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COMMUNICATION

Efficient and convenient C-3 functionalization of indoles through $Ce(OAc)_3$/TBHP-mediated oxidative C–H bond activation in the presence of β-cyclodextrin

Yu Lin Hu,* Hui Jiang and Ming Lu*

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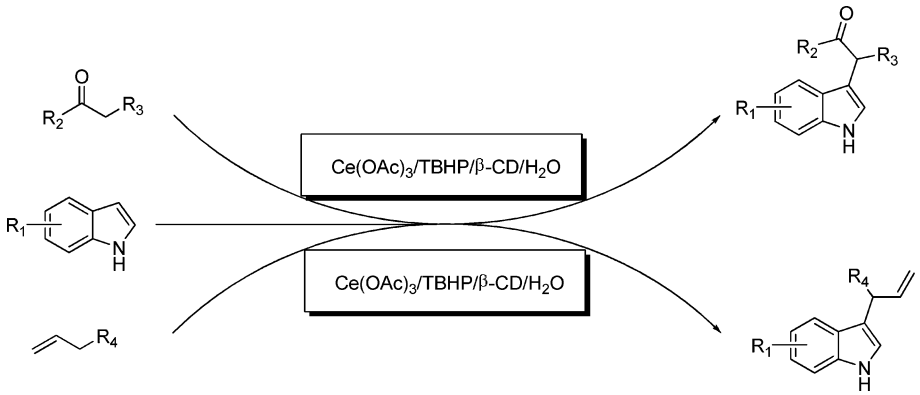
A simple, green and efficient protocol for the selective C-3 functionalization of indoles with ketones and olefins *via* $Ce(OAc)_3$-TBHP mediated oxidative C–H activation in the presence of β-cyclodextrin in water has been developed. This atom-economical protocol affords the target products in good to excellent yields. The products can be separated by a simple extraction with organic solvent, and the catalytic system can be recycled and reused without loss of catalytic activity.

Indoles are key structural units in many natural products and important pharmaceuticals, and have wide applications in medicinal chemistry.[1,2] In particular, 3-alkylated indoles are important building blocks for the synthesis of various biologically-active molecules.[2] Therefore, there has been tremendous interest in developing efficient methods for the synthesis of these molecules, and a well known method constitutes the Friedel–Crafts alkylation of indoles. Traditionally, the most common way for such conversions have been Lewis and Brønsted acid-promoted reactions.[3] However, these protocols, are generally associated with one or more disadvantages, such as long reaction times, high reaction temperatures, low yields, complex handling procedures, problematic side reactions, environmental concerns associated with the use of poorly manageable catalysts and the release of large amounts of environmentally hazardous wastes. To overcome these limitations, the use of transition metal complexes,[4] ionic liquids,[5] phase transfer catalysis,[6] micellar catalysis,[7] microwaves,[8] ultrasonic irradiation[9] and others[10] have been applied to accomplish this transformation with different degrees of success. More recently, selectively-direct C–H bond activation has been extensively studied. This synthetic strategy is intriguing for the chemical and pharmaceutical industries because it may not only significantly simplify and shorten the synthetic route for various types of organic compounds but also allow the utilization of readily available, cheap and environmentally-benign starting materials (the atom economy concept).[11] Therefore, the transition metal-catalyzed arylation of indoles through direct C–H bond activation have been developed with some innovative progress in recent years,[12] and various oxidative intermolecular cross-dehydrogenative coupling (CDC) reactions by using two different C–H bonds have also been developed (*e.g.*, sp^3 C–H with sp^3 C–H, sp^2 C–H with sp^2 C–H, sp^3 C–H with sp^2 C–H, sp^3 C–H with sp C–H),[13] whilst most of the reactions still have some shortcomings, like high reaction temperatures, long reaction times, the use of expensive, toxic and moisture sensitive reagents and difficulties in recycling the catalyst. Consequently, the development of a more general and practical method under mild conditions, and preferably using environmentally friendly and inexpensive reagents, is highly desirable.

Water is a safe, economical and environmentally-benign solvent.[14] However, the fundamental problem with performing reactions in water is that many organic substrates are hydrophobic and insoluble in water. Cyclodextrins (CDs), obtained from the enzymatic degradation of starch, are cyclic oligosaccharides possessing hydrophobic cavities, which have attracted much attention as aqueous-based hosts for inclusion complex phenomena with a wide variety of guests. Inclusion complex formation occurs as a result of an interaction between the hydrophobic cavity of the CD with the hydrophobic portion of the guest. They can bind substrates selectively, and catalyze a wide range of chemical and photochemical reactions by supramolecular catalysis, involving the reversible formation of host–guest complexes with the substrates by non-covalent bonding, such as seen in enzymes.[15] These attractive features of CDs prompted us to investigate reactions, under biomimetic conditions. We herein report an efficient and environmentally friendly protocol for the direct regioselective C-3 alkylation of indoles with ketones and olefins to synthesize 3-alkylindoles *via* $Ce(OAc)_3$/TBHP-mediated oxidative C–H bond activation in the presence of β-cyclodextrin (β-CD) in water (Scheme 1).

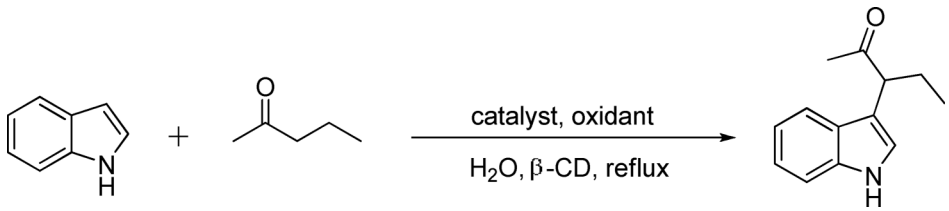
The investigation was initiated by using the direct alkylation of 1*H*-indole with pentan-2-one as a model reaction (Table 1). Initial reaction screening led to disappointing results in the absence of a catalyst; the reaction proceeded very slowly, and the yield was only 27% after 24 h (Table 1, entry 1). The results mean that the oxidant TBHP alone does not work effectively in

College of Chemical Engineering, Nanjing University of Science and Technology, Nanjing, 210094, P. R. China.
E-mail: huyulin1982@163.com, luming1963@163.com; Fax: +86 025-84315030; Tel: +86 025-84315030



Scheme 1 Direct C-3 alkylation of indoles with ketones and olefins.

Table 1 Optimization of the conditions for C-3 acylation of 1*H*-indole with pentan-2-one[a]



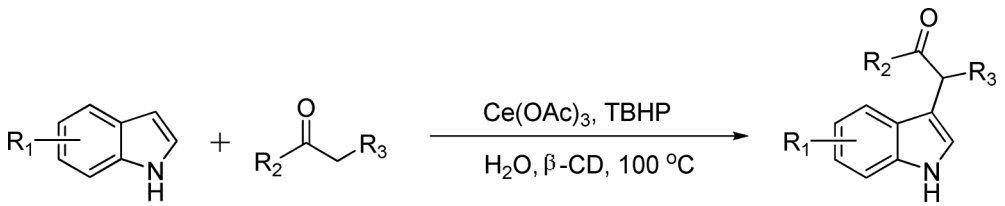
Entry	Catalyst	Oxidant	Time/h	Yield (%)[b]
1	—	TBHP	24	27
2	$Cu(OAc)_2$	TBHP	12	75
3	$Zn(OAc)_2$	TBHP	18	54
4	$Fe(OAc)_2$	TBHP	12	72
5	$Ce(OAc)_3$	TBHP	12	84
6	$Pd(OAc)_2$	TBHP	12	67
7	$CeCl_3$	TBHP	16	78
8	$CuCl_2$	TBHP	16	69
9	$Ce(OAc)_3$	TBHP	16	75[c]
10	$Ce(OAc)_3$	TBHP	12	84[d]
11	$Ce(OAc)_3$	TBHP	12	83[e]
12	$Ce(OAc)_3$	—	24	25
13	$Ce(OAc)_3$	$FeCl_3$	12	58
14	$Ce(OAc)_3$	$K_2S_2O_8$	14	46
15	$Ce(OAc)_3$	$AgNO_3$	12	65
16	$Ce(OAc)_3$	DDQ	12	77
17	$Ce(OAc)_3$	Ag_2O	12	75
18	$Ce(OAc)_3$	H_2O_2	12	78

[a] Reactions were carried out using 1*H*-indole (1 mmol), pentan-2-one (1.5 mmol), catalyst (0.15 mmol), oxidant (2 mmol) and β-CD (0.1 mmol) in H_2O (2 mL) at 100 °C. [b] Isolated yield. [c] No β-CD was added. [d] The first run. [e] The second run.

the reaction. The effects of different catalysts, such as $Cu(OAc)_2$, $Zn(OAc)_2$, $Fe(OAc)_2$, $Ce(OAc)_3$, $Pd(OAc)_2$, $CeCl_3$ and $CuCl_2$, were then screened in this alkylation (Table 1, entries 2–8), and it was observed that $Ce(OAc)_3$ demonstrated the best performance. For a blank test (Table 1, entry 9), a lower yield of the product was obtained when the same reaction condition were used in the absence of β-CD. This result indicates that β-CD must play an important role in accelerating the rate of the reaction. In addition, the oxidant is crucial for this reaction, and its lack leads to a much lower yield (Table 1, entry 12). Besides TBHP, we also tried to use other types of oxidants in this model reaction (Table 1, entries 13–18), and the results showed that TBHP demonstrated the best performance in terms of yield and reaction rate. Furthermore, the catalytic system could be typically recovered and reused with no appreciable decrease in yield and reaction rate (Table 1, entries 10 and 11). Therefore, the combination of $Ce(OAc)_3$, TBHP and β-CD was chosen as the optimal materials for further exploration.

The direct C-3 alkylation of a variety of indoles with ketones was successful and gave the desired corresponding 3-alkylindoles in good to excellent yields, as summarized in Table 2. Various types of indoles can be successfully converted to their corresponding products with pentan-2-one (Table 2, entries 1, 6–9), whereas the electron-deficient indoles were less reactive (Table 2, entries 8 and 9) than the electron-rich examples (Table 2, entries 6 and 7); longer reaction times were required to achieve good yields. In addition, in order to examine a greater range of ketones to better illustrate the scope and limitations of this protocol, we investigated the reactions with other ketones, such as octan-2-one, 3-oxobutanenitrile, 1-*p*-tolylpropan-2-one and

Table 2 C-3 alkylation of indoles with ketones[a]



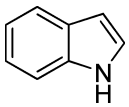
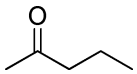
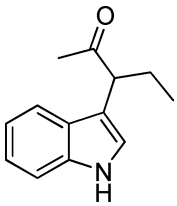
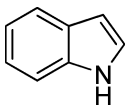
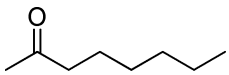
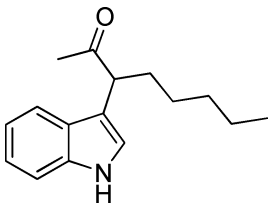
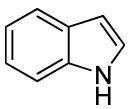
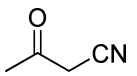
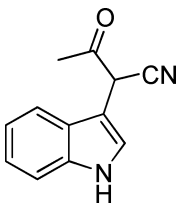
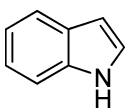
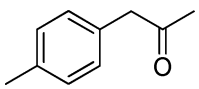
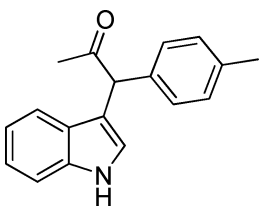
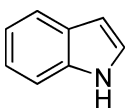
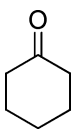
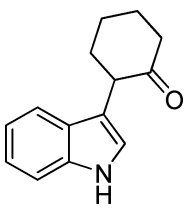
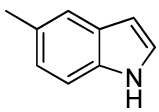
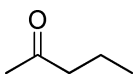
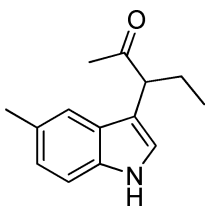
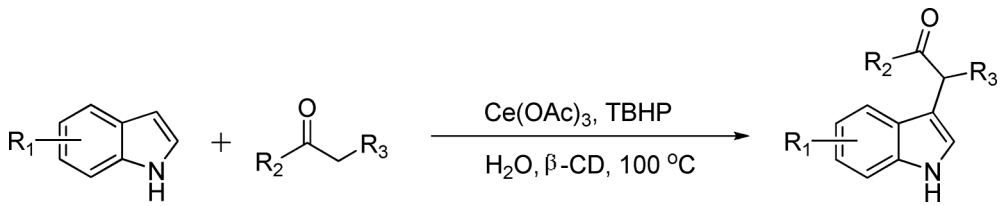
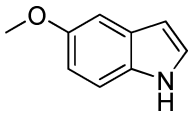
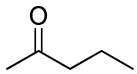
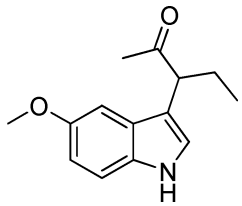
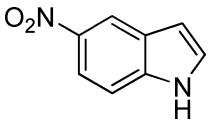
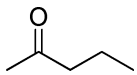
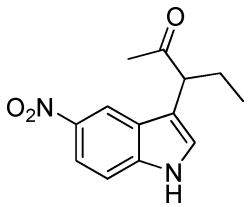
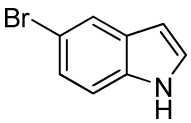
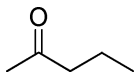
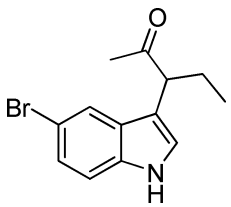
Entry	Indole	Ketone	Product	Time/h	Yield (%)[b]
1				12	84
2				12	78
3				10	93
4				10	90
5				12	85
6				12	85

Table 2 (*Contd.*)



Entry	Indole	Ketone	Product	Time/h	Yield (%)[b]
7				12	88
8				16	74
9				16	77

[a] Reactions were carried out using indole (1 mmol), ketone (1.5 mmol), $Ce(OAc)_3$ (0.15 mmol), TBHP (2 mmol), and β-CD (0.1 mmol) in H_2O (2 mL) at 100 °C. [b] Isolated yield.

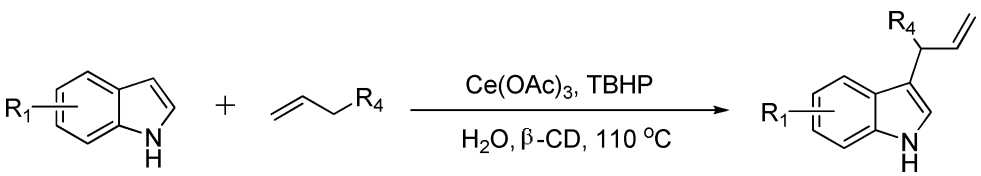
cyclohexanone, using 1*H*-indole as a representative substrate (Table 2, entries 2–5). Good yields of the expected products were obtained. It was also observed that the electronic nature of the substituents on the ketones had some impact on the reaction rate. Electron-deficient ketones (Table 2, entries 3 and 4) were more reactive than the electron-rich examples (Table 2, entries 1, 2, and 5), providing excellent yields.

The other portion of this work involved the application of our catalytic protocol to prepare 3-allylic indoles by the direct C-3 alkylation of indoles with olefins. The optimal reaction conditions were found to be the similar to those in the case of the alkylation of indoles with ketones, and the desired products were obtained in good to excellent yield (Table 3). The results reveal that our protocol can facilitate efficiently the direct C-3 alkylation of indoles with olefins. Various indoles were efficiently converted to their corresponding 3-allylic indoles with olefins using the catalytic protocol (Table 3, entries 1–8). Olefins such as but-3-enenitrile and allylbenzene (Table 3, entries 1 and 2) reacted more quickly than hex-1-ene and cyclohexene (Table 3, entries 3 and 4), giving products in higher yields, which might be attributed to the electron deficiency effect. Moreover, the substituents on the benzene ring of the indole greatly influenced the reaction; electron-rich indoles (Table 3, entries 5 and 6) were more reactive than electron-deficient examples (Table 3, entries 7 and 8) and shorter reaction times were needed to reach good yields. Obviously, our protocol was found to be more effective for the alkylation of indoles with ketones than for the alkylation of indoles with olefins, which might be attributed to the different reactive abilities of the active hydrogen of ketones and olefins.

According to the literature[16] and the observations in our reactions, taking the C-3 acylation of 1*H*-indole with pentan-2-one as an example, a possible mechanism is proposed (Scheme 2). In the reaction, the catalyst $Ce(OAc)_3$ provides a source of Ce(III), which reacts with the oxidant TBHP to form Ce(IV)═O (**2**). Then, **2** reacts with the substrate to form transition state **3**. **3** then very rapidly affords Ce(III) and water to yield the desired product. The trivalent cerium ion is then re-oxidized to Ce(IV)═O by TBHP to complete the catalytic cycle. It appears that the formation of **3** from **2** and the substrate is the rate-determining step.

In conclusion, we have developed an efficient and convenient $Ce(OAc)_3$/TBHP-mediated oxidative C–H bond activation between a carbonylic or allylic sp^3 C–H and the C-3 position of indoles in a β-CD/water system. This novel methodology

Table 3 C-3 alkylation of indoles with olefins[a]



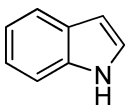
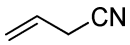
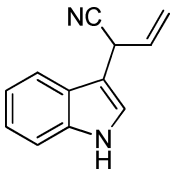
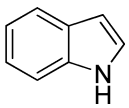
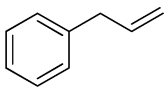
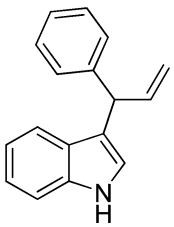
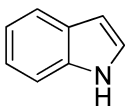
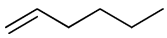
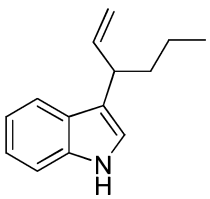
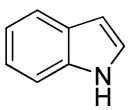
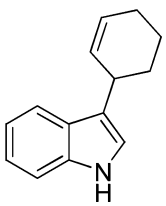
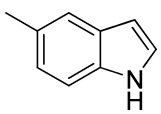
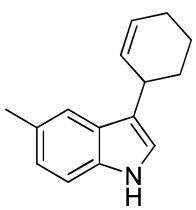
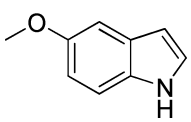
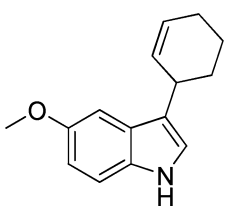
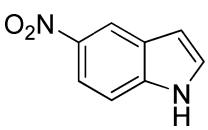
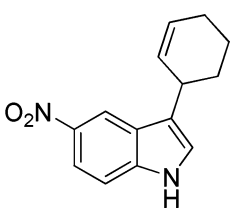
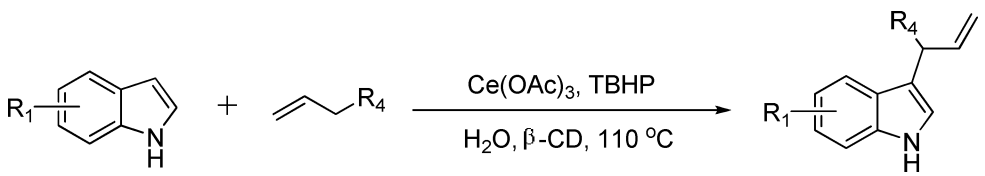
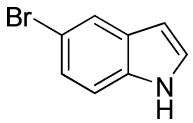
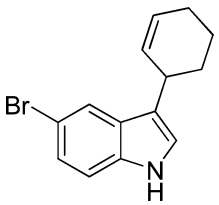
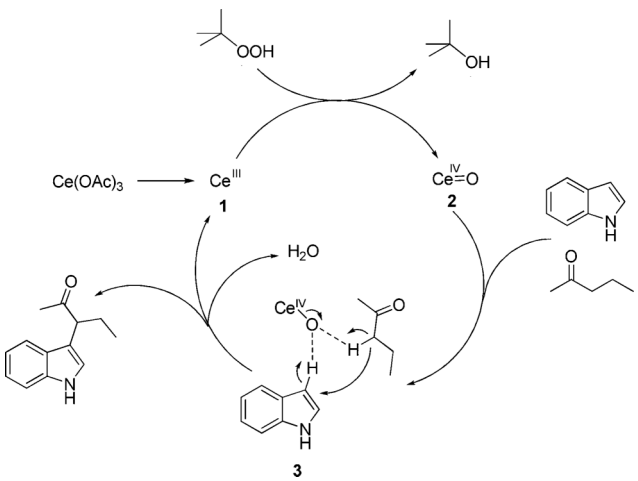
Entry	Indole	Olefin	Product	Time/h	Yield (%)[b]
1				12	87
2				12	85
3				14	78
4				14	81
5				14	82
6				14	84
7				18	68

Table 3 (*Contd.*)



Entry	Indole	Olefin	Product	Time/h	Yield (%)[b]
8				18	73

[a] Reactions were carried out using indole (1 mmol), olefin (1.5 mmol), $Ce(OAc)_3$ (0.15 mmol), TBHP (2 mmol) and β-CD (0.1 mmol) in H_2O (2 mL) at 110 °C. [b] Isolated yield.



Scheme 2 Possible mechanism for the C-3 acylation of 1*H*-indole with pentan-2-one.

provides an efficient and regioselective approach to directly use carbonylic or allylic sp^3 C–H bonds for the purpose of C–C bond formation. Advantages of our procedure include simplicity of operation, good yields, low cost and excellent recyclability of the catalytic system. The scope, definition of the mechanism and synthetic application of this reaction are currently under study in our laboratory.

Experimental

All the chemicals were acquired from commercial sources and used without any pre-treatment. All reagents were of analytical grade. NMR spectra were recorded on a Bruker 500-MHz spectrometer using $CDCl_3$ as the solvent and tetramethylsilane (TMS) as the internal standard. High performance liquid chromatography (HPLC) experiments were performed on a liquid chromatograph (Dionex Softron GmbH, America), consisting of a pump (P680) and ultraviolet-visible light detector (UVD) system (170U). Elemental analyses were performed on a Vario EL III instrument (Elementar Analysensysteme GmbH, Germany).

Typical procedure for the reaction (Table 2, entry 1)

To a stirred solution of 1*H*-indole (1 mmol), $Ce(OAc)_3$ (0.15 mmol), TBHP (2 mmol) and β-CD (0.1 mmol) in H_2O (2 mL) was added pentan-2-one (1.5 mmol), and stirring was then continued at 100 °C for 12 h, the reaction progress being monitored by HPLC. Upon completion, the reaction was cooled to room temperature, and the mixture was extracted with dichloromethane (3 × 10 mL), washed with water (2 × 10 mL) and then dried using anhydrous sodium sulfate. Then, the crude mixture was purified by column chromatography on silica gel to afford a yellow solid of 3-(1*H*-indol-3-yl)pentan-2-one (168.5 mg, 84% yield). The bottom aqueous layer (catalytic system) was concentrated under vacuum and fresh substrates (1*H*-indole, TBHP) and H_2O were then recharged into the residual β-CD/$Ce(OAc)_3$; the next run was performed under identical reaction conditions.

^{1}H-NMR (500 MHz, $CDCl_3$): δ (ppm) = 1.34 (t, 3H, CH_3), 2.28 (m, 2H, CH_2), 2.67 (s, 3H, CH_3), 3.89 (t, 1H, CH), 7.08–7.17 (m, 2H), 7.24 (s, 1H), 7.38–7.52 (m, 2H), 8.06 (br, 1H, NH); ^{13}C-NMR (500 MHz, $CDCl_3$): δ (ppm) = 18.3, 28.7, 31.2, 60.4, 111.5, 112.8, 118.4, 119.7, 122.1, 123.2, 127.5, 138.2, 209.1; Elemental analysis % calc. (% found): C 77.51 (77.58), H 7.53 (7.51), N 6.99 (6.96), O 7.92 (7.95).

3-(1*H*-Indol-3-yl)octan-2-one (Table 2, entry 2)

^{1}H-NMR (500 MHz, $CDCl_3$): δ (ppm) = 0.97 (t, 3H, CH_3), 1.24–1.36 (m, 6H, $CH_2CH_2CH_2$), 1.84 (m, 2H, CH_2), 2.47 (s, 3H, CH_3), 3.78 (t, 1H, CH), 7.09–7.15 (m, 2H), 7.22 (s, 1H), 7.35–7.54 (m, 2H), 8.09 (br, 1H, NH); ^{13}C-NMR (500 MHz, $CDCl_3$): δ (ppm) = 13.9, 22.8, 25.4, 28.2, 31.3, 32.1, 60.2, 111.3, 112.5, 118.6, 119.4, 121.9, 123.5, 127.2, 137.7, 208.9; Elemental analysis % calc. (% found): C 78.95 (78.97), H 8.67 (8.70), N 5.77 (5.76), O 6.58 (6.57).

2-(1*H*-Indol-3-yl)-3-oxobutanenitrile (Table 2, entry 3)

^{1}H-NMR (500 MHz, $CDCl_3$): δ (ppm) = 2.56 (s, 3H, CH_3), 4.82 (s, 1H, CH), 7.12–7.16 (m, 2H), 7.26 (s, 1H), 7.41–7.59 (m, 2H), 8.07 (br, 1H, NH); ^{13}C-NMR (500 MHz, $CDCl_3$): δ (ppm) = 27.8, 48.3, 111.0, 111.9, 117.5, 119.2, 120.1, 121.7, 122.6, 127.7, 136.8, 207.6; Elemental analysis % calc. (% found): C 72.67 (72.71), H 5.07 (5.08), N 14.10 (14.13), O 8.09 (8.07).

1-(1*H*-Indol-3-yl)-1-*p*-tolylpropan-2-one (Table 2, entry 4)

^{1}H-NMR (500 MHz, $CDCl_3$): δ (ppm) = 2.62 (s, 3H, CH_3), 2.39 (s, 3H, CH_3), 4.75 (s, 1H, CH), 7.02–7.19 (m, 7H), 7.24 (s, 1H), 7.49 (m, 1H), 7.78 (m, 1H), 8.36 (br, 1H, NH); ^{13}C-NMR (500 MHz, $CDCl_3$): δ (ppm) = 21.7, 28.2, 74.6, 111.3, 118.6, 119.7, 120.5, 121.2, 121.9, 122.5, 126.4, 127.8, 129.6, 136.5, 137.2, 209.4. Elemental analysis % calc. (% found): C 82.09 (82.10), H 6.53 (6.51), N 5.36 (5.32), O 6.07 (6.08).

2-(1*H*-Indol-3-yl)cyclohexanone (Table 2, entry 5)

^{1}H-NMR (500 MHz, $CDCl_3$): δ (ppm) = 1.75–1.87 (m, 6H, $CH_2CH_2CH_2$), 2.36 (t, 2H, CH_2), 3.62 (t, 1H, CH), 7.09–7.14 (m, 2H), 7.22 (s, 1H), 7.41–7.62 (m, 2H), 8.12 (br, 1H, NH); ^{13}C-NMR (500 MHz, $CDCl_3$): δ (ppm) = 26.2, 27.8, 36.5, 44.3, 59.1, 111.6, 112.3, 119.0, 120.4, 121.4, 123.1, 126.5, 136.9, 209.8. Elemental analysis % calc. (% found): C 78.83 (78.84), H 7.06 (7.09), N 6.58 (6.57), O 7.47 (7.50).

3-(5-Methyl-1*H*-indol-3-yl)pentan-2-one (Table 2, entry 6)

^{1}H-NMR (500 MHz, $CDCl_3$): δ (ppm) = 1.32 (t, 3H, CH_3), 2.28 (m, 2H, CH_2), 2.65 (s, 3H, CH_3), 2.72 (s, 3H, CH_3), 3.85 (t, 1H, CH), 7.10–7.28 (m, 3H), 7.54 (s, 1H), 8.08 (br, 1H, NH); ^{13}C-NMR (500 MHz, $CDCl_3$): δ (ppm) = 18.5, 23.2, 28.8, 31.0, 60.7, 111.3, 112.1, 118.7, 120.5, 123.4, 127.6, 129.4, 135.7, 209.3; Elemental analysis % calc. (% found): C 78.07 (78.10), H 7.92 (7.96), N 6.53 (6.51), O 7.42 (7.43).

3-(5-Methoxy-1*H*-indol-3-yl)pentan-2-one (Table 2, entry 7)

^{1}H-NMR (500 MHz, $CDCl_3$): δ (ppm) = 1.35 (t, 3H, CH_3), 2.26 (m, 2H, CH_2), 2.64 (s, 3H, CH_3), 3.87 (t, 1H, CH), 3.92 (s, 3H, CH_3), 7.01–7.12 (m, 2H), 7.23–7.29 (m, 2H), 8.11 (br, 1H, NH); ^{13}C-NMR (500 MHz, $CDCl_3$): δ (ppm) = 18.7, 28.4, 31.0, 53.9, 60.5, 102.6, 111.9, 112.3, 112.7, 123.5, 128.2, 129.4, 151.5, 208.7; Elemental analysis % calc. (% found): C 72.69 (72.70), H 7.42 (7.41), N 6.04 (6.06), O 13.82 (13.83).

3-(5-Nitro-1*H*-indol-3-yl)pentan-2-one (Table 2, entry 8)

^{1}H-NMR (500 MHz, $CDCl_3$): δ (ppm) = 1.27 (t, 3H, CH_3), 2.25 (m, 2H, CH_2), 2.63 (s, 3H, CH_3), 3.81 (t, 1H, CH), 7.21 (s, 1H), 7.46 (d, 1H), 7.87–7.95 (m, 2H), 8.13 (br, 1H, NH); ^{13}C-NMR (500 MHz, $CDCl_3$): δ (ppm) = 19.3, 27.9, 30.6, 60.8, 111.2, 112.4, 114.7, 122.8, 127.3, 129.2, 131.5, 142.4, 209.7; Elemental analysis % calc. (% found): C 63.41 (63.40), H 5.71 (5.73), N 11.39 (11.38), O 19.47 (19.49).

3-(5-Bromo-1*H*-indol-3-yl)pentan-2-one (Table 2, entry 9)

^{1}H-NMR (500 MHz, $CDCl_3$): δ (ppm) = 1.31 (t, 3H, CH_3), 2.27 (m, 2H, CH_2), 2.65 (s, 3H, CH_3), 3.83 (t, 1H, CH), 7.21–7.26 (m, 2H), 7.32–7.43 (m, 2H), 8.10 (br, 1H, NH); ^{13}C-NMR (500 MHz, $CDCl_3$): δ (ppm) = 18.7, 28.4, 30.9, 61.2, 111.4, 113.7, 117.1, 120.6, 123.0, 124.3, 128.7, 137.2, 209.4; Elemental analysis % calc. (% found): C 63.72 (55.73), H 5.05 (5.04), Br 28.54 (28.52), N 4.97 (5.00), O 5.69 (5.71).

2-(1*H*-Indol-3-yl)but-3-enenitrile (Table 3, entry 1)

^{1}H-NMR (500 MHz, $CDCl_3$): δ (ppm) = 4.27 (d, 1H), 5.17 (m, 2H), 5.86 (m, 1H), 7.07–7.21 (m, 3H), 7.42 (d, 1H), 7.75 (d, 1H), 8.25 (br, 1H, NH); ^{13}C-NMR (500 MHz, $CDCl_3$): δ (ppm) = 38.5, 110.7, 111.6, 118.5, 119.7, 120.5, 122.4, 123.2, 128.5, 133.6, 138.7; Elemental analysis % calc. (% found): C 79.11 (79.10), H 5.50 (5.53), N 15.38 (15.37).

3-(1-Phenylallyl)-1*H*-indole (Table 3, entry 2)

^{1}H-NMR (500 MHz, $CDCl_3$): δ (ppm) = 4.74–4.89 (m, 3H), 6.27 (m, 1H), 6.97–7.34 (m, 8H), 7.64 (m, 1H), 7.83 (m, 1H), 8.49 (br, 1H, NH); ^{13}C-NMR (500 MHz, $CDCl_3$): δ (ppm) = 59.4, 111.6, 119.4, 120.2, 120.9, 121.8, 122.3, 124.9, 128.2, 129.1, 130.5, 132.7, 137.6, 140.8, 144.2; Elemental analysis % calc. (% found): C 87.50 (87.52), H 6.51 (6.48), N 5.97 (6.00).

3-(Hex-1-en-3-yl)-1*H*-indole (Table 3, entry 3)

^{1}H-NMR (500 MHz, $CDCl_3$): δ (ppm) = 0.95 (t, 3H, CH_3), 1.28 (m, 2H, CH_2), 1.64 (m, 2H, CH_2), 3.78 (m, 1H, CH), 5.07–5.18 (m, 3H), 7.05–7.21 (m, 3H), 7.37 (d, 1H), 7.68 (m, 1H), 8.27 (br, 1H, NH); ^{13}C-NMR (500 MHz, $CDCl_3$): δ (ppm) = 15.7, 20.9, 41.3, 52.5, 110.7, 111.9, 116.4, 118.2, 120.5, 122.0, 124.2, 127.5, 138.7, 142.4; Elemental analysis % calc. (% found): C 84.36 (84.37), H 8.57 (8.60), N 7.01 (7.03).

3-(Cyclohex-2-enyl)-1*H*-indole (Table 3, entry 4)

^{1}H-NMR (500 MHz, $CDCl_3$): δ (ppm) = 1.72–2.07 (m, 6H, $CH_2CH_2CH_2$), 3.56 (m, 1H, CH), 5.46–5.51 (m, 2H), 7.07–7.24 (m, 3H), 7.45 (m, 1H), 7.72 (m, 1H), 8.59 (br, 1H, NH); ^{13}C-NMR (500 MHz, $CDCl_3$): δ (ppm) = 23.1, 25.4, 33.7, 44.8, 111.3, 112.4, 119.2, 120.5, 122.2, 123.5, 127.6, 128.5, 131.4, 137.7; Elemental analysis % calc. (% found): C 85.20 (85.24), H 7.67 (7.66), N 7.08 (7.10).

3-(Cyclohex-2-enyl)-5-methyl-1*H*-indole (Table 3, entry 5)

^{1}H-NMR (500 MHz, $CDCl_3$): δ (ppm) = 1.68–2.35 (m, 9H), 3.69 (m, 1H, CH), 5.43–5.52 (m, 2H), 7.21–7.35 (m, 3H), 7.75 (m, 1H), 8.67 (br, 1H, NH); ^{13}C-NMR (500 MHz, $CDCl_3$): δ (ppm) = 21.3, 23.8, 25.7, 33.6, 45.4, 111.5, 111.9, 120.1, 121.5, 123.9, 127.8, 129.2, 130.7, 132.5, 136.8; Elemental analysis % calc. (% found): C 85.21 (85.26), H 8.13 (8.11), N 6.67 (6.63).

3-(Cyclohex-2-enyl)-5-methoxy-1*H*-indole (Table 3, entry 6)

^{1}H-NMR (500 MHz, $CDCl_3$): δ (ppm) = 1.65–2.12 (m, 6H, $CH_2CH_2CH_2$), 3.47 (m, 1H, CH), 3.78 (s, 3H, CH_3), 5.51–5.62 (m, 2H), 6.92–7.13 (m, 2H), 7.21–7.28 (m, 2H), 8.53 (br, 1H,

NH); ^{13}C-NMR (500 MHz, $CDCl_3$): δ (ppm) = 21.7, 24.5, 33.5, 44.7, 58.7, 103.4, 111.5, 112.3, 114.7, 123.5, 127.4, 128.7, 132.6, 134.5, 152.7; Elemental analysis % calc. (% found): C 79.24 (79.26), H 7.51 (7.54), N 6.17 (6.16), O 7.02 (7.04).

3-(Cyclohex-2-enyl)-5-nitro-1*H*-indole (Table 3, entry 7)

^{1}H-NMR (500 MHz, $CDCl_3$): δ (ppm) = 1.62–2.04 (m, 6H, $CH_2CH_2CH_2$), 3.42 (m, 1H, CH), 5.53–5.65 (m, 2H), 7.19 (s, 1H), 7.52 (d, 1H), 7.91–8.05 (m, 2H), 8.37 (br, 1H, NH); ^{13}C-NMR (500 MHz, $CDCl_3$): δ (ppm) = 22.4, 24.8, 34.1, 43.6, 110.7, 113.5, 115.6, 124.0, 125.8, 128.2, 129.3, 132.4, 134.1, 149.2; Elemental analysis % calc. (% found): C 69.37 (69.41), H 5.83 (5.82), N 11.55 (11.56), O 13.20 (13.21).

5-Bromo-3-(cyclohex-2-enyl)-1*H*-indole (Table 3, entry 8)

^{1}H-NMR (500 MHz, $CDCl_3$): δ (ppm) = 1.67–1.98 (m, 6H, $CH_2CH_2CH_2$), 3.46 (m, 1H, CH), 5.48–5.64 (m, 2H), 7.15–7.27 (m, 2H), 7.37–7.46 (m, 2H), 8.33 (br, 1H, NH); ^{13}C-NMR (500 MHz, $CDCl_3$): δ (ppm) = 21.8, 25.2, 34.5, 44.1, 111.5, 114.4, 117.3, 122.7, 123.9, 125.3, 127.5, 130.8, 133.2, 139.5; Elemental analysis % calc. (% found): C 60.87 (60.89), H 5.09 (5.11), Br 28.92 (28.93), N 5.10 (5.07).

Acknowledgements

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