Organic & Biomolecular Chemistry

ROYAL SOCIETY OF CHEMISTRY

PAPER

View Article Online
View Journal | View Issue

Cite this: *Org. Biomol. Chem.*, 2021, **19**, 6085

Enantioselective fluorination of 3-indolinone-2-carboxylates with NFSI catalyzed by chiral bisoxazolines†

Swarnayu Banik,[a,b] Tanmoy Sahoo,[a,b] B. Sridhar [c] and B. V. Subba Reddy *[a,b]

Received 25th January 2021,
Accepted 10th June 2021

DOI: 10.1039/d1ob00144b

rsc.li/obc

A chiral Cu(I)–bisoxazoline complex catalyzed enantioselective electrophilic fluorination of 3-indolinone-2-carboxylates with NFSI has been accomplished to produce chiral 2-fluoro-3-indolinone-2-carboxylates in good yields with excellent enantioselectivities. This is the first report on the enantioselective fluorination of 2-substituted 3-indolinones using a chiral Cu(I)–bisoxazoline complex.

Introduction

The selective fluorination of organic molecules is a challenging task in modern organic synthesis.[1] In fact, the incorporation of fluorine into an organic molecule dramatically alters its properties in terms of lipophilicity, thermal stability, binding ability, and permeability.[2] Therefore, the substitution of a hydrogen atom by fluorine has become one of the essential methods in the design of new chemical entities (NCEs) to increase their effectiveness, half-life and bio-absorption and also to modulate their acidity, thereby improving their biological and pharmacological properties.[3] Furthermore, fluorine containing compounds constitute over 50% of blockbuster drugs (Fig. 1).[4]

As a result, several methods have been developed using either electrophilic or nucleophilic fluorinating agents for the fluorination of organic compounds.[5] In particular, catalytic enantioselective fluorination is an important transformation to produce fluorine containing chiral intermediates that are building blocks for drugs and pharmaceuticals.[6] Consequently, several methods have been reported on the enantioselective fluorination of α-branched carbonyl compounds.[7–9] Indeed, there are some reports on the asymmetric fluorination of cyclic β-ketoesters.[10] However, there are no reports on the enantioselective fluorination of 3-indolinone-2-carboxylates. Unlike cyclic β-ketoesters,[11] the functionalization of *N*-containing β-ketoesters, for instance, indolinone-2-carboxylates, is slightly difficult using electrophilic fluorinating agents because the electrophilic fluorine strongly coordinates with a nitrogen atom, resulting in no fluorination or in fluorination with low yields. Therefore, we attempted the fluorination of *N*-containing cyclic β-ketoesters by tuning the reactivity of the nitrogen atom.

Results and discussion

Herein, we report a novel strategy for the enantioselective fluorination of 3-indolinone-2-carboxylates using *N*-fluorobenzenesulfonimide (NFSI) as a source of electrophilic fluorine and a Cu(I)–bisoxazoline complex as a chiral source.[12] The precursors, 3-indolinone-2-carboxylates, were prepared according to a known procedure.[13] The ligands L1–L5 were prepared by using the procedure reported in the literature (Fig. 2).[14]

To optimize the reaction conditions, we conducted the reaction using different metal salts and chiral ligands under diverse conditions and the results are presented in Table 1. Initially, the reaction was performed with **4a** and NFSI using

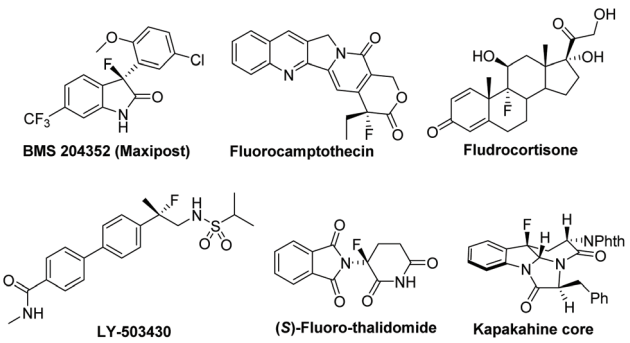


Fig. 1 Biologically active fluoro-molecules.

[a]*Fluoro & Agrochemicals, CSIR-Indian Institute of Chemical Technology, Hyderabad, India. E-mail: basireddy@iict.res.in; http://www.iictindia.org*
[b]*Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, UP 201002, India*
[c]*Laboratory of X-ray Crystallography, CSIR-Indian Institute of Chemical Technology, Hyderabad-500 007, India*

†Electronic supplementary information (ESI) available. CCDC 2047903. For ESI and crystallographic data in CIF or other electronic format see DOI: 10.1039/d1ob00144b

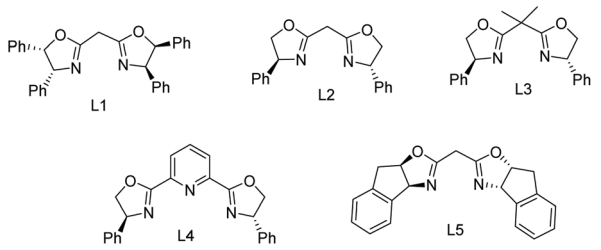
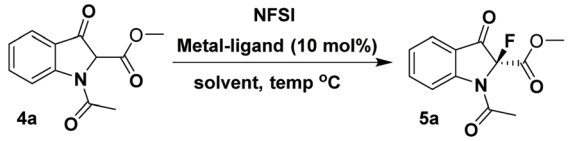


Fig. 2 Chiral ligands L1–L5.

Table 1 Screening of various metal–ligand complexes[a]



Entry	Ligand	Solvent	Metal salt	T (°C)	IY[b] (%)	ee[c] (%)
1	L-1	$^{i}Pr_2O$	CuOTf	20	78	75
2	L-1	$^{i}Pr_2O$	$Cu(OAc)_2{\cdot}H_2O$	20	85	86
3	L-1	$^{i}Pr_2O$	$CuOAc{\cdot}4H_2O$	20	90	95
4	L-2	$^{i}Pr_2O$	$CuOAc{\cdot}4H_2O$	20	81	74
5	L-3	$^{i}Pr_2O$	$CuOAc{\cdot}4H_2O$	20	84	84
6	L-4	$^{i}Pr_2O$	$CuOAc{\cdot}4H_2O$	20	57	65
7	L-5	$^{i}Pr_2O$	$CuOAc{\cdot}4H_2O$	20	69	60
8	L-1	DCM	$CuOAc{\cdot}4H_2O$	20	72	10
9	L-1	$CHCl_3$	$CuOAc{\cdot}4H_2O$	20	76	27
10	L-1	ACN	$CuOAc{\cdot}4H_2O$	20	63	30
11	L-1	Me_2CO	$CuOAc{\cdot}4H_2O$	20	20	10
12	L-1	MeOH	$CuOAc{\cdot}4H_2O$	20	49	20
13	L-1	EtOAc	$CuOAc{\cdot}4H_2O$	20	15	4
14	L-1	THF	$CuOAc{\cdot}4H_2O$	20	81	70
15	L-1	Et_2O	$CuOAc{\cdot}4H_2O$	20	86	84
16	L-1	MTBE	$CuOAc{\cdot}4H_2O$	20	94	90
17	L-1	$^{i}Pr_2O$	$CuOAc{\cdot}4H_2O$	25	88	92
18	L-1	$^{i}Pr_2O$	$CuOAc{\cdot}4H_2O$	0	83	68
19	L-1	$^{i}Pr_2O$	$CuOAc{\cdot}4H_2O$	15	85	86
20	L-1	$^{i}Pr_2O$	$CuOAc{\cdot}4H_2O$	20	88	84[d]
21	L-1	$^{i}Pr_2O$	$CuOAc{\cdot}4H_2O$	20	91	80[e]
22	L-1	$^{i}Pr_2O$	$NiCl_2{\cdot}6H_2O$	20	67	62
23	L-1	$^{i}Pr_2O$	$Co(OAc)_2{\cdot}4H_2O$	20	71	78
24	L-1	$^{i}Pr_2O$	$Co(acac)_2$	20	70	50
25	L-1	$^{i}Pr_2O$	CoF_2	20	76	72
26	L-1	$^{i}Pr_2O$	$Pd(OAc)_2$	20	67	72
27	L-1	$^{i}Pr_2O$	$FeCl_2$	20	55	14
28	L-1	$^{i}Pr_2O$	$FeCl_3{\cdot}6H_2O$	20	65	20
29	L-1	$^{i}Pr_2O$	AgOAc	20	43	26
30	L-1	$^{i}Pr_2O$	$CuOAc{\cdot}4H_2O$	20	90	92[f]

[a] All reactions were performed with **4a** (0.22 mmol), NFSI (0.17 mmol) and 10 mol% metal–ligand complex for over 14 h. [b] Isolated yield. [c] ee (%) was determined using HPLC (OJ–H chiral column, 9 : 1 hexane : isopropanol, 1 mL min^{-1} flow rate). [d] One equivalent of HFIP was added. [e] MS. 4 Å were added. [f] **4a** (0.22 mmol) and 10 mol% metal–ligand complex were added together and stirred for 30 min, and then NFSI (0.17 mmol) was added.

CuOTf and ligand L1 in diisopropyl ether at 20 °C. After 10 h, the desired fluoro compound **5a** was isolated in 78% yield with 75% ee.

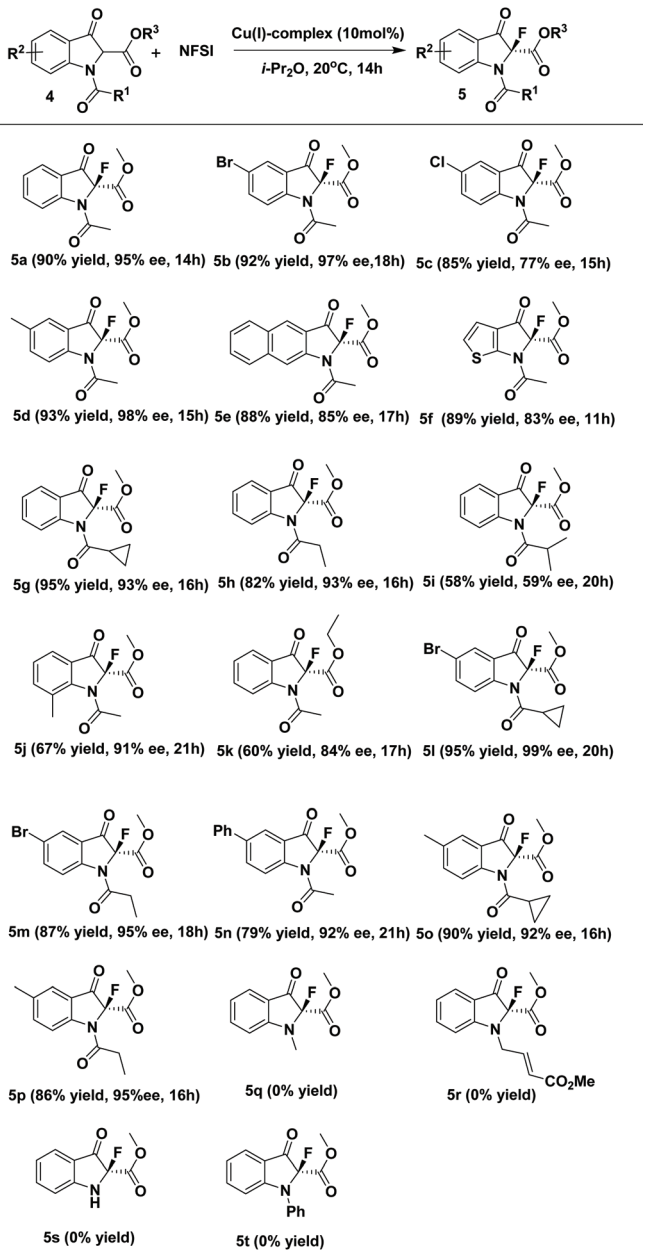
To improve the ee, we tested the reaction with different copper salts under similar reaction conditions. Indeed, Cu $(OAc)_2{\cdot}H_2O$ afforded **5a** with a slightly higher yield and selectivity (85% yield and 86% ee). To our delight, Cu(I) acetate afforded the product with an excellent yield and selectivity. To improve the ee, the reaction was performed using different ligands (L1–L5) (entries 3–7, Table 1). The best results were obtained with L1. In order to understand the effect of the solvent, the reaction was conducted in different solvents such as DCM, $CHCl_3$, CH_3CN, acetone, MeOH, EtOAc, THF, Et_2O, and MTBE (entries 8–16, Table 1). Among them, diisopropyl ether furnished the best results in terms of the yield and ee. Subsequently, we examined the effect of the temperature ranging from 0–25 °C (entries 17–19, Table 1). The best conversion and selectivity were achieved at 20 °C. To improve the ee further, we examined the effect of additives such as hexafluoroisopropanol (HFIP). Unfortunately, product **5a** was obtained in 88% yield with a low ee (84%) (entry 20, Table 1). Next, the reaction was conducted in the presence of 4 Å molecular sieves under the optimized conditions. However, the ee of **5a** was further decreased to 80% (entry 21). Furthermore, the reaction was carried out with different metal salts such as Ni(II), Co(II), Pd(II), Fe(II), Fe(III) and Ag(I) to examine their catalytic efficiency (entries 22–29, Table 1). Among these, Cu(I) acetate gave the best selectivity with L1 under the optimized conditions.

Encouraged by the above results, we extended the scope of this methodology to other substrates. The substituent present on the aromatic ring of 3-indolinone-2-carboxylate had some effect on the conversion and selectivity (Table 2). The presence of a more bulky group at the 5-position of the aromatic ring resulted in products with high enantioselectivities (**5b**, **5l** and **5m**, Table 2). However, the substituent present at the 7-position of 3-indolinone-2-carboxylate afforded the product in a lower yield than that present at the 5-position (**5j**, Table 2). A sterically hindered 2-naphthyl derivative also afforded the product with a good yield and selectivity (**5e**, Table 2). Similarly, the substrate derived from 2-aminothiophene-3-carboxylate afforded the product in a good yield (**5f**, Table 2).

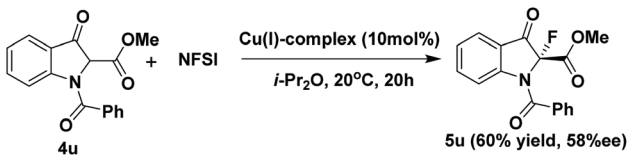
The substituent present on the N-atom is crucial for the success of the reaction. The reaction was quite successful with amide derivatives of 3-indolinone-2-carboxylate (Table 2). In contrast, isobutyramide afforded the product with a low yield and ee (**5i**, Table 2) compared to other amides such as acetamide, propionamide and cyclopropanecarboxamide. However, the reaction did not proceed with substrates bearing *N*-methyl, *N*-allyl, *N*-phenyl and free NH groups (**5q**, **5r**, **5s** and **5t**, Table 2). To our delight, the substrate bearing the *N*-benzoyl (**5u**) group gave the product in 60% yield with 58% ee (Scheme 1).

The sequence of addition also played a key role in achieving the best results. Indeed, the best results were obtained when NFSI is activated first with a metal–ligand complex.[15] Conversely, a low selectivity was observed when 3-indolinone-2-carboxylate was activated by a chiral metal–ligand complex before the addition of NFSI (92% ee; entry 30, Table 1). The structure of product **5d** was determined by single crystal X-ray diffraction analysis (Fig. 3).[16]Based on the above observations, we proposed a tentative reaction mechanism for this trans-

Table 2 Substrate scope[a]



[a] All reactions were performed with **4a** (0.22 mmol), NFSI (0.17 mmol) and 10 mol% metal–ligand complex for over 14 h.



Scheme 1 Fluorination of methyl 1-benzoyl-3-oxoindoline-2-carboxylate (**4u**).

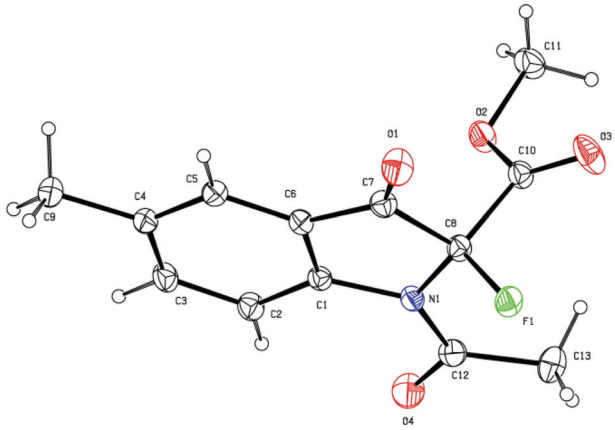
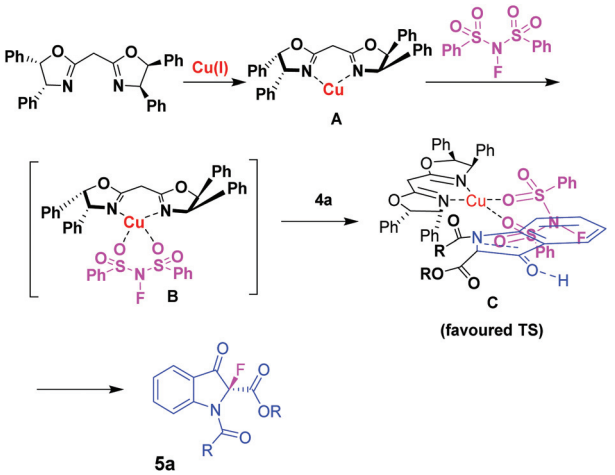


Fig. 3 ORTEP diagram of **5d**.

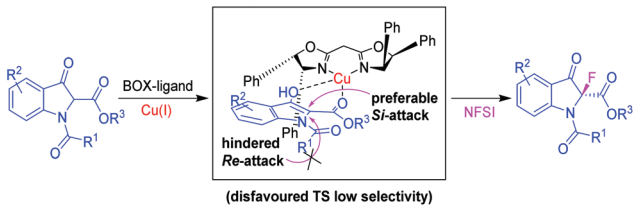


Scheme 2 A plausible reaction mechanism.

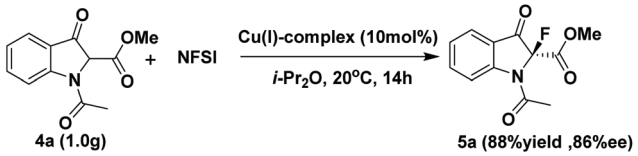
formation (Scheme 2). Initially, the Cu(I) metal coordinates with ligand L1 to form the Cu(I)–bisoxazoline complex (A). Subsequently, this metal–ligand complex (A) activates NFSI to generate the active complex (B). The preferential Si-face attack of F^+ on **4a** affords the desired **5a** with a high yield and selectivity. In a model C, the spacial alignment of amide and ester groups exist below to the plane of phenyl rings of chiral metal ligand complex B. As a result, the substrate bearing bulky ester and amide groups affords products with low selectivities (**5i**, **5k** and **5u**). In the case of bulky substituents present on the phenyl ring (*e.g.* **5b**, **5d** and **5n**), the reaction proceeds through TS model C to avoid the steric hindrance of phenyl groups that exist below the plane of chiral complex B.

Alternately, when the metal–ligand complex coordinates initially with β-ketoester instead of NFSI, the product was obtained with a low ee (Scheme 3).

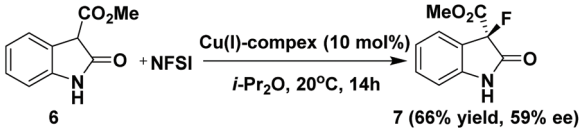
To demonstrate its practicality, we performed the asymmetric fluorination of substrate **4a** at the 1.0 g scale. Interestingly, the product was obtained in 88% yield with 86% ee (Scheme 4).



Scheme 3 A disfavoured spacial alignment.



Scheme 4 Gram-scale reaction.



Scheme 5 Enantioselective fluorination of methyl 2-oxoindoline-3-carboxylate **6**.

To illustrate its application, we successfully employed this method for the enantioselective fluorination of a chiral precursor of kapakahine from methyl 2-oxoindoline-3-carboxylate **6**.[17] Interestingly, the desired chiral fluoro intermediate **7** was obtained in 66% yield with 59% ee (Scheme 5).

Conclusions

In conclusion, we successfully accomplished the fluorination of nitrogen cyclic β-ketoesters using a chiral Cu(I)–bisoxazoline complex. This method is highly selective to functionalize 3-indolinone-2-carboxylates at the active methylene site with NFSI to produce the corresponding chiral fluoro derivatives. It is very useful to produce pharmacologically relevant fluoro indolinone scaffolds in a highly enantioselective manner.

Experimental section

General methods

All reactions were performed in oven-dried round bottom flasks; the flasks were fitted with rubber septa and the reactions were conducted under a nitrogen atmosphere. Glass syringes were used to transfer solvents. The crude products were purified by column chromatography on a silica gel 100–200 mesh. Thin layer chromatography (TLC) plates were visualized by exposure to ultraviolet light at 254 nm, and by exposure to iodine vapours and/or by exposure to a methanolic acidic solution of *p*-anisaldehyde followed by heating (<1 min) on a hot plate (approx. 250 °C). Organic solutions were concentrated on a rotary evaporator at 35–40 °C. Melting points (MP) were obtained on a Buchi B-540 apparatus. ^{1}H, ^{13}C (proton decoupled) and ^{19}F NMR spectra were recorded in $CDCl_3$ at 300, 400 or 500 MHz (^{1}H), 101 MHz (^{13}C) and 376 or 377 MHz (^{19}F). Chemical shifts (δ) were reported in parts per million (ppm) with respect to TMS as an internal standard. Coupling constants (J) were reported in hertz (Hz). Mass spectra and HRMS spectra were recorded on a mass spectrometer by electrospray ionization (ESI) and atmospheric pressure chemical ionization (APCI) techniques. Infrared spectra (IR) were recorded with a thin film of the solvated ($CHCl_3$) sample. Optical rotations were recorded using a PerkinElmer (model-341) polarimeter. Enantiomeric excesses (ee) were determined by HPLC (Shimadzu) analysis by using DAICEL Chiralpak OD–H, OJ–H and other columns.

Fluorination of methyl 3-indolinone-2-carboxylates

Preparation of racemic compounds. A flame dried 20 mL screw cap reaction tube with a stir bar was evacuated and backfilled with nitrogen. This tube was charged with the fluorinating agent *N*-fluorobenzenesulfonimide (NFSI) (0.8 equiv.) and 10 mL of diisopropyl ether followed by the addition of substrate **4** (1 equiv.) and potassium carbonate (0.6 equiv.). The reaction mixture was stirred overnight at room temperature and upon consumption of the starting material, the solvent was evaporated to provide the crude product, which was purified by column chromatography using an ethyl acetate/*n*-hexane (1/19 to 1/9 v/v) mixture to afford the pure product **5**.

Preparation of chiral compounds (5). A flame dried 20 mL screw cap reaction tube with a stir bar was evacuated and backfilled with nitrogen. This tube was charged with the fluorinating agent *N*-fluorobenzenesulfonimide (NFSI) (0.8 equiv.) and 10 mL of diisopropyl ether followed by 10 mol% of the Cu(I)–ligand (L1) complex under a nitrogen atmosphere. After stirring for 30 min at room temperature, substrate **4** (1 equiv.) was added and the mixture was stirred at 20 °C for over 14 h. The reaction was monitored by TLC. Upon consumption of the starting material, the solvent was evaporated to provide the crude product, which was purified by column chromatography using an ethyl acetate/*n*-hexane (1/19 to 1/9 v/v) mixture to afford the pure product **5**.

Methyl (*S*)-1-acetyl-2-fluoro-3-oxoindoline-2-carboxylate (5a). Yield (40 mg, 90%), white solid, mp 118 °C, ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.52 (s, 1H), 7.80 (dd, J = 7.7, 0.7 Hz, 1H), 7.75 (ddd, J = 8.6, 7.4, 1.4 Hz, 1H), 7.31 (td, J = 7.6, 0.7 Hz, 1H), 3.91 (s, 3H), 2.33 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 186.9 (d, J_{C-F} = 16.5 Hz), 168.3, 163.5 (d, J_{C-F} = 35.8 Hz), 153.7, 139.1, 125.6, 125.5, 119.6, 118.4, 94.7 (d, J_{C-F} = 229.9 Hz), 54.4, 23.8. ^{19}F NMR (377 MHz, $CDCl_3$) δ −138.38. IR (thin film): ν_{max}/cm^{-1} 1756, 1701, 1582, 1496, 1365, 1174, 1148, 762. HRMS (ESI Orbitrap) calcd for $C_{12}H_{11}O_4NF$ $[M + H]^+$: 252.0667, found: 252.0666. HPLC analysis (DAICEL Chiralpak OJ–H, *n*-hexane/2-PrOH = 90/10, 1 mL min^{-1}, 254 nm, minor

(23.78 min), major (27.34 min), 95% ee; $[\alpha]_D^{20}$ +38.4 (c = 0.8, $CHCl_3$).

Methyl (*S*)-1-acetyl-5-bromo-2-fluoro-3-oxoindoline-2-carboxylate (5b). Yield (48 mg, 92%), pale yellow solid, mp 132 °C, ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.44 (s, 1H), 7.90 (d, J = 1.8 Hz, 1H), 7.83 (dd, J = 8.8, 2.0 Hz, 1H), 3.91 (s, 3H), 2.31 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 185.7 (d, J_{C-F} = 16.8 Hz), 168.2, 163.0 (d, J_{C-F} = 35.8 Hz), 152.6, 141.5, 128.1, 121.2, 119.9, 118.5, 94.6 (d, J_{C-F} = 231.6 Hz), 54.5, 23.7. ^{19}F NMR (377 MHz, $CDCl_3$) δ −137.95. HRMS (ESI Orbitrap) calcd for $C_{12}H_{10}O_4NBrF$ $[M + H]^+$: 329.9766, found: 329.9761. HPLC analysis (DAICEL Chiralpak OJ–H, n-hexane/2-PrOH = 90/10, 1 mL min^{-1}, 254 nm, minor (23.24 min), major (33.15 min), 97% ee; $[\alpha]_D^{20}$ +40.5 (c = 0.7, $CHCl_3$).

Methyl (*S*)-1-acetyl-5-chloro-2-fluoro-3-oxoindoline-2-carboxylate (5c). Yield (45 mg, 85%), white solid, mp 98 °C, ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.49 (s, 1H), 7.75 (d, J = 2.2 Hz, 1H), 7.69 (dd, J = 8.9, 2.3 Hz, 1H), 3.91 (s, 3H), 2.31 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 185.9 (d, J_{C-F} = 17.0 Hz), 168.2, 163.1 (d, J_{C-F} = 35.8 Hz), 152.2, 138.7, 131.3, 125.0, 120.9, 119.6, 94.8 (d, J_{C-F} = 231.3 Hz), 54.5, 23.7. ^{19}F NMR (377 MHz, $CDCl_3$) δ −137.92. IR (thin film): ν_{max}/cm^{-1} 1778, 1712, 1598, 1432, 1338, 1269, 1193, 1124, 1071, 770. HRMS (ESI Orbitrap) calcd for $C_{12}H_{10}O_4NClF$ $[M + H]^+$: 286.0271, found: 286.0269. HPLC analysis (DAICEL Chiralpak OJ–H, n-hexane/2-PrOH = 90/10, 1 mL min^{-1}, 254 nm, minor (26.71 min), major (34.71 min), 77% ee; $[\alpha]_D^{20}$ +10.3 (c = 0.2, $CHCl_3$).

Methyl (*S*)-1-acetyl-2-fluoro-5-methyl-3-oxoindoline-2-carboxylate (5d). Yield (50 mg, 93%), white solid, mp 114 °C, ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.41 (s, 1H), 7.58 (s, 1H), 7.56 (d, J = 8.5 Hz, 1H), 3.89 (s, 3H), 2.40 (s, 3H), 2.30 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 187.0 (d, J_{C-F} = 16.4 Hz), 168.1, 163.5 (d, J_{C-F} = 36.1 Hz), 140.1, 135.7, 125.3, 119.6, 118.2, 118.1, 95.0 (d, J_{C-F} = 230.0 Hz), 54.3, 23.7, 20.7. ^{19}F NMR (377 MHz, $CDCl_3$) δ −138.44. IR (thin film): ν_{max}/cm^{-1} 1783, 1744, 1705, 1492, 1379, 1329, 1246, 1198, 764. HRMS (ESI Orbitrap) calcd for $C_{13}H_{13}O_4NF$ $[M + H]^+$: 266.0823, found: 266.0830. HPLC analysis (DAICEL Chiralpak OJ–H, n-hexane/2-PrOH = 90/10, 1 mL min^{-1}, 254 nm, minor (16.96 min), major (22.72 min), 98% ee; $[\alpha]_D^{20}$ +40.5 (c = 0.7, $CHCl_3$).

Methyl (*S*)-1-acetyl-2-fluoro-3-oxo-2,3-dihydro-1*H*-benzo[*f*]indole-2-carboxylate (5e). Yield (47 mg, 88%), pale yellow solid, mp 156 °C, ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.85 (s, 1H), 8.40 (s, 1H), 7.93 (t, J = 9.2 Hz, 2H), 7.67 (t, J = 7.4 Hz, 1H), 7.52 (t, J = 7.5 Hz, 1H), 3.91 (s, 3H), 2.39 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 187.2 (d, J_{C-F} = 17.1 Hz), 168.9, 163.7 (d, J_{C-F} = 36.8 Hz), 145.4, 139.2, 131.0, 130.6, 130.3, 128.8, 128.3, 126.7, 119.4, 115.0, 95.4 (d, J_{C-F} = 230.1 Hz), 54.4, 23.9. ^{19}F NMR (377 MHz, $CDCl_3$) δ −135.86. IR (thin film): ν_{max}/cm^{-1} 1775, 1701, 1624, 1378, 1315, 1160, 760. HRMS (ESI Orbitrap) calcd for $C_{16}H_{13}O_4NF$ $[M + H]^+$: 302.0823, found: 302.0836. HPLC analysis (DAICEL Chiralpak OD–H, n-hexane/2-PrOH = 90/10, 1 mL min^{-1}, 254 nm, minor (11.73 min), major (12.62 min), 85% ee; $[\alpha]_D^{20}$ +50.6 (c = 0.8, $CHCl_3$).

Methyl (*S*)-6-acetyl-5-fluoro-4-oxo-5,6-dihydro-4*H*-thieno[2,3-*b*]pyrrole-5-carboxylate (5f). Yield (48 mg, 89%), white solid, mp 138 °C, ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.03 (dd, J = 14.8, 5.5 Hz, 2H), 3.93 (s, 3H), 2.28 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 178.0 (d, J_{C-F} = 17.3 Hz), 170.3, 164.8, 162.5 (d, J_{C-F} = 34.8 Hz), 125.0, 123.1, 117.9, 98.7 (d, J_{C-F} = 236.9 Hz), 54.5, 21.3. ^{19}F NMR (377 MHz, $CDCl_3$) δ −138.78. IR (thin film): ν_{max}/cm^{-1} 1777, 1729, 1697, 1346, 1284, 1187, 756. HRMS (ESI Orbitrap) calcd for $C_{10}H_9O_4NFS$ $[M + H]^+$: 258.0231, found: 258.0232. HPLC analysis (DAICEL Chiralpak OD–H, n-hexane/2-PrOH = 92/8, 1 mL min^{-1}, 254 nm, minor (12.41 min), major (15.47 min), 83% ee; $[\alpha]_D^{20}$ +74.3 (c = 0.8, $CHCl_3$).

Methyl (*S*)-1-(cyclopropanecarbonyl)-2-fluoro-3-oxoindoline-2-carboxylate (5g). Yield (51 mg, 95%), white solid, mp 141 °C, ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.45 (d, J = 8.4 Hz, 1H), 7.80 (dd, J = 7.6, 0.6 Hz, 1H), 7.76–7.70 (m, 1H), 7.32–7.26 (m, 1H), 3.88 (s, 3H), 1.99–1.78 (m, 1H), 1.46–1.34 (m, 1H), 1.07–0.97 (m, 2H), 0.97–0.90 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 187.1 (d, J_{C-F} = 17.2 Hz), 172.1 (d, J_{C-F} = 2.6 Hz), 163.5 (d, J_{C-F} = 36.3 Hz), 154.1, 139.0, 125.6, 125.3, 119.5, 118.4, 94.8 (d, J_{C-F} = 228.2 Hz), 54.1, 14.0 (d, J_{C-F} = 4.5 Hz), 10.8, 9.3. ^{19}F NMR (376 MHz, $CDCl_3$) δ −136.56. IR (thin film): ν_{max}/cm^{-1} 1778, 1742, 1697, 1406, 1292, 1100, 760. HRMS (ESI Orbitrap) calcd for $C_{14}H_{13}O_4NF$ $[M + H]^+$: 278.0823, found: 278.0831. HPLC analysis (DAICEL Chiralpak OJ–H, n-hexane/2-PrOH = 95/5, 0.8 mL min^{-1}, 254 nm, minor (25.49 min), major (33.34 min), 93% ee; $[\alpha]_D^{20}$ +21.2 (c = 0.7, $CHCl_3$).

Methyl (*S*)-2-fluoro-3-oxo-1-propionylindoline-2-carboxylate (5h). Yield (44 mg, 82%), white solid, mp 106 °C, ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.44 (s, 1H), 7.77 (d, J = 7.7 Hz, 1H), 7.72 (t, J = 7.9 Hz, 1H), 7.26 (t, J = 7.5 Hz, 1H), 3.87 (s, 3H), 2.66 (dq, J = 14.7, 7.2 Hz, 1H), 2.34 (dd, J = 15.3, 7.1 Hz, 1H), 1.21 (t, J = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 187.1 (d, J_{C-F} = 16.6 Hz), 172.2 (d, J_{C-F} = 2.1 Hz), 163.5 (d, J_{C-F} = 35.7 Hz), 153.9, 139.1, 125.8, 125.4, 119.6, 118.2, 94.6 (d, J_{C-F} = 229.7 Hz), 54.3, 29.1, 8.7. ^{19}F NMR (376 MHz, $CDCl_3$) δ −138.20. IR (thin film): ν_{max}/cm^{-1} 1783, 1744, 1469, 1374, 1292, 1185, 762. HRMS (ESI Orbitrap) calcd for $C_{13}H_{13}O_4NF$ $[M + H]^+$: 266.0846, found: 266.0853. HPLC analysis (DAICEL Chiralpak OJ–H, n-hexane/2-PrOH = 90/10, 1 mL min^{-1}, 254 nm, minor (14.27 min), major (22.45 min), 93% ee; $[\alpha]_D^{20}$ +11.8 (c = 1.0, $CHCl_3$).

Methyl (*S*)-2-fluoro-1-isobutyryl-3-oxoindoline-2-carboxylate (5i). Yield (31 mg, 58%), colourless liquid, ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.51 (s, 1H), 7.80 (dd, J = 7.6, 0.6 Hz, 1H), 7.78–7.72 (m, 1H), 7.30 (t, J = 7.5 Hz, 1H), 3.89 (s, 3H), 2.76 (s, 1H), 1.28 (d, J = 6.5 Hz, 3H), 1.16 (d, J = 6.6 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 187.0 (d, J_{C-F} = 16.7 Hz), 176.6, 163.6 (d, J_{C-F} = 35.5 Hz), 154.0, 139.1, 125.7, 125.5, 119.9, 118.6, 94.7 (d, J_{C-F} = 229.7 Hz), 54.3, 34.6 (d, J_{C-F} = 1.7 Hz), 20.5, 18.6. ^{19}F NMR (376 MHz, $CDCl_3$) δ −137.54. HRMS (ESI Orbitrap) calcd for $C_{14}H_{15}O_4NF$ $[M + H]^+$ = 280.0980, found: 280.0973. HPLC analysis (DAICEL Chiralpak OJ-H, n-hexane/2-PrOH = 90/10, 1 mL min^{-1}, 254 nm, minor (9.63 min), major (10.94 min), 59% ee; $[\alpha]_D^{20}$ +1.8 (c = 1.9, $CHCl_3$).

Methyl (*S*)-1-acetyl-2-fluoro-7-methyl-3-oxoindoline-2-carboxylate (5j). Yield (36 mg, 67%), light pink solid, mp 116 °C, ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.66 (d, J = 7.6 Hz, 1H), 7.58 (d, J = 7.4 Hz, 1H), 7.28 (d, J = 7.5 Hz, 1H), 3.90 (s, 1H), 2.31 (d, J = 0.7

Hz, 1H), 2.29 (s, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 187.8 (d, J = 17.3 Hz), 168.0, 163.8 (d, J = 36.2 Hz), 153.0, 141.6, 129.8, 126.2, 123.3, 121.9, 95.7 (d, J = 230.7 Hz), 54.3, 24.0 (d, J = 2.4 Hz), 21.2. ^{19}F NMR (377 MHz, $CDCl_3$) δ −136.29. HRMS (ESI Orbitrap) calcd for $C_{13}H_{13}O_4NF$ $[M + H]^+$: 266.0823, found: 266.0827. HPLC analysis (DAICEL Chiralpak OJ–H, *n*-hexane/2-PrOH = 90/10, 1 mL min^{-1}, 254 nm, minor (20.79 min), major (25.05 min), 91% ee; $[\alpha]_D^{20}$ +36.2 (c = 1.2, $CHCl_3$).

Ethyl (*S*)-1-acetyl-2-fluoro-3-oxoindoline-2-carboxylate (5k). Yield (32 mg, 60%), pale yellow liquid, ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.52 (s, 1H), 7.80 (d, J = 7.7 Hz, 1H), 7.75 (ddd, J = 8.6, 7.4, 1.4 Hz, 1H), 7.31 (td, J = 7.7, 0.7 Hz, 1H), 4.46–4.28 (m, 2H), 2.33 (s, 3H), 1.31 (t, J = 7.1 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 187.1 (d, J_{C-F} = 16.6 Hz), 168.3 (d, J_{C-F} = 1.0 Hz), 163.0 (d, J_{C-F} = 35.4 Hz), 139.0, 129.2, 128.0, 125.7, 125.5, 119.6, 118.3, 94.7 (d, J_{C-F} = 230.3 Hz), 64.1, 23.8, 14.0. ^{19}F NMR (376 MHz, $CDCl_3$) δ −138.35. HRMS (ESI Orbitrap) Exact mass calcd for $C_{13}H_{13}O_4NF$ $[M + H]^+$: 266.0828, found: 266.0822. HPLC analysis (DAICEL Chiralpak OJ–H, *n*-hexane/2-PrOH = 90/10, 1 mL min^{-1}, 254 nm, minor (12.29 min), major (14.88 min), 84% ee, $[\alpha]_D^{20}$ +23.5 (c = 1.1, $CHCl_3$).

Methyl (*S*)-5-bromo-1-(cyclopropanecarbonyl)-2-fluoro-3-oxoindoline-2-carboxylate (5l). Yield (50 mg, 95%), white solid, mp 135 °C, ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.37 (d, J = 8.9 Hz, 1H), 7.90 (d, J = 2.1 Hz, 1H), 7.80 (dd, J = 8.9, 2.2 Hz, 1H), 3.88 (s, 3H), 1.86 (qdd, J = 7.8, 4.6, 1.3 Hz, 1H), 1.40 (ddt, J = 9.2, 7.0, 4.0 Hz, 1H), 1.08–0.97 (m, 2H), 0.97–0.91 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 186.0 (d, J_{C-F} = 17.3 Hz), 172.0 (d, J_{C-F} = 2.7 Hz), 163.1 (d, J_{C-F} = 36.2 Hz), 152.9, 141.4, 128.0, 121.1, 120.0, 118.3, 94.7 (d, J_{C-F} = 229.5 Hz), 54.3, 13.9 (d, J_{C-F} = 4.6 Hz), 11.0, 9.5. ^{19}F NMR (377 MHz, $CDCl_3$) δ −136.09. HRMS (ESI Orbitrap) calcd for $C_{14}H_{12}O_4NBrF$ $[M + H]^+$: 358.0285, found: 358.0280. HPLC analysis (DAICEL Chiralpak OJ–H, *n*-hexane/2-PrOH = 93/7, 0.8 mL min^{-1}, 254 nm, minor (18.44 min), major (29.97 min), 99% ee; $[\alpha]_D^{20}$ −13.4 (c = 1.8, $CHCl_3$).

Methyl (*S*)-5-bromo-2-fluoro-3-oxo-1-propionyl indoline-2-carboxylate (5m). Yield (46 mg, 87%) white solid, mp 128 °C, ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.42 (s, 1H), 7.90 (d, J = 2.1 Hz, 1H), 7.82 (dd, J = 8.9, 2.2 Hz, 1H), 3.90 (s, 3H), 2.66 (dq, J = 21.9, 7.2 Hz, 1H), 2.33 (dd, J = 16.3, 7.4 Hz, 1H), 1.23 (t, J = 7.3 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 185.9 (d, J_{C-F} = 16.7 Hz), 172.1, 163.1 (d, J_{C-F} = 35.7 Hz), 152.8, 141.5, 128.1, 121.2, 119.9, 118.4, 94.5 (d, J_{C-F} = 230.8 Hz), 54.5, 29.0, 8.7. ^{19}F NMR (377 MHz, $CDCl_3$) δ −137.67. IR (thin film): ν_{max}/cm^{-1} 1783, 1748, 1711, 1464, 1371, 1301, 1185, 1118, 771. HRMS (ESI Orbitrap) calcd for $C_{13}H_{12}O_4NBrF$ $[M + H]^+$: 344.1298, found: 344.1304. HPLC analysis DAICEL Chiralpak OJ–H, *n*-hexane/2-PrOH = 90/10, 1 mL min^{-1}, 254 nm, minor (12.67 min), major (20.32 min), 95% ee; $[\alpha]_D^{20}$ −1.0 (c = 0.3, $CHCl_3$).

Methyl (*S*)-1-acetyl-2-fluoro-3-oxo-5-phenylindoline-2-carboxylate (5n). Yield (42 mg, 79%), pale yellow solid, mp 168 °C, ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.59 (s, 1H), 7.99 (s, 1H), 7.97 (d, J = 2.1 Hz, 1H), 7.58 (dd, J = 8.0, 0.9 Hz, 2H), 7.51–7.45 (m, 2H), 7.43–7.37 (m, 1H), 3.92 (s, 3H), 2.34 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 187.0 (d, J_{C-F} = 16.6 Hz), 168.2, 163.4 (d, J_{C-F} = 35.8 Hz), 152.9, 139.0, 138.5, 137.9, 129.2, 128.2, 126.9, 123.5, 120.2, 120.1, 118.6, 118.5, 95.1 (d, J_{C-F} = 229.9 Hz), 54.4, 23.8. ^{19}F NMR (377 MHz, $CDCl_3$) δ −138.08. IR (thin film): ν_{max}/cm^{-1} 1779, 1745, 1712, 1476, 1378, 1324, 1179, 1124, 1073, 772. HRMS (ESI Orbitrap) calcd for $C_{18}H_{15}FNO_4$ $[M + H]^+$: 328.0982, found: 328.0977. HPLC analysis DAICEL Chiralpak OJ–H, *n*-hexane/2-PrOH = 90/10, 1 mL min^{-1}, 254 nm, minor (43.11 min), major (58.35 min), 92% ee; $[\alpha]_D^{20}$ −4.0 (c = 0.3, $CHCl_3$).

Methyl (*S*)-1-(cyclopropanecarbonyl)-2-fluoro-5-methyl-3-oxoindoline-2-carboxylate (5o). Yield (48 mg, 90%), pale yellow solid, mp 98 °C, ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.33 (d, J = 8.4 Hz, 1H), 7.58 (s, 1H), 7.54 (dd, J = 8.5, 1.6 Hz, 1H), 3.87 (s, 3H), 2.40 (s, 3H), 1.94–1.82 (m, 1H), 1.50–1.33 (m, 1H), 1.09–0.97 (m, 2H), 0.95–0.84 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 187.2 (d, J_{C-F} = 17.0 Hz), 171.9 (d, J_{C-F} = 2.6 Hz), 163.6 (d, J_{C-F} = 36.4 Hz), 152.3, 140.0, 135.5, 125.3, 119.6, 118.2, 95.0 (d, J_{C-F} = 228.0 Hz), 54.1, 20.7, 13.9 (d, J_{C-F} = 4.3 Hz), 10.6, 9.2. ^{19}F NMR (377 MHz, $CDCl_3$) δ −136.64. IR (thin film): ν_{max}/cm^{-1} 1781, 1744, 1698, 1489, 1443, 1407, 1312, 1191, 1095, 776. HRMS (ESI Orbitrap) Exact mass calcd for $C_{15}H_{15}O_4NF$ $[M + H]^+$: 292.0967, found: 292.0962. HPLC analysis DAICEL Chiralpak OJ–H, *n*-hexane/2-PrOH = 90/10, 1 mL min^{-1}, 254 nm, minor (13.24 min), major (17.22 min), 92% ee; $[\alpha]_D^{20}$ +14.8 (c = 0.3, $CHCl_3$).

Methyl (*S*)-2-fluoro-5-methyl-3-oxo-1-propionyl indoline-2-carboxylate (5p). Yield (46 mg, 86%), white solid, mp 88 °C, ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.38 (s, 1H), 7.58 (s, 1H), 7.56 (d, J = 8.5 Hz, 1H), 3.89 (s, 3H), 2.67 (dq, J = 14.5, 7.1 Hz, 1H), 2.40 (s, 3H), 2.35 (s, 1H), 1.23 (t, J = 7.3 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 187.1 (d, J_{C-F} = 16.6 Hz), 172.0 (d, J_{C-F} = 2.2 Hz), 163.6 (d, J_{C-F} = 35.7 Hz), 152.1, 140.1, 135.5, 125.4, 119.7, 118.0, 94.9 (d, J_{C-F} = 229.6 Hz), 54.2, 29.4 (d, J = 75.1 Hz), 20.7, 8.7. ^{19}F NMR (377 MHz, $CDCl_3$) δ −138.20. IR (thin film): ν_{max}/cm^{-1} 1782, 1744, 1706, 1489, 1376, 1302, 1194, 1117, 1068, 768. HRMS (ESI Orbitrap) calcd for $C_{14}H_{15}O_4NF$ $[M + H]^+$: 280.0972, found: 280.0977. HPLC analysis DAICEL Chiralpak OJ–H, *n*-hexane/2-PrOH = 90/10, 1 mL min^{-1}, 254 nm, minor (12.11 min), major (19.53 min), 95% ee; $[\alpha]_D^{20}$ +10.0 (c = 0.3, $CHCl_3$).

Methyl (*R*)-1-benzoyl-2-fluoro-3-oxoindoline-2-carboxylate (5u). Yield (32 mg, 60%), yellowish white solid, mp 159 °C, ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.81 (dd, J = 7.7, 0.6 Hz, 1H), 7.78 (s, 1H), 7.70–7.65 (m, 1H), 7.64 (dd, J = 7.2, 1.0 Hz, 2H), 7.61–7.57 (m, 1H), 7.49 (t, J = 7.7 Hz, 2H), 7.33–7.28 (m, 1H), 3.59 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 187.3 (d, J_{C-F} = 18.7 Hz), 169.0, 162.5 (d, J_{C-F} = 34.1 Hz), 153.8, 138.4, 133.9, 132.3, 128.7, 128.3 (d, J_{C-F} = 1.7 Hz), 125.9, 125.7, 120.3, 118.5, 94.8 (d, J_{C-F} = 230.6 Hz), 53.8. ^{19}F NMR (377 MHz, $CDCl_3$) δ −131.10. HRMS (ESI Orbitrap) calcd for $C_{17}H_{12}O_4NF$ $[M + H]^+$: 314.0823, found: 314.0828, HPLC analysis DAICEL Chiralpak OD–H, *n*-hexane/2-PrOH = 90/10, 1 mL min^{-1}, 254 nm, major (13.78 min), minor (23.82 min), 58% ee; $[\alpha]_D^{20}$ +22.9 (c = 0.6, $CHCl_3$).

Methyl (*R*)-3-fluoro-2-oxoindoline-3-carboxylate (7). Yield (36 mg, 66%), orange white solid, mp 132 °C, ^{1}H NMR

(400 MHz, $CDCl_3$) δ 8.41 (s, 1H), 7.40 (t, J = 7.0 Hz, 2H), 7.11 (t, J = 7.6 Hz, 1H), 6.97 (d, J = 8.1 Hz, 1H), 3.82 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 170.4 (d, J_{C-F} = 21.1 Hz), 165.6 (d, J_{C-F} = 31.6 Hz), 142.3 (d, J_{C-F} = 5.3 Hz), 132.6 (d, J_{C-F} = 2.9 Hz), 125.3, 123.8 (d, J_{C-F} = 2.4 Hz), 123.3 (d, J_{C-F} = 19.4 Hz), 111.2, 90.4 (d, J_{C-F} = 202.3 Hz), 53.6. ^{19}F NMR (471 MHz, $CDCl_3$) δ −164.40. HRMS (ESI Orbitrap) calcd for $C_{10}H_9O_3NF$ $[M + H]^+$: 210.0490, found: 210.0485. HPLC analysis DAICEL Chiralpak OD–H, *n*-hexane/2-PrOH = 88/12, 1 mL min^{-1}, 254 nm, minor (7.83 min), major (9.76 min), 59% ee; $[\alpha]_D^{20}$ +34.2 (c = 0.5, $CHCl_3$).

Author contributions

The manuscript has been written with contributions from all the authors.

Conflicts of interest

There are no conflicts to declare.

Acknowledgements

SB thanks the DST, New Delhi, for the award of a fellowship. Manuscript communication number: IICT/Pubs./2020/ 306.

Notes and references

1 S. D. Halperin, D. Kwon, M. Holmes, E. L. Regalado, L. C. Campeau, D. A. DiRocco and R. Britton, *Org. Lett.*, 2015, **17**(21), 5200–5203.

2 P. Shah and A. D. Westwell, *J. Enzyme Inhib. Med. Chem.*, 2007, **22**(5), 527–540.

3 Y. Zhou, J. Wang, Z. Gu, S. Wang, W. Zhu, J. L. Acena, V. A. Soloshonok, K. Izawa and H. Liu, *Chem. Rev.*, 2016, **116**, 422–518.

4 (*a*) H. Mei, J. Han, S. Fustero, M. Medio-Simon, D. M. Sedgwick, C. Santi, R. Ruzziconi and V. A. Soloshonok, *Chem. – Eur. J.*, 2019, **25**, 11797–11819; (*b*) Y. Wang, S.-Y. Gwon, Y.-A. Son and S.-H. Kim, *Mol. Cryst. Liq. Cryst.*, 2012, **566**, 61; (*c*) X. Fan, Q. Wang, Y. Wei and M. Shi, *Chem. Commun.*, 2018, **54**, 10503.

5 D. E. Yerien, S. Bonesi and A. Postigo, *Org. Biomol. Chem.*, 2016, **14**, 8398–8427.

6 (*a*) X. Yang, T. Wu, R. J. Phipps and F. D. Toste, *Chem. Rev.*, 2015, **115**(2), 826–870; (*b*) S. Lectard, Y. Hamashima and M. Sodeoka, *Adv. Synth. Catal.*, 2010, **352**, 2708–2732; (*c*) R. Thornbury, G. Schäfer and F. D. Toste, *Modern Synthesis Processes and Reactivity of Fluorinated Compounds Progress in Fluorine Science*, 2017, pp. 223–263; (*d*) Y. Takeuchi, T. Shiragami, K. Kimura, E. Suzuki and N. Shibata, *Org. Lett.*, 1999, **1**(10), 1571–1573; (*e*) B. Treguier and S. P. Roche, *Org. Lett.*, 2014, **16**, 278–281.

7 Q. Zhang, D. P. Stockdale, J. C. Mixdorf, J. J. Topczewski and H. M. Nguyen, *J. Am. Chem. Soc.*, 2015, **137**(37), 11912.

8 (*a*) M. D. Fielenbach, A. Braunton, A. Kjœrsgaard and K. A. Jørgensen, *Angew. Chem., Int. Ed.*, 2005, **44**, 3703–3705; (*b*) D. D. Steiner, N. Mase and C. F. Barbas III, *Angew. Chem., Int. Ed.*, 2005, **44**, 3706–3710.

9 (*a*) K. Shibatomi, K. Kitahara, T. Okimi, Y. Abe and S. Iwasa, *Chem. Sci.*, 2016, **7**, 1388–1392; (*b*) T. D. Beeson and D. W. C. MacMillan, *J. Am. Chem. Soc.*, 2005, **127**, 8826.

10 (*a*) L. Hintermann and A. Togni, *Angew. Chem., Int. Ed.*, 2000, **39**, 4359–4362; (*b*) Y. Hamashima, K. Yagi, H. Takano, L. Tamás and M. Sodeoka, *J. Am. Chem. Soc.*, 2002, **124**(49), 14530–14531; (*c*) D. Y. Kim and E. J. Park, *Org. Lett.*, 2002, **4**(4), 545–547; (*d*) L. Hintermann, M. Perseghini and A. Togni, *Beilstein J. Org. Chem.*, 2011, **7**, 1421–1435; (*e*) T. Niu, X. Han, D. Huang, K. H. Wang, Y. Su, Y. Hu and Y. Fu, *J. Fluor. Chem.*, 2015, **175**, 6–11; (*f*) J. Peng and D. M. Du, *RSC Adv.*, 2014, **4**, 2061–2067.

11 J. A. Ma and D. Cahard, *Tetrahedron: Asymmetry*, 2004, **15**, 1007–1011.

12 Y. Guan, J. W. Attard and A. E. Mattson, *Chem. – Eur. J.*, 2020, **26**, 1742–1747.

13 (*a*) S. Yarlagadda, B. Ramesh, C. R. Reddy, L. Srinivas, B. Sridhar and B. V. S. Reddy, *Org. Lett.*, 2017, **19**(1), 170–173; (*b*) V. Collot, M. Schmitt, P. Mad and J. Bourguignon, *Heterocycles*, 1999, **51**(12), 2823–2847; (*c*) R. Adepu, R. Sunke, C. L. T. Meda, D. Rambabu, G. R. Krishna, C. M. Reddy, G. S. Deora, K. V. L. Parsa and M. Pal, *Chem. Commun.*, 2013, **49**, 190–192.

14 (*a*) A. Sakakura, R. Kondo and K. Ishihara, *Org. Lett.*, 2005, **7**(10), 1971–1974; (*b*) Y. Grell, N. Demirel, K. Harms and E. Meggers, *Organometallics*, 2019, **38**(19), 3852–3859; (*c*) Y. Guan, J. W. Attard and A. E. Mattson, *Chem. – Eur. J.*, 2020, **26**(8), 1742–1747.

15 (*a*) K. Shibatomi, Y. Tsuzuki and S. Iwasa, *Chem. Lett.*, 2008, **37**(10), 1098–1099; (*b*) Y. Zhang, K. Shibatomi and H. Yamamoto, *Synlett*, 2005, 2837–2842; (*c*) Y. Zhang, K. Shibatomi and H. Yamamoto, *J. Am. Chem. Soc.*, 2004, **126**(46), 15038–15039.

16 CCDC 2047903 contains the supplementary crystallographic data for the structure.† .

17 (*a*) N. Selavakumar, B. Y. Reddy, A. M. Azhagan, M. K. Khera, J. M. Babu and J. Iqbal, *Tetrahedron Lett.*, 2003, **44**, 7065–7069; (*b*) A. A. Audi, C. Ramachandran and G. G. Pai, *WO Pat*, 093928, 2013.