2; entries 5-7). The yield decreases with an increase in steric bulk at the C-4 position. The bromocyclization afforded comparatively lower yields of 4-oxo-2,3-diaryl-pteridin-8-ium halide owing to the more reactive nature of the bromine (Table 2, entries 8-11). All these reactions resulted in the formation of 4-oxo-2,3-diarylpteridin-8-ium halide, 4a-k, and competitive 7-endo dig cyclized products were not formed. The Impure compounds, 4a-k were purified by using a solvent mixture of dichloromethane and diethyl ether (1:9) without performing any column chromatography.

The plausible mechanism involved the iodonium ion's coordination with the triple bond of the *N*-propargyl of the pyrimidinone ring during its initial formation. The subsequent *exo-dig* nucleophilic attack of the C-4 substituted secondary amino group results in the production of the 4-oxo-2,3-diaryl-3,4,5,6,7,8-hexahydro-pteridin-8-ium halide in good yields. Approach-**a** for haloamination is preferred while competitive approach-**b** is disfavored due to the development of a more stabilised six-membered fused pyrazine ring than the competitive seven-membered fused diazepine ring (Scheme 3).

### Conclusion

In summary, an efficient regioselective protocol for the formation of functionalized pteridines has been reported. The operational simplicity, shorter reaction time, good substrate scope, column chromatography-free approach, and regioselectivity are the attractive features of the present method. Further exploration of the full scope of these reactions and their extension to other arenes and heteroarenes will be reported in due course.

# **Experimental section**

General procedure for the formation of N-(4-dialkylamino-6-oxo-1,2-diaryl-1,6-dihydro-pyrimidinin-5-yl)-4-methylbenzenesulfonamide (2a-h)

To a solution of 5-amino pyrimidinones 1a-h (2 g, 1.950-2.550 mmoles) and triethylamine (3 eq.) in dry CHCl<sub>3</sub> (50 mL) at 0 °C, was added dropwise a solution of p-TsCl (2.0 eq.) mixed in dry chloroform. The advancement of the reaction was checked by tlc. At the end of the reaction (overnight stirring), a usual workup was carried out using water and chloroform. The organic layers were combined, dried over sodium sulfate, and concentrated to get the crude product. The impure crude product was loaded into the column and purified by using ethyl acetate and hexane (2:8) as an eluent. The crude compounds

were further purified using a mixture of 10% dichloromethane in diethyl ether to obtain *N*-(4-dialkylamino-6-oxo-1,2-diaryl-1,6-dihydro-pyrimidinin-5-yl)-4-methyl-benzenesulfonamide (2a–h) as pure compounds in good yields.

# General procedure for the formation of *N*-(4-dialkylamino-6-oxo-1,2-diaryl-1,6-dihydro-pyrimidinin-5-yl)-*N*-prop-2-ynyl-benzenesulfonamide (3a–h)

To a well-stirred solution of N-(4-dialkylamino-6-oxo-1,2-diaryl-1,6-dihydro-pyrimidinin-5-yl)-4-methyl-benzenesulfonamide (2a-h) (1 g, 1.870-2.170 mmoles) in dry CHCl<sub>3</sub> (30 mL) at 0 °C, was added, a solid sodium hydride (1.2 eq.) in small increments. The reaction was initially stirred for fifteen minutes and then the propargyl bromide (1.2 eq.) was added dropwise. The advancement of the reaction was checked by tlc. At the end of the reaction (5 hours stirring), a usual workup was carried out using ethyl acetate and water. The organic layers were combined, dried over sodium sulfate, and concentrated to obtain the crude product. The impure crude product was loaded into the column and purified by using a solution of ethyl acetate and hexane (1:9) as an eluent. The crude product was further purified using 10% dichloromethane in diethyl ether to obtain N-(4-dialkylamino-6-oxo-1,2-diaryl-1,6-dihydro-pyrimidinin-5-yl)-N-prop-2-ynyl-benzenesulfonamide (3a-h) good yields.

# $\label{eq:N-(4-(diethylamino)-6-oxo-1,2-diphenyl-1,6-dihydropyrimidin-5-yl)-4-methyl-N-(prop-2-yn-1-yl) benzenesul fon a midel of the property of the proper$

(3a). (1 g, 2.05 mmoles of 2a); yield-92%; white solid;  $^1$ H NMR (400 MHz, CDCl<sub>3</sub>):  $\delta$  7.71 (d, J = 8.3 Hz, 2H), 7.18–7.26 (m, 10H), 6.84 (dd, J = 7.3, 2.2 Hz, 2H), 4.69 (dd, J = 17.2, 2.6 Hz, 1H), 4.58 (dd, J = 17.2, 2.6 Hz, 1H), 4.13 (m, J = 14.1, 7.1 Hz, 2H), 3.82 (m, J = 14.1, 7.1 Hz, 2H), 2.42 (s, 3H), 2.31 (t, J = 2.5 Hz, 1H), 1.39 (t, J = 7.0 Hz, 6H). 13C NMR (101 MHz, CDCl3):  $\delta$  161.05, 158.61, 154.84, 143.39, 137.19, 135.72, 134.95, 129.65, 129.23, 129.08, 128.83, 128.54, 128.33, 127.98, 127.80, 96.62, 79.51, 73.25, 43.69, 39.74, 21.62, 13.80. HRMS (ESI + TOF) calcd for  $C_{30}H_{31}N_4O_3S^+$  (MH $^+$ ): 527.2111, found: 527.2115.

General procedure for the synthesis of hexahydro-pteridines (4a-k). To a solution of pyrimidinones, 3a-h (500 mg, 0.870–1.000 mmoles) in dry dichloromethane (20 mL) was added bromine or iodine (3 eq.) in small amounts at room temperature. The advancement of the reaction was checked by tlc. At the end of the reaction, (20 minutes stirring) the mixture was first quenched with an aqueous solution of sodium thiosulphate, and then workup was carried out using dichloromethane and brine solution. The filtrate was dried over sodium sulfate and concentrated to get the crude product. The crude product was purified using a solution of 10% dichloromethane in diethyl ether to get a pure compound, 4a-k in good yields.

(*E*)-8,8-Diethyl-7-(iodomethylene)-4-oxo-2,3-diphenyl-5-tosyl-3,4,5,6,7,8-hexahydropteridin-8-ium, iodide (4a). (500 mg, 0.95 mmol of 3a); (680 mg recovered, yield-89%); white solid;  $^1$ H NMR (400 MHz, CDCl<sub>3</sub>): δ 7.63 (d, J = 8.5 Hz, 2H), 7.39–7.32 (m, 6H), 7.25–7.20 (m, 6H), 5.43 (d, J = 1.8 Hz, 1H), 4.99 (d, J = 17.3 Hz, 1H), 4.79 (dd, J = 17.1, 2.1 Hz, 1H), 4.51 (m, J = 14.7, 7.4 Hz, 1H), 4.16 (m, J = 13.8, 7.2 Hz, 1H), 3.94 (m, J = 14.6,

7.4 Hz, 1H), 3.78 (m, J = 14.6, 7.1 Hz, 1H), 2.49 (s, 3H), 1.56 (t, J = 7.4 Hz, 3H), 1.42 (t, J = 7.4 Hz, 3H). 13C NMR (101 MHz, CDCl<sub>3</sub>):  $\delta$  157.56, 155.46, 153.81, 146.41, 145.19, 134.10, 132.06, 131.94, 131.29, 130.29, 129.89, 129.78, 128.77, 128.29, 98.53, 64.57, 46.35, 21.99, 13.09; HRMS (ESI + TOF) calcd for  $C_{30}H_{30}IN_4O_3S^+$  (M<sup>+</sup>): 653.1078, found: 653.1107.

## Conflicts of interest

Authors declare no conflict of interest.

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#### References

- 1 A. Burger, *Medicinal Chemistry*, New York (NY), 1970, vol. 72, p. 719.
- 2 J. Delgado and W. W. Remers, Wilson and Gisvold's Textbook of Organic Medicinal and Pharmaceutical Chemistry, ed. Lippinicott Williams and Wilkins, Philadelphia, PA, USA, 1998, p. 185.
- 3 S. Milstien, G. Kapatos, R. A. Levine and B. Shane, *Chemistry and Biology of Pteridines and Folates: Proceedings of the 12th International Symposium on Pteridines and Folates, National Institutes of Health*, Springer Science & Business Media, Bethesda, Maryland, 2012.
- 4 T. Sasada, F. Kobayashi, N. Sakai and T. Konakahara, *Org. Lett.*, 2009, **11**, 2161–2164.
- 5 J. Dörrstein, R. Scholz, D. Schwarz, D. Schieder, V. Sieber, F. Walther and C. Zollfrank, *Compos. Struct.*, 2018, 189, 349–356.
- 6 U. Leurs, E. Lajkó, G. Mező, E. Orbán, P. Öhlschläger, A. Marquardt, L. Kőhidai and M. Manea, Eur. J. Med. Chem., 2012, 52, 173–183.
- 7 M.-H. Li, S. K. Choi, T. P. Thomas, A. Desai, K.-H. Lee, A. Kotlyar, M. M. B. Holl and J. R. Baker Jr., *Eur. J. Med. Chem.*, 2012, 47, 560–572.
- 8 A. Rosowsky, R. A. Forsch, J. H. Freisheim and R. G. Moran, *J. Med. Chem.*, 1989, 32, 517–520.
- 9 A. Rosowsky, J. Galivan, G. Beardsley, H. Bader and B. O'Connor, *Cancer Res.*, 1992, 52, 2148–2155.
- 10 Z. Zhang, J. Wu, F. Ran, Y. Guo, R. Tian, S. Zhou, X. Wang, Z. Liu, L. Zhang and J. Cui, Eur. J. Med. Chem., 2009, 44, 764–771.
- 11 G. Fredi and A. Dorigato, *Adv. Ind. Eng. Polym. Res.*, 2021, 4, 159–177.
- 12 C.-H. Lee, M. Jiang, M. Cowart, G. Gfesser, R. Perner, K. H. Kim, Y. G. Gu, M. Williams, M. F. Jarvis and E. A. Kowaluk, *J. Med. Chem.*, 2001, 44, 2133–2138.
- 13 C. Enzinger, B. Wirleitner, N. Spöttl, G. Böck, D. Fuchs and G. Baier-Bitterlich, *Neurochem. Int.*, 2002, 41, 71–78.
- 14 D. Voet and J. Voet, *Biochemistry*, John Wiley & Sons, Hoboken, NJ, 3rd edn, 2004, pp. 909–984.

- 15 Y. Ding, J.-L. Girardet, K. L. Smith, G. Larson, B. Prigaro, V. C. Lai, W. Zhong and J. Z. Wu, *Bioorg. Med. Chem. Lett.*, 2005, 15, 675–678.
- 16 P. Raboisson, O. Lenz, T.-I. Lin, D. Surleraux, S. Chakravarty, A. Scholliers, K. Vermeiren, F. Delouvroy, T. Verbinnen and K. Simmen, *Bioorg. Med. Chem. Lett.*, 2007, 17, 1843–1849.
- 17 H. Iwamura, N. Masuda, K. Koshimizu and S. Matsubara, *Plant Sci. Lett.*, 1980, **20**, 15–18.
- 18 E. Katilius, Z. Katiliene and N. W. Woodbury, *Anal. Chem.*, 2006, **78**, 6484–6489.
- 19 M. S. Palanki, E. Dneprovskaia, J. Doukas, R. M. Fine, J. Hood, X. Kang, D. Lohse, M. Martin, G. Noronha and R. M. Soll, J. Med. Chem., 2007, 50, 4279–4294.
- 20 R. J. Stanley, Z. Hou, A. Yang and M. E. Hawkins, *J. Phys. Chem. B*, 2005, **109**, 3690–3695.
- 21 G. Wenska, B. Skalski, I. Tomska-Foralewska and S. Paszyc, *Helv. Chim. Acta*, 2001, **84**, 3726–3734.
- 22 F. E. Hahn and M. C. Jahnke, Angew. Chem., Int. Ed., 2008, 47, 3122–3172.
- 23 D. J. Brown, Fused Pyrimidines, John Wiley & Sons, 2009, Part3: Pteridines, vol. 24.
- 24 M. Koller, in *Handbook of Microalgae-Based Processes and Products*, ed. E. Jacob-Lopes, M. M. Maroneze, M. I. Queiroz and L. Q. Zepka, Academic Press, 2020, pp. 597–645, DOI: 10.1016/B978-0-12-818536-0.00022-1.
- 25 A. Albert, Q. Rev., Chem. Soc., 1952, 6, 197-237.
- 26 E. S. H. E. Ashry, S. Youssif, M. E. Ahwany and M. E. Sanan, *J. Chem. Res.*, 2005, **2005**, 262–266.
- 27 S. Goswami and A. C. Maity, *Chem. Lett.*, 2007, 36(9), 1118–1119.
- 28 V. A. Mamedov, N. A. Zhukova, A. T. Gubaidullin, V. V. Syakaev, M. S. Kadyrova, T. Y. N. Beschastnova, O. B. Bazanova, I. D. K. Rizvanov and S. K. Latypov, *J. Org. Chem.*, 2018, 83, 14942–14953.
- 29 A. Marchal, M. Melguizo, M. Nogueras, A. Sanchez and J. N. Low, *Synlett*, 2002, **2002**, 0255–0258.
- 30 V. Carmona-Martínez, A. J. Ruiz-Alcaraz, M. Vera, A. Guirado, M. Martínez-Esparza and P. García-Peñarrubia, Med. Res. Rev., 2019, 39, 461–516.
- 31 R. A. Naikoo, R. Kumar, P. Singh and G. Bhargava, *Synth. Commun.*, 2021, **51**, 1232–1241.
- 32 R. A. Naikoo, R. Kumar, V. Kumar and G. Bhargava, *Synth. Commun.*, 2021, **51**, 1451–1477.
- 33 R. Sharma and C. Mohan, J. Heterocycl. Chem., 2017, 54, 1833–1839.
- 34 B. Kuila, Y. Kumar, D. Mahajan, K. Kumar, P. Singh and G. Bhargava, *RSC Adv.*, 2016, **6**, 57485–57489.
- 35 Y. Kumar, B. Kuila, D. Mahajan, P. Singh, B. Mohapatra and G. Bhargava, *Tetrahedron Lett.*, 2014, 55, 2793–2795.
- 36 G. M. Shelke, V. K. Rao, M. Jha, T. S. Cameron and A. Kumar, *Synlett*, 2015, **26**, 404–407.
- 37 R. Sharma, D. Y. Gawande, C. Mohan and R. K. Goel, *Med. Chem. Res.*, 2016, **25**, 1420–1424.