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# Synthesis, structure and *in vitro* cytotoxicity testing of some 2-aroylbenzofuran-3-ols

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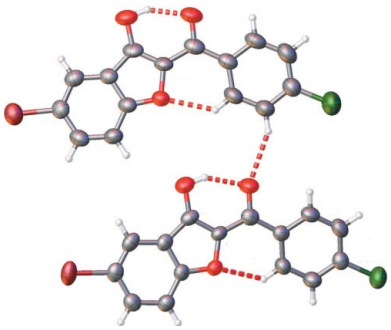
Five 2-aroyl-5-bromobenzo[*b*]furan-3-ol compounds (two of which are new) and four new 2-aroyl-5-iodobenzo[*b*]furan-3-ol compounds were synthesized starting from salicylic acid. The compounds were characterized by mass spectrometry and $^{1}$H NMR and $^{13}$C NMR spectroscopy. Single-crystal X-ray diffraction studies of four compounds, namely, (5-bromo-3-hydroxybenzofuran-2-yl)(4-fluorophenyl)methanone, $C_{15}H_8BrFO_3$, (5-bromo-3-hydroxybenzofuran-2-yl)(4-chlorophenyl)methanone, $C_{15}H_8BrClO_3$, (5-bromo-3-hydroxybenzofuran-2-yl)(4-bromophenyl)methanone, $C_{15}H_8Br_2O_3$, and (4-bromophenyl)(3-hydroxy-5-iodobenzofuran-2-yl)methanone, $C_{15}H_8BrIO_3$, were also carried out. The compounds were tested for their *in vitro* cytotoxicity on the four human cancer cell lines KB, Hep-G2, Lu-1 and MCF7. Six compounds show good inhibiting abilities on Hep-G2 cells, with $IC_{50}$ values of 1.39–8.03 μ*M*.

## 1. Introduction

Benzofurans have been considered as fundamental units in numerous bioactive compounds and are present in a large number of bioactive natural compounds. The benzofuran nucleus is present in a huge number of bioactive natural compounds. For example, (+)-liphagal is a selective phosphoinositide-3-kinase α-inhibitor (Marion *et al.*, 2006), cyclopenta[*b*]benzofuran compounds possess antitumour and antiviral activities (Kim *et al.*, 2006), while derivatives of egonol have antioxidant and anti-inflammatory activities (Timmers *et al.*, 2015). Synthetic benzofuran derivatives are found to possess antitumour and anticancer (Shi *et al.*, 2016; Marquès *et al.*, 2016; Napiórkowska *et al.*, 2019; Asadi *et al.*, 2017), antimicrobial (Asadi *et al.*, 2017; He *et al.*, 2017; Xu *et al.*, 2019) and antitubercular (Xu *et al.*, 2019) activities. Some synthetic benzofuran derivatives have been investigated in the role of osteogenic (Marquès *et al.*, 2016; Kushwaha *et al.*, 2018; Modukuri *et al.*, 2017) or vasorelaxant (Hassan *et al.*, 2014) agents. 2-Aroylbenzofuran-3-ols, being a class of typical benzofuran derivatives, not only possess antimicrobial (Kulkarni *et al.*, 2014), antitumour (Sargolzaei *et al.*, 2016) and α-glucosidase inhibition (Spasov *et al.*, 2017) properties, but are also useful intermediates for the synthesis of several compounds having various biological activities (Shi *et al.*, 2016; Dong *et al.*, 2013; Rashmi *et al.*, 2015). Although many 2-aroylbenzofuran-3-ols have been synthesized and studied for



their biological activities, the structural characteristics and cytotoxic activity of 2-aroyl-5-bromobenzo[*b*]furan-3-ol and 2-aroyl-5-iodobenzo[*b*]furan-3-ol compounds have not been studied much. We present here the synthesis of nine 2-aroyl-5-bromo/iodobenzofuran-3-ol compounds starting from salicylic acid. In addition to the synthesis and structure analysis of these compounds, the *in vitro* toxicity on the four human cancer cell lines KB, Hep-G2, Lu-1 and MCF7 has been tested.

## 2. Experimental

All chemicals were obtained from commercial sources and were used without further purification. The melting points were determined in open capillaries and are uncorrected. The IR spectra were recorded on an FT–IR Shimadzu 8400-S. NMR spectra were measured on a Bruker Avance 500 MHz in DMSO-$d_6$ using residual solvent DMSO-$d_6$ signals as the internal references. Mass spectra were recorded on a Sciex X500 QTOF mass spectrometer.

### 2.1. Synthesis and crystallization

Benzofuran derivatives **4a**–**4i** were synthesized as shown in Fig. 1. Methyl salicylate (**2**) (Cong *et al.*, 2012), methyl 5-bromo-2-hydroxybenzoate (**3a**) (Thin *et al.*, 2018) and methyl 2-hydroxy-5-iodobenzoate (**3b**) (Cong *et al.*, 2018) were synthesized according to previously reported methods.

**Methyl salicylate (2):** liquid; b.p. 494–495 K, yield 73%.

**Methyl 5-bromo-2-hydroxybenzoate (methyl 5-bromosalicylate) (3a):** white needles, m.p. 332–333 K, yield 92%; IR ($\nu$, cm$^{-1}$): 3188, 2957, 1680, 1605, 625; $^1$H NMR ($\delta$, ppm): 10.50 (1H, *br*, OH), 7.82 (1H, *d*, $^4J$ = 2.5 Hz, H6), 7.64 (1H, *dd*, $^3J$ = 8.0 Hz, $^4J$ = 2.5 Hz, H4), 6.96 (1H, *d*, $^3J$ = 8.0 Hz, H3), 3.88 (3H, *s*, $OCH_3$).

**Methyl 2-hydroxy-5-iodobenzoate (methyl 5-iodosalicylate) (3b):** white needles, m.p. 347–348 K, yield 85%; IR ($\nu$, cm$^{-1}$): 3156, 3080, 2949, 1676, 1604, 527; $^1$H NMR ($\delta$, ppm): 10.46, (1H, *s*, OH), 7.98 (1H, *d*, $^4J$ = 2.0 Hz, H6), 7.75 (1H, *d*, $^3J$ = 8.5 Hz, $^4J$ = 2.5 Hz, H4), 6.82 (1H, *d*, $^3J$ = 9.0 Hz, H3), 3.87 (3H, *s*, $OCH_3$).

**2.1.1. General procedure for the synthesis of 2-aroyl-5-halobenzo[*b*]furan-3-ol compounds 4a–4i.** Anhydrous potassium carbonate (0.896 mg, 6.4 mmol) was added to a mixture of methyl 5-halosalicylate (2.1 mmol) and substituted phenacyl bromide (2.1 mmol) in dried dimethylformamide (DMF, 10 ml) at room temperature while stirring. After 1 h of stirring, the reaction mixture was poured into ice-cold water and acidified with 1 *N* HCl. The precipitate obtained was filtered off and crystallized from an appropriate solvent to give the corresponding products **4a**–**4i**.

The crystals of **4a**, **4b**, **4c** and **4h** were suitable for X-ray diffraction.

**(5-Bromo-3-hydroxybenzofuran-2-yl)(4-fluorophenyl)methanone (4a):** yellow crystals, recrystallized from a mixture of ethanol and water; m.p. 391–393 K [melting point according to Kulkarni *et al.* (2014): 393 K]; yield 84%. IR ($\nu$, cm$^{-1}$): 3057 (C$sp^2$—H), 1614 (C═O), 1597, 1528 (C═C), 625 (C—Br); $^1$H NMR: 8.06 (3H, *m*, Ar-H), 7.71 (1H, *m*, Ar-H), 7.64 (1H, *m*, Ar-H), 7.40 (2H, *m*, Ar-H); $^{13}$C NMR: 181.8, 166.1, 164.1, 152.4, 148.3, 136.4, 134.2, 132.8, 132.4, 132.3, 124.4, 123.7, 115.9, 115.8, 115.6, 115.3; MS: *m*/*z* 332.9564 $[M - H]^+$; calculation for $C_{15}H_7BrFO_3$: *M* = 332.9568 a.u.

**(5-Bromo-3-hydroxybenzofuran-2-yl)(4-chlorophenyl)methanone (4b):** yellow crystals, recrystallized from a mixture of ethanol and water; m.p. 436–437 K [melting point according to Kulkarni *et al.* (2014): 435–438 K]; yield 93%. IR ($\nu$, cm$^{-1}$): 3254 (O—H), 3078 (C$sp^2$—H), 1599, 1566 (C═O, C═C), 660 (C—Br); $^1$H NMR: 8.13 (1H, *d*, $^4J$ = 2.0 Hz, Ar-H), 7.98 (2H, *d*, $^3J$ = 8.5 Hz, Ar-H), 7.72 (1H, *dd*, $^3J$ = 8.5, $^4J$ = 2.0 Hz, Ar-H), 7.63 (3H, *m*, Ar-H); $^{13}$C NMR: 181.9, 152.5, 148.4, 137.8, 136.4, 132.9, 131.3, 128.9, 124.5, 123.7, 115.6, 115.3; MS: *m*/*z* 350.9434 $[M + H]^+$; calculation for $C_{15}H_9BrClO_3$: *M* = 350.9424 a.u.

**(5-Bromo-3-hydroxybenzofuran-2-yl)(4-bromophenyl)methanone (4c):** yellow crystals, recrystallized from a mixture of ethanol and water; m.p. 426–427 K [melting point according to Kulkarni *et al.* (2014): 425–426 K]; yield 91%. IR ($\nu$, cm$^{-1}$):

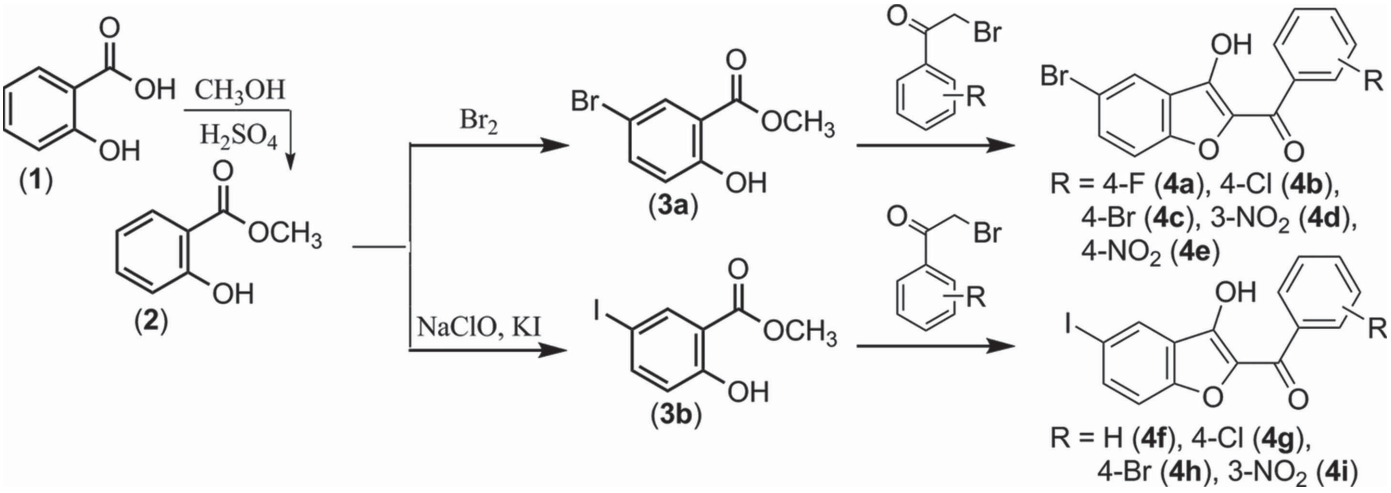



**Figure 1**
The synthetic route for the preparation of benzofuran derivatives **4a**–**4i**.

**Table 1**
Experimental details.

Experiments were carried out with Mo $K\alpha$ radiation using a Rigaku OD SuperNova Single source diffractometer with an Eos detector. H atoms were treated by a mixture of independent and constrained refinement.

| | **4a** | **4b** | **4c** | **4h** |
|---|---|---|---|---|
| Crystal data | | | | |
| Chemical formula | $C_{15}H_8BrFO_3$ | $C_{15}H_8BrClO_3$ | $C_{15}H_8Br_2O_3$ | $C_{15}H_8BrIO_3$ |
| $M_r$ | 335.12 | 351.57 | 396.03 | 443.02 |
| Crystal system, space group | Monoclinic, $P2_1/c$ | Monoclinic, $P2_1/c$ | Triclinic, $P\overline{1}$ | Monoclinic, $I2/a$ |
| Temperature (K) | 293 | 294 | 294 | 293 |
| $a, b, c$ (Å) | 3.8598 (4), 11.7229 (10), 27.679 (2) | 26.4034 (10), 3.9818 (1), 26.2773 (10) | 7.0725 (4), 7.0884 (5), 14.6069 (8) | 26.4214 (8), 4.76309 (13), 46.6213 (14) |
| $\alpha, \beta, \gamma$ (°) | 90, 93.255 (9), 90 | 90, 104.605 (4), 90 | 92.230 (5), 103.091 (5), 101.219 (6) | 90, 106.034 (3), 90 |
| $V$ (Å$^3$) | 1250.38 (19) | 2673.34 (17) | 696.98 (8) | 5638.9 (3) |
| $Z$ | 4 | 8 | 2 | 16 |
| $\mu$ (mm$^{-1}$) | 3.30 | 3.28 | 5.82 | 5.11 |
| Crystal size (mm) | 0.5 × 0.15 × 0.05 | 0.4 × 0.15 × 0.05 | 0.35 × 0.15 × 0.05 | 0.35 × 0.15 × 0.05 |
| Data collection | | | | |
| Absorption correction | Multi-scan (*CrysAlis PRO*; Rigaku OD, 2018) | Multi-scan (*CrysAlis PRO*; Rigaku OD, 2018) | Multi-scan (*CrysAlis PRO*; Rigaku OD, 2018) | Gaussian (*CrysAlis PRO*; Rigaku OD, 2018) |
| $T_{min}$, $T_{max}$ | 0.447, 1.000 | 0.572, 1.000 | 0.523, 1.000 | 0.582, 1.000 |
| No. of measured, independent and observed [$I > 2\sigma(I)$] reflections | 7646, 2543, 1873 | 27661, 5419, 3168 | 14183, 2840, 1867 | 30966, 5733, 4448 |
| $R_{int}$ | 0.040 | 0.064 | 0.046 | 0.036 |
| $(\sin\theta/\lambda)_{max}$ (Å$^{-1}$) | 0.625 | 0.625 | 0.625 | 0.625 |
| Refinement | | | | |
| $R[F^2 > 2\sigma(F^2)]$, $wR(F^2)$, $S$ | 0.045, 0.097, 1.07 | 0.052, 0.102, 1.01 | 0.046, 0.109, 1.04 | 0.048, 0.123, 1.07 |
| No. of reflections | 2543 | 5419 | 2840 | 5733 |
| No. of parameters | 185 | 369 | 185 | 369 |
| No. of restraints | 0 | 0 | 0 | 2 |
| $\Delta\rho_{max}$, $\Delta\rho_{min}$ (e Å$^{-3}$) | 0.44, −0.45 | 0.56, −0.42 | 0.44, −0.40 | 1.78, −1.21 |

Computer programs: *CrysAlis PRO* (Rigaku OD, 2018), *olex2.solve* (Bourhis *et al.*, 2015), *SHELXS* (Sheldrick, 2008), *SHELXT* (Sheldrick, 2015*a*), *SHELXL2016* (Sheldrick, 2015*b*) and *OLEX2* (Dolomanov *et al.*, 2009).

3337 (O—H), 3076 (C$sp^2$—H), 1601, 1562 (C═O, C═C), 658 (C—Br); $^1$H NMR: 8.13 (1H, *d*, $^4J$ = 2.0 Hz, Ar-H), 7.90 (2H, *d*, $^3J$ = 8.5 Hz, Ar-H), 7.77 (1H, *dd*, $^3J$ = 8.5, $^4J$ = 2.0 Hz, Ar-H), 7.72 (2H, *d*, $^4J$ = 2.0 Hz, Ar-H), 7.62 (1H, *d*, $^3J$ = 8.5 Hz, Ar-H); $^{13}$C NMR: 182.0, 152.5, 148.4, 136.8, 136.4, 132.9, 131.5, 126.8, 124.5, 123.7, 115.6, 115.4; MS: *m*/*z* 394.8757 $[M + H]^+$; calculation for $C_{15}H_9Br_2O_3$: $M$ = 394.8918 a.u.

**(5-Bromo-3-hydroxybenzofuran-2-yl)(3-nitrophenyl)methanone (4d):** yellow crystals, recrystallized from a mixture of ethanol and water; m.p. 428–431 K; yield 76%. IR ($\nu$, cm$^{-1}$): 3274 (O—H), 1631 (C═O), 1613, 1577, 1530 (C═C), 659 (C—Br); $^1$H NMR: 8.62 (1H, *m*, Ar-H), 8.38 (1H, *s*, Ar-H), 8.24 (2H, *m*, Ar-H), 8.12 (1H, *d*, $^3J$ = 8.5 Hz, Ar-H), 7.89 (1H, *m*, Ar-H), 7.75 (1H, *m*, Ar-H); $^{13}$C NMR: 180.5, 152.9, 148.0, 139.2, 136.2, 135.8, 133.2, 130.5, 127.1, 124.8, 124.1, 123.7, 115.5, 115.3; MS: *m*/*z* 361.9642 $[M + H]^+$; calculation for $C_{15}H_9BrNO_5$: $M$ = 361.9664 a.u.

**(5-Bromo-3-hydroxybenzofuran-2-yl)(4-nitrophenyl)methanone (4e):** yellow crystals, recrystallized from a mixture of acetone and water; m.p. 438–439 K; yield 83%. IR ($\nu$, cm$^{-1}$): 3292 (O—H), 3098 (C$sp^2$—H), 1624 (C═O), 1597, 1547 (C═C), 660 (C—Br); $^1$H NMR: 8.37 (2H, *d*, $^3J$ = 8.5 Hz, Ar-H), 8.23 (1H, *d*, $^4J$ = 2.5 Hz, Ar-H), 8.12 (2H, *d*, $^3J$ = 8.5 Hz, Ar-H), 7.74 (1H, *dd*, $^3J$ = 8.5, $^4J$ = 2.5 Hz, Ar-H), 7.63 (1H, $^3J$ = 9.0 Hz, Ar-H); $^{13}$C NMR: 181.3, 152.9, 149.7, 143.5, 136.3, 133.3, 130.6, 125.4, 124.9, 123.8, 116.3, 115.6, 115.3; MS: *m*/*z* 359.9510 $[M - H]^+$; calculation for $C_{15}H_7BrNO_5$: $M$ = 359.9513 a.u.

**(3-Hydroxy-5-iodobenzofuran-2-yl)(phenyl)methanone (4f):** yellow crystals, recrystallized from a mixture of acetone and water; m.p. 411–412 K; yield 78%. IR ($\nu$, cm$^{-1}$): 3084 (OH), 1609 (C═O), 1572, 1520 (C═C), 561 (C—I); $^1$H NMR: 8.30 (1H, *d*, $^4J$ = 1.5 Hz, Ar-H), 7.97 (2H, *d*, $^3J$ = 7.0 Hz, Ar-H), 7.84 (1H, *m*, Ar-H), 7.65 (1H, *dd*, $^3J_1 = {}^3J_2$ = 7.0, Ar-H), 7.56 (2H, *d*, $^3J$ = 7.0 Hz, Ar-H), 7.49 (1H, *dd*, $^3J_1$ = 9.0, $^4J_2$ = 5.0, Ar-H); $^{13}$C NMR: 183.2, 152.9, 148.0, 138.3, 138.7, 136.1, 132.9, 130.4, 129.4, 128.8, 124.4, 115.6, 87.3; MS: *m*/*z* 364.9652 $[M + H]^+$; calculation for $C_{19}H_{16}ClIN_2NaO_4$: $M$ = 364.9675 a.u.

**(4-Chlorophenyl)(3-hydroxy-5-iodobenzofuran-2-yl)methanone (4g):** yellow crystals, recrystallized from a mixture of ethanol and water; m.p. 443–444 K; yield 88%. IR ($\nu$, cm$^{-1}$): 3231 (OH), 1616 (C═O), 1591, 1567, 1531 (C═C), 565 (C—I); $^1$H NMR: 8.29 (1H, *d*, $^4J$ = 1.5 Hz, Ar-H), 7.97 (2H, *d*, $^3J$ = 9.0 Hz, Ar-H), 7.84 (1H, *dd*, $^3J$ = 9.0, $^4J$ = 2.0 Hz, Ar-H), 7.62 (2H, *d*, $^3J$ = 9.0 Hz, Ar-H), 7.48 (1H, *d*, $^3J$ = 9.0 Hz, Ar-H); $^{13}$C NMR: 181.4, 152.5, 147.6, 137.9, 137.2, 135.9, 135.4, 130.8, 130.0, 128.3, 123.8, 115.0, 86.7; MS: *m*/*z* 396.9119 $[M - H]^+$; calculation for $C_{15}H_7ClIO_3$: $M$ = 396.9134 a.u.

**(4-Bromophenyl)(3-hydroxy-5-iodobenzofuran-2-yl)methanone (4h):** yellow crystals, recrystallized from a mixture of acetone and water; m.p. 441–442 K; yield 91%. IR ($\nu$, cm$^{-1}$):

Table 2
Hydrogen-bond geometry (Å, °) for **4a**.

| $D$—H···$A$ | $D$—H | H···$A$ | $D$···$A$ | $D$—H···$A$ |
|---|---|---|---|---|
| O19—H19···O11 | 0.77 (5) | 2.03 (4) | 2.692 (4) | 144 (4) |
| C17—H17···O1 | 0.93 | 2.32 | 2.942 (4) | 124 |
| C16—H16···O11$^{i}$ | 0.93 | 2.51 | 3.428 (4) | 170 |
| C5—H5···O19$^{ii}$ | 0.93 | 2.61 | 3.454 (5) | 150 |

Symmetry codes: (i) $-x+2, y-\frac{1}{2}, -z+\frac{1}{2}$; (ii) $-x+1, -y+1, -z+1$.

3447 (O—H), 1614 (C═O), 1584, 1561, 1522 (C═C), 561 (C—I); $^1$H NMR: 8.31 (1H, *d*, $^4J$ = 1.5 Hz, Ar-H), 7.87 (3H, *m*, Ar-H), 7.78 (2H, *d*, $^3J$ = 8.5 Hz, Ar-H), 7.50 (1H, *d*, $^3J$ = 9.0 Hz, Ar-H); $^{13}$C NMR: 181.8, 152.9, 148.0, 138.3, 136.9, 135.9, 131.8, 131.5, 130.6, 128.1, 126.7, 124.4, 115.6, 87.3; MS: *m*/*z* 442.8761 $[M + H]^+$; calculation for $C_{15}H_9BrIO_3$: *M* = 442.8780 a.u.

**(3-Hydroxy-5-iodobenzofuran-2-yl)(3-nitrophenyl)methanone (4i):** yellow crystals, recrystallized from a mixture of ethanol and water; m.p. 435–436 K; yield 80%. IR (ν, cm$^{-1}$): 3245 (O—H), 3072 (C*sp*$^2$—H), 1614 (C═O), 1577, 1527 (C═C), 560 (C—I); $^1$H NMR: 8.59 (1H, *s*, Ar-H), 8.39 (1H, *dd*, $^3J$ = 8.0, $^4J$ = 2.0 Hz, Ar-H), 8.26 (1H, *d*, $^4J$ = 8.0 Hz, Ar-H), 8.08 (1H, *s*, Ar-H), 7.76 (1H, *dd*, $^3J_1$ = $^3J_2$ = 8.0 Hz, Ar-H), 7.66 (1H, *dd*, $^3J$ = 8.0, $^4J$ = 1.5 Hz, Ar-H), 7.56 (1H, *d*, $^3J$ = 8.0 Hz, Ar-H); $^{13}$C NMR: 180.4, 153.6, 148.4, 147.8, 138.8, 137.3, 136.4, 135.6, 130.3, 129.7, 127.4, 124.2, 118.1, 115.4, 87.1; MS: *m*/*z* 407.9374 $[M - H]^-$; calculation for $C_{15}H_7INO_5$: *M* = 407.9374 a.u.

### 2.2. Refinement

Crystal data, data collection and structure refinement details for **4a**, **4b**, **4c** and **4h** are summarized in Table 1. The O-bound H atoms (H19 and also H39 for **4b** and **4h**) were located from a difference Fourier map and refined freely for **4a**–**4c** or with O—H = 0.78 ± 0.01 Å for **4h**. The C-bound H atoms were placed in calculated positions (C—H = 0.93 Å) and were refined using a riding model, with $U_{iso}$(H) values set at 1.2$U_{eq}$(C).

### 2.3. *In vitro* cell tests

Compounds **4a**, **4b** and **4d**–**4i** were evaluated for their cytotoxicity against four human cancer cell lines, namely, KB (epidermoid carcinoma cancer), Hep-G2 (hepatoma carcinoma cancer), Lu (human lung adenocarcinoma cells) and MCF7 (human breast cancer cells). The cell lines were obtained from the American Type Culture Collection (USA) ATCC. The cells were grown in RPMI 1640 medium supplemented with 10% fetal bovine serum, 100 U ml$^{-1}$ penicillin and 100 µg ml$^{-1}$ streptomycin at 310 K in a humidified atmosphere (95% air and 5% $CO_2$). The exponentially growing cells were used throughout the experiments. The inhibitory effects of the compounds on the growth of the human cancer cell lines were determined by measuring the metabolic activity using a 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) assay, as reported previously (Cong *et al.*, 2018).

All the experiments were performed four or five times and the mean absorbance values were calculated. The results are expressed as the percentage of inhibition that produced a reduction in the absorbance by the treatment of the compounds compared to the untreated controls. A dose–response curve was generated and the inhibitory concentration of 50% ($IC_{50}$) was determined for each compound, as well as each cell line.

## 3. Results and discussion

### 3.1. Synthesis of 2-aroyl-5-halobenzo[*b*]furan-3-ol) compounds 4a–4i

Nine 2-aroyl-5-halobenzofuran-3-ol derivatives, **4a**–**4i**, were synthesized with yields between 76 and 93% starting from salicylic acid **1** (Fig. 1). Methyl salicylate (**2**), methyl 5-bromo-2-hydroxybenzoate (**3a**) and methyl 2-hydroxy-5-iodobenzoate (**3a**) were synthesized previously by our research group (Cong *et al.*, 2012, 2018; Thin *et al.*, 2018). The IR spectra of **3a**–**3b** show a strong band at 1680 cm$^{-1}$ corresponding to a C═O stretching vibration of the ester group. The $^1$H NMR spectra of **3a** and **3b** show the presence of the methoxy group as a singlet signal (3H) at δ 3.88 and 3.87, respectively. The three signals in the aromatic area, including a doublet signal (1H, $^4J$ = 2.0 Hz), a doublet of doublet signals (1H, $^3J$ = 8.0, $^4J$ = 2.0 Hz) and a doublet signal (1H, $^3J$ = 8.0 Hz), are typical for a benzene ring with three substituents at positions 1, 2 and 5.

To obtain the desired (5-halo-3-hydroxybenzo[*b*]furan-2-yl)(substituted phenyl)methanones (**4a**–**4i**), methyl 5-bromosalicylate (**3a**) or methyl 5-iodosalicylate (**3b**) were reacted with a substituted phenacyl bromide compound in DMF in the presence of potassium carbonate. This is considered an effective synthesis method for the preparation of 2-aroylbenzofuran-3-ol compounds (Kulkarni *et al.*, 2014). The physical and spectral properties of **4a**–**4c** were available in the literature (Kulkarni *et al.*, 2014).

In the IR spectra of **4a**–**4i**, the OH group often shows only a weak absorption. The reason is that these compounds may exist in the 2-aroylbenzofuran-3(2*H*)-one form (Kulkarni *et al.*, 2014). The C═O bond in the aroyl group absorbs at low

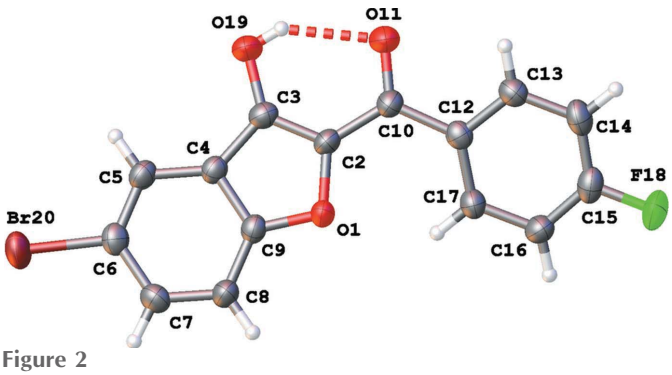



Figure 2
The molecular structure of **4a**, showing the atom-labelling scheme. Displacement ellipsoids are drawn at the 50% probability level.

**Table 3**
Hydrogen-bond geometry (Å, °) for **4b**.

| *D*—H···*A* | *D*—H | H···*A* | *D*···*A* | *D*—H···*A* |
|---|---|---|---|---|
| O19—H19···O11 | 0.86 (5) | 1.87 (5) | 2.631 (5) | 147 (5) |
| C17—H17···O1 | 0.93 | 2.29 | 2.951 (5) | 128 |
| O39—H39···O31 | 0.91 (6) | 1.80 (6) | 2.627 (6) | 150 (7) |
| C37—H37···O21 | 0.93 | 2.25 | 2.926 (6) | 129 |
| C36—H36···O11 | 0.93 | 2.40 | 3.235 (6) | 149 |
| C8—H8···O39$^{i}$ | 0.93 | 2.67 | 3.434 (6) | 140 |

Symmetry code: (i) $x, -y+\frac{1}{2}, z-\frac{1}{2}$.

**Table 4**
Hydrogen-bond geometry (Å, °) for **4c**.

| *D*—H···*A* | *D*—H | H···*A* | *D*···*A* | *D*—H···*A* |
|---|---|---|---|---|
| O19—H19···O11 | 0.84 (6) | 1.93 (6) | 2.669 (5) | 146 (5) |
| C17—H17···O1 | 0.93 | 2.28 | 2.948 (5) | 129 |
| O19—H19···O11$^{i}$ | 0.84 (6) | 2.60 (6) | 3.174 (5) | 127 |
| C14—H14···Br20$^{ii}$ | 0.93 | 3.05 | 3.959 (5) | 165 |
| C16—H16···O11$^{iii}$ | 0.93 | 2.61 | 3.287 (6) | 130 |

Symmetry codes: (i) $-x, -y, -z+1$; (ii) $x, y, z+1$; (iii) $x, y+1, z$.

frequency (around 1610 cm$^{-1}$) due to conjugation with both the benzene and the benzofuran rings. In the $^{1}$H NMR spectra of **4a**–**4i**, the signal of the OH proton is also rarely observed, which can be explained by the exchangeable character of the proton and/or hydrogen-bond formation. Apart from the C$sp^{2}$ signals in the aromatic area, the C=O carbon signal of the aroyl group usually appears at $\delta$ 180–182 in the $^{13}$C NMR spectra of **4a**–**4i**. In the mass spectra, the pseudo-molecular peaks $[M+H]^{+}$ or $[M-H]^{-}$ of **4a**–**4i** are in agreement with their molecular formulae.

### 3.2. Crystal structures of 2-aroyl-5-halobenzofuran-3-ol derivatives 4a–4c and 4h

For compounds **4a**–**4c** and **4h**, crystals suitable for X-ray diffraction were obtained during crystallization experiments using ethanol–water and acetone–water mixtures.

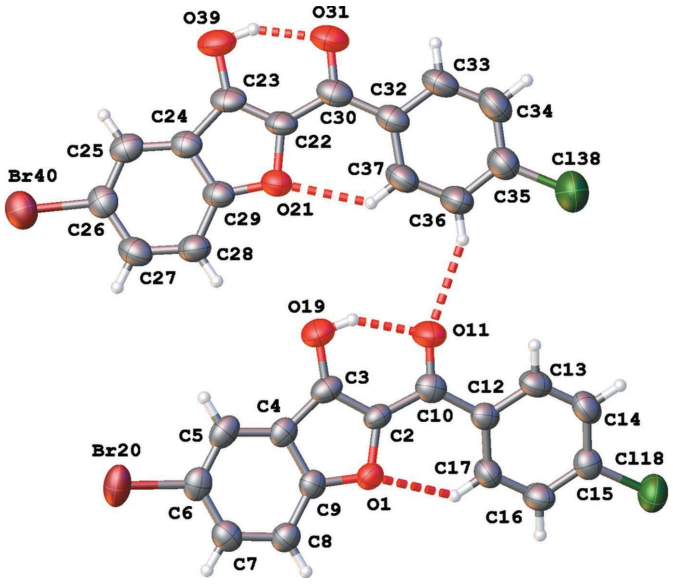



**Figure 4**
The molecular structure of **4b**, showing the atom-labelling scheme for both crystallographically unique molecules. Displacement ellipsoids are drawn at the 50% probability level.

Compound **4a** crystallizes in the space group $P2_1/c$ with one molecule in the asymmetric unit (Fig. 2). The dihedral angle between the best planes through the benzofuran (atoms O1–C9) and phenyl (C12–C17) rings is 23.00 (16)°. The intramolecular O19—H19···O11 hydrogen bond (Table 2) keeps the last atom close to the benzofuran plane [deviation = 0.123 (3) Å]. The small value for the O11—C10—C12—C13 torsion angle [17.1 (5)°] causes a second intramolecular C17—H17···O1 interaction (Table 2).

The crystal packing of **4a** is characterized by F···Br contacts [3.136 (2) Å], resulting in chain formation in the *c* direction (Fig. 3). Parallel chains interact through two types of C—H···O interactions (Table 2), of which one involves the formation of an inversion dimer generating an $R_2^2(10)$ loop. The resulting layers are almost parallel to the (102) plane and

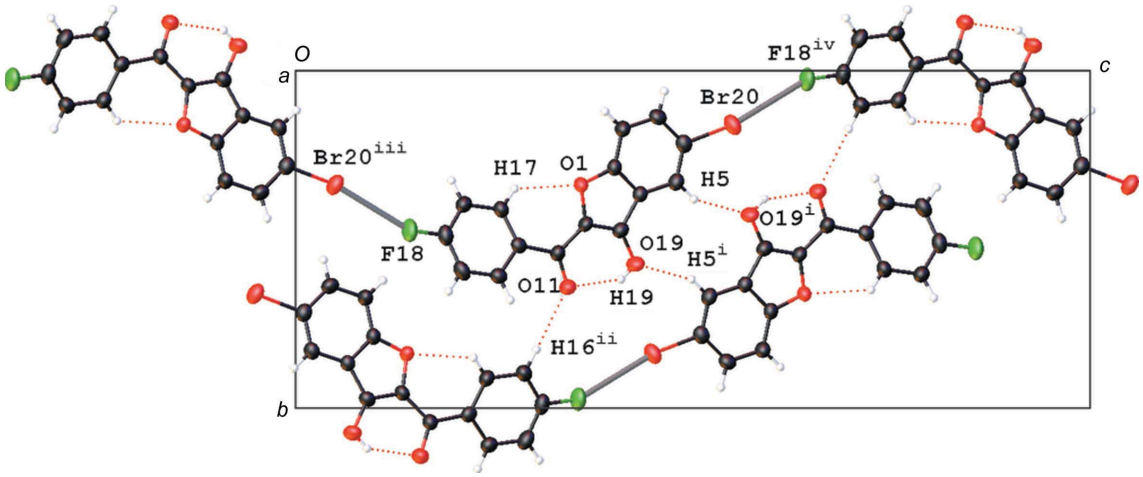



**Figure 3**
Packing diagram for **4a**, viewed along the *a* axis, showing the F···Br (green), O—H···O (red) and C—H···O (red) interactions. [Symmetry codes: (i) $-x+1, -y+1, -z+1$; (ii) $-x+2, y+\frac{1}{2}, -z+\frac{1}{2}$; (iii) $x+1, -y+\frac{1}{2}, z-\frac{1}{2}$; (iv) $x-1, -y+\frac{1}{2}, z+\frac{1}{2}$.]

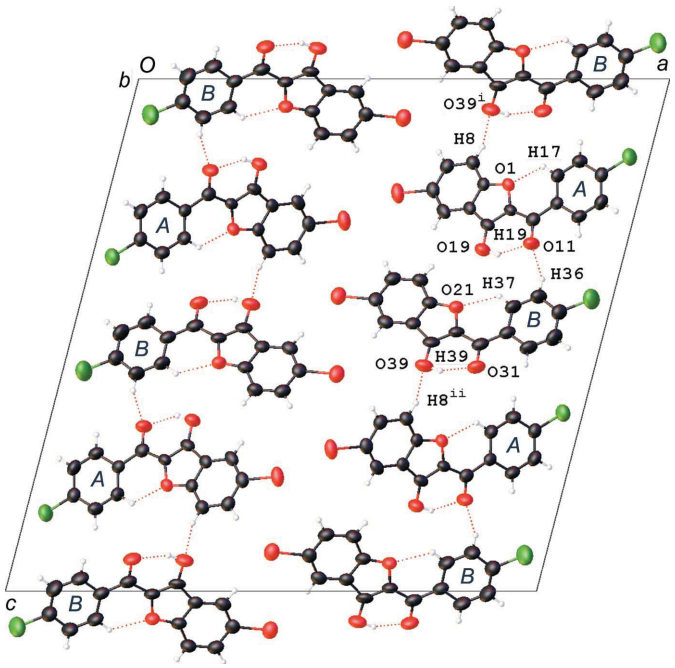



**Figure 5**
Packing diagram for **4b**, viewed along the *b* axis, showing the O—H···O (red) and C—H···O (red) interactions. Letters *A* and *B* indicate molecules *A* (atoms O1–Br20) and *B* (atoms O21–Br40). [Symmetry codes: (i) $x, -y+\frac{1}{2}, z-\frac{1}{2}$; (ii) $x, -y+\frac{1}{2}, z+\frac{1}{2}$.]

stack further along the *a* axis with centroid-to-centroid distances between stacking rings of 3.860 (2) Å.

Compound **4b** also crystallizes in the space group $P2_1/c$, but with two molecules (denoted *A* for that containing atoms O1–Br20 and *B* for that containing atoms O21–Br40) in the asymmetric unit (Fig. 4). An overlay of both structures gives an r.m.s. deviation of 0.0899 Å. Compared to **4a**, both molecules are more planar, as indicated by the smaller dihedral angle between the two ring systems of 6.58 (19)° in molecule *A* and 15.98 (18)° in molecule *B*. Atoms O11 and O31 deviate by only −0.033 (3) and 0.030 (4) Å, respectively, from the benzofuran plane. Also, the O11—C10—C12—C13 [11.6 (6)°] and O31—C30—C32—C33 [3.5 (7)°] torsion angles are reduced. The intramolecular O—H···O hydrogen bonds are shorter compared to those in **4a** (Table 3).

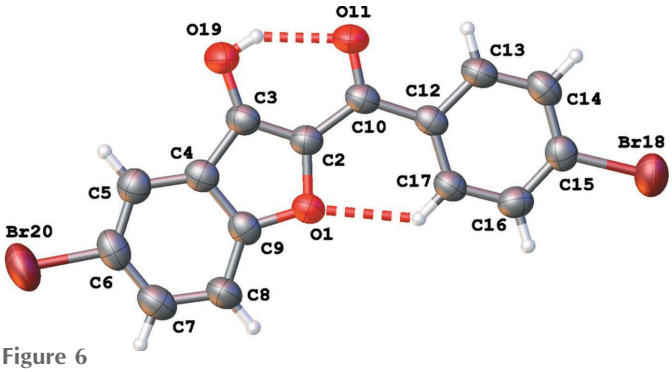



**Figure 6**
The molecular structure of **4c**, showing the atom-labelling scheme. Displacement ellipsoids are drawn at the 50% probability level.

Molecules *A* and *B* are linked *via* C36—H36···O11 hydrogen-bond interactions. These *A*–*B* dimers form chains running in the *c* direction through C8—H8···O39$^{i}$ hydrogen bonds (Table 3 and Fig. 5). The planes of neighbouring *A*–*B* dimers in this chain make an angle of 113.0 (2)°. Parallel

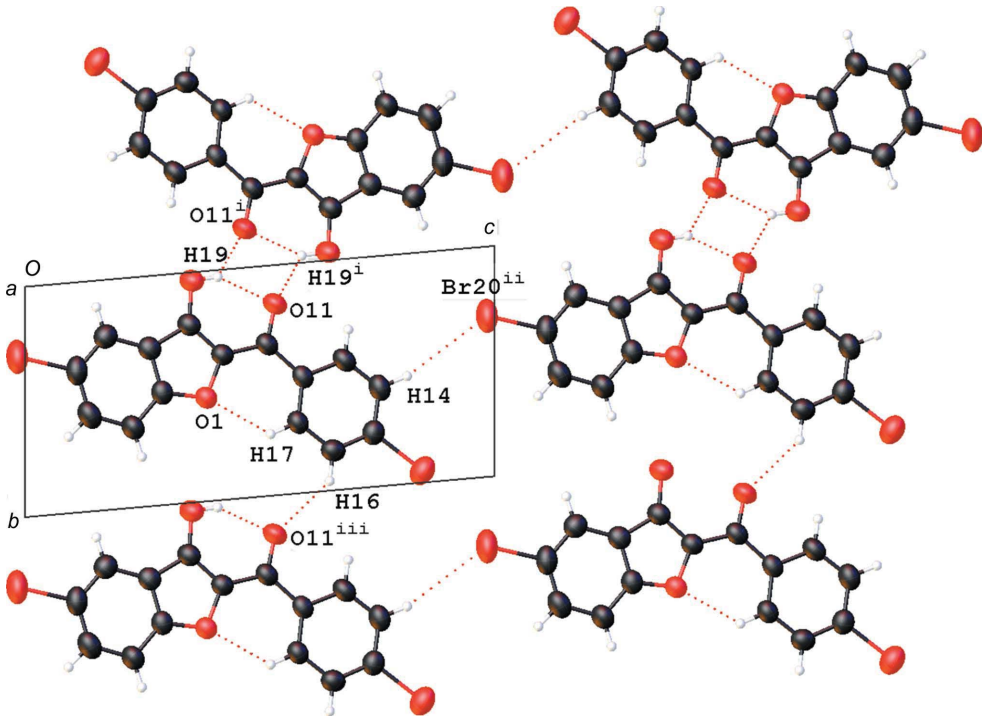



**Figure 7**
Packing diagram for **4c**, viewed along the *a* axis, showing the O—H···O (red), C—H···O (red) and C—H···Br (brown) interactions. [Symmetry codes: (i) $-x, -y, -z+1$; (ii) $x, y, z+1$; (iii) $x, y+1, z$.]

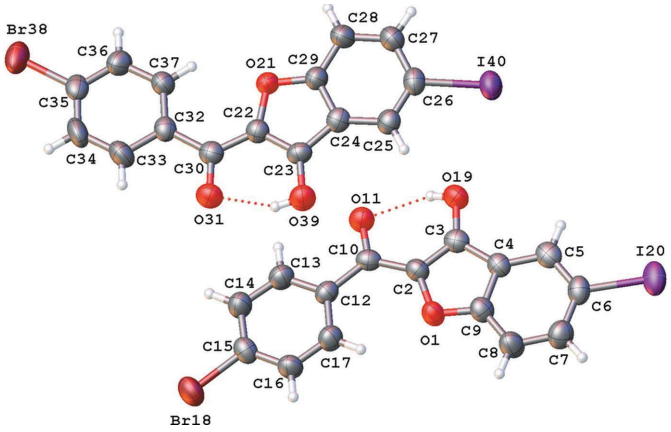



**Figure 8**
The molecular structure of **4h**, showing the atom-labelling scheme for both crystallographically unique molecules. Displacement ellipsoids are drawn at the 50% probability level.

chains show close Br20···Br20 [3.5934 (7) Å] and Cl18···Cl38 [3.452 (2) Å] contacts, and form a corrugated board-like layer extending in the *ac* plane.

Compound **4c** crystallizes in the space group $P\overline{1}$ and is quasi-planar (Fig. 6). The r.m.s. deviation of the best plane through all the non-H atoms is 0.024 Å, with atom O1 deviating most (0.049 Å). The ring systems are inclined to each other by only 1.74 (18)° and the O11—C10—C12—C13 torsion angle is 0.0 (6)°. The quasi-planarity of the molecule does not further shorten the intramolecular hydrogen bonds (Table 4).

The crystal packing of **4c** is built up by C14—H14···Br20$^{ii}$ interactions, resulting in chains of molecules running in the *c* direction. At one side of the chain, inversion dimers are formed by O19—H19···O11$^{i}$ interactions. At the other side of the chain, C16—H16···O11$^{iii}$ interactions extend further the layer of molecules parallel to the $(7\overline{2}0)$ plane (Table 4 and Fig. 7). The rings in the layers stack on top of each other. The shortest centroid-to-centroid distance is observed for the stacking of the benzofuran and phenyl rings [*Cg*···*Cg* = 3.483 (2) Å and slippage = 0.399 Å].

**Table 5**
Hydrogen-bond geometry (Å, °) for **4h**.

| *D*—H···*A* | *D*—H | H···*A* | *D*···*A* | *D*—H···*A* |
|---|---|---|---|---|
| O19—H19···O11 | 0.76 (10) | 2.05 (9) | 2.680 (7) | 140 (9) |
| C17—H17···O1 | 0.93 | 2.24 | 2.919 (8) | 129 |
| O39—H39···O31 | 0.79 (7) | 1.90 (9) | 2.617 (7) | 151 |
| C37—H37···O21 | 0.93 | 2.28 | 2.950 (8) | 128 |
| C13—H13···O39$^{i}$ | 0.93 | 2.50 | 3.231 (9) | 135 |

Symmetry code: (i) $x, y+1, z$.

Compound **4h** crystallizes in the space group *I*2/*a* and comprises two equivalents of the molecule (denoted *A* for that containing atoms O1–I20 and *B* for that containing atoms O21–I40) in the asymmetric unit, as shown in Fig. 8. An overlay of both structures gives an r.m.s. deviation of 0.1233 Å. The dihedral angle between the two ring systems is 1.6 (3)° in *A* and 7.1 (3)° in *B*. Atoms O11 and O31 deviate by 0.113 (5) and −0.037 (5) Å, respectively, from the benzofuran plane. The O11—C10—C12—C13 [0.4 (9)°] and O31—C30—C32—C33 [7.0 (9)°] torsion angles are small. The intramolecular O—H···O hydrogen bonds are comparable to those in **4a** and **4c** (Table 5).

Molecules of **4h** are held together in the solid state by $X\cdots\pi$ interactions (with $X$ = I, Br and O): I40···*Cg*6$^{i}$ [3.992 (3) Å], Br38···*Cg*7$^{ii}$ [3.684 (3) Å], O11···*Cg*1$^{ii}$ [3.411 (5) Å] and

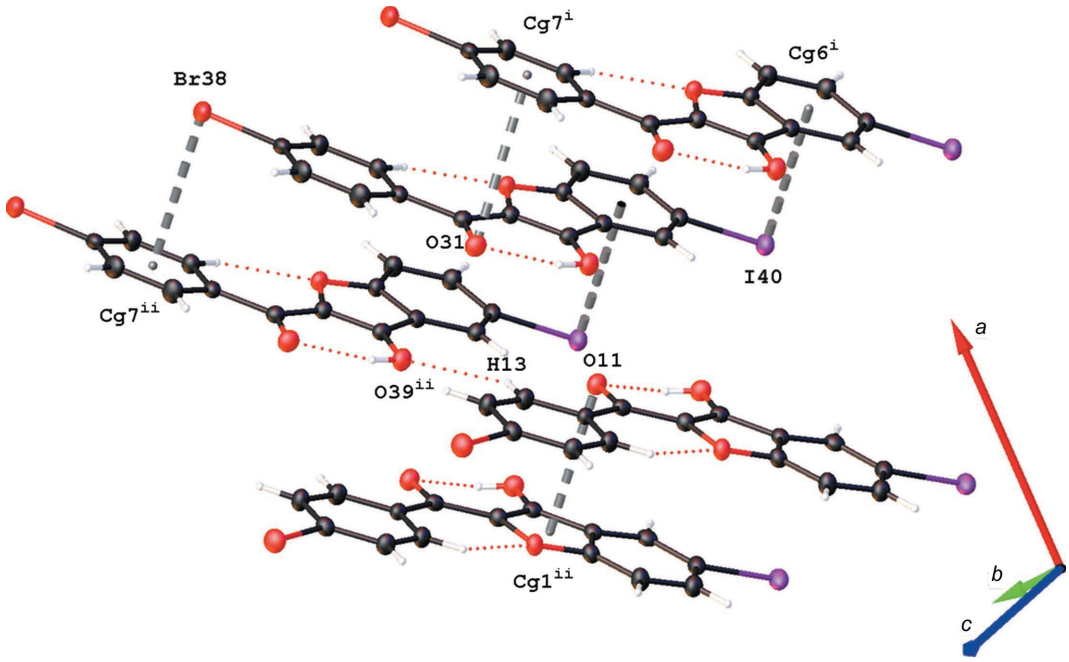



**Figure 9**
Partial packing diagram for **4h**, showing the $X\cdots\pi$ interactions, with $X$ = I, Br and O (grey), and O—H···O (red) interactions. *Cg*1, *Cg*6 and *Cg*7 are the centroids of the O1/C2–C4/C9, C24–C29 and C32–C37 rings, respectively. [Symmetry codes: (i) $x, y-1, z$; (ii) $x, y+1, z$.]

**Table 6**
Inhibition capacity of compounds **4a**, **4b** and **4d**–**4i** against four human cancer cell lines at a concentration of 128 μg ml$^{-1}$.

| Compound | Inhibition percentage (%) | | | |
|---|---|---|---|---|
| | KB | Hep-G2 | Lu-1 | MCF-7 |
| **4a** | 88 | 88 | 90 | 96 |
| **4b** | 93 | 96 | 100 | 100 |
| **4d** | 96 | 90 | 97 | 74 |
| **4e** | 95 | 88 | 87 | 85 |
| **4f** | 85 | 92 | 96 | 100 |
| **4g** | 82 | 92 | 92 | 100 |
| **4h** | 76 | 85 | 95 | 94 |
| **4i** | 90 | 92 | 97 | 98 |

**Table 7**
Cytotoxicity of compounds **4a**, **4b** and **4d**–**4i** ($IC_{50}{}^{a}$, μ*M*).

| Compound | KB | Hep-G2 | Lu-1 | MCF-7 |
|---|---|---|---|---|
| **4a** | 15.72 ± 0.36 | **5.69** ± 0.12 | 60.61 ± 1.20 | 23.95 ± 0.45 |
| **4b** | 13.72 ± 0.31 | **8.03** ± 0.23 | 34.06 ± 0.60 | 14.86 ± 0.23 |
| **4d** | 17.56 ± 0.33 | 13.16 ± 0.28 | 210.91 ± 5.01 | 88.65 ± 1.58 |
| **4e** | 12.27 ± 0.22 | **1.39** ± 0.02 | 62.86 ± 1.33 | **5.54** ± 0.08 |
| **4f** | 21.98 ± 0.38 | 11.14 ± 0.26 | 48.55 ± 0.71 | 21.98 ± 0.44 |
| **4g** | 20.07 ± 0.48 | **3.2** ± 0.09 | 49.60 ± 0.98 | 10.54 ± 0.20 |
| **4h** | 42.93 ± 0.93 | **5.50** ± 0.11 | 115.08 ± 2.31 | 18.10 ± 0.32 |
| **4i** | 43.72 ± 0.86 | **3.25** ± 0.07 | 56.44 ± 1.30 | 42.67 ± 0.81 |
| **Ellipticine** | 1.22 ± 0.08 | 1.34 ± 0.08 | 1.83 ± 0.20 | 2.15 ± 0.20 |

Note: (*a*) $IC_{50}$ is the concentration of the compound required to inhibit cell growth by 50%. Values < 10 μ*M* are indicated in **bold**.

O31···*Cg*7$^{i}$ [3.890 (6) Å] [Fig. 9; *Cg*1, *Cg*6 and *Cg*7 are the centroids of the O1/C2–C4/C9, C24–C29 and C32–C37 rings, respectively; symmetry codes: (i) $x, y-1, z$; (ii) $x, y+1, z$]. This is complemented by an intermolecular C13—H13···O39$^{i}$ hydrogen bond between molecules *A* and *B* (Fig. 9 and Table 5).

No voids are observed in the crystal packings of these compounds.

### 3.3. *In vitro* cytotoxicity of compounds 4a, 4b and 4d–4i

Compounds **4a**, **4b** and **4d**–**4i** were evaluated for their cytotoxicity against the four cancer cell lines KB (mouth epidermal carcinoma cells), Hep-G2 (human liver hepatocellular carcinoma cells), Lu-1 (human lung adenocarcinoma cells) and MCF7 (human breast cancer cells). The cytotoxic effects of these compounds were estimated in terms of growth inhibition percentage and expressed as $IC_{50}$, which is the concentration of a compound which reduces the absorbance of treated cells by 50% with reference to the control (untreated cells). The inhibition capacities against the four human cancer cell lines are listed in Table 6. All of compounds **4a**, **4b** and **4d**–**4i** displayed significant growth inhibition in the range 74–100% at 128 μg ml$^{-1}$ on the four cancer cell lines. In particular, compound **4b** expressed an inhibition ability in the range 93–100% at the same concentration.

The $IC_{50}$ values in Table 7 indicate that most of the examined compounds possess at least moderate cytotoxic activity, and some compounds even display a promising activity profile. It is important to note that the separate pharmacophores display considerably less potent cytotoxic activities compared to the most promising compounds, *i.e.* **4a**, **4b**, **4e** and **4g**–**4i** ($IC_{50}$ values between 1.39 and 8.03 μ*M*), which show a reasonable activity against the two human cancer cell lines Hep-G2 and MCF7. In particular, compound **4e** exhibits a strong anticancer effect against Hep-G2 cells, with an $IC_{50}$ value (1.39 μ*M*) similar to ellipticine (1.34 μ*M*).

## 4. Conclusions

Starting from salicylic acid, we have synthesized nine 2-aroyl-5-halobenzofuran-3-ol derivatives, **4a**–**4i**, with yields between 76 and 93%. The compounds were characterized by MS and NMR spectroscopy. Crystals suitable for X-ray diffraction were obtained for compounds **4a**, **4b**, **4c** and **4h**. An intramolecular O—H···O hydrogen bond keeps the molecules close to being planar, with dihedral angles between the planes of the benzofuran and phenyl rings ranging from 1.6 (3) to 23.00 (16)°. In the solid state, molecules are held together by halogen–halogen and C—H···O/Br interactions, complemented by π–π interactions for **4c** and *X*···π interactions in the case of **4h** (with *X* = I, Br and O). Compounds **4a**, **4b** and **4d**–**4i** were evaluated for their cytotoxicity against four human cancer cell lines. Six compounds showed significant inhibiting abilities on Hep-G2 cells, with $IC_{50}$ values of 1.39–8.03 μ*M*. With a shape similar to DAPI (4′,6-diamidino-2-phenylindole), these compounds can bind to DNA as a minor-groove binder (Vlieghe *et al.*, 1999), which could explain the cytotoxicity. However, it cannot be excluded that the compounds intercalate between DNA base pairs in a way similar to ellipticine (Canals *et al.*, 2005).

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# supporting information

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## Synthesis, structure and *in vitro* cytotoxicity testing of some 2-aroylbenzofuran-3-ols

**Nguyen Tien Cong, Huynh Thi Xuan Trang, Pham Duc Dung, Tran Hoang Phuong, Vu Quoc Trung, Nguyen Dang Dat, Dang Thi Tuyet Anh, Nguyen Van Tuyen and Luc Van Meervelt**

### Computing details

For all structures, data collection: *CrysAlis PRO* (Rigaku OD, 2018); cell refinement: *CrysAlis PRO* (Rigaku OD, 2018); data reduction: *CrysAlis PRO* (Rigaku OD, 2018). Program(s) used to solve structure: olex2.solve (Bourhis *et al.*, 2015) for (4a); *SHELXS* (Sheldrick, 2008) for (4b); SHELXT (Sheldrick, 2015a) for (4c), (4h). For all structures, program(s) used to refine structure: *SHELXL2016* (Sheldrick, 2015b); molecular graphics: OLEX2 (Dolomanov *et al.*, 2009); software used to prepare material for publication: OLEX2 (Dolomanov *et al.*, 2009).

### (5-Bromo-3-hydroxybenzofuran-2-yl)(4-fluorophenyl)methanone (4a)

*Crystal data*

$C_{15}H_8BrFO_3$
$M_r$ = 335.12
Monoclinic, $P2_1/c$
$a$ = 3.8598 (4) Å
$b$ = 11.7229 (10) Å
$c$ = 27.679 (2) Å
$\beta$ = 93.255 (9)°
$V$ = 1250.38 (19) Å$^3$
$Z$ = 4
$F(000)$ = 664
$D_x$ = 1.780 Mg m$^{-3}$
Mo $K\alpha$ radiation, $\lambda$ = 0.71073 Å
Cell parameters from 2736 reflections
$\theta$ = 2.9–25.3°
$\mu$ = 3.30 mm$^{-1}$
$T$ = 293 K
Needle, yellow
0.5 × 0.15 × 0.05 mm

*Data collection*

Rigaku OD SuperNova Single source diffractometer with an Eos detector
Radiation source: micro-focus sealed X-ray tube, SuperNova (Mo) X-ray Source
Mirror monochromator
Detector resolution: 15.9631 pixels mm$^{-1}$
$\omega$ scans
Absorption correction: multi-scan (CrysAlis PRO; Rigaku OD, 2018)
$T_{min}$ = 0.447, $T_{max}$ = 1.000
7646 measured reflections
2543 independent reflections
1873 reflections with $I > 2\sigma(I)$
$R_{int}$ = 0.040
$\theta_{max}$ = 26.4°, $\theta_{min}$ = 2.8°
$h$ = −4→4
$k$ = −14→14
$l$ = −34→33

*Refinement*

Refinement on $F^2$
Least-squares matrix: full
$R[F^2 > 2\sigma(F^2)]$ = 0.045
$wR(F^2)$ = 0.097
$S$ = 1.07
2543 reflections
185 parameters
0 restraints
Primary atom site location: iterative
Hydrogen site location: mixed
H atoms treated by a mixture of independent and constrained refinement

$w = 1/[\sigma^2(F_o^2) + (0.0352P)^2 + 0.4417P]$
where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{max} = 0.001$

$\Delta\rho_{max} = 0.44$ e Å$^{-3}$
$\Delta\rho_{min} = -0.45$ e Å$^{-3}$

*Special details*

**Geometry**. All esds (except the esd in the dihedral angle between two l.s. planes) are estimated using the full covariance matrix. The cell esds are taken into account individually in the estimation of esds in distances, angles and torsion angles; correlations between esds in cell parameters are only used when they are defined by crystal symmetry. An approximate (isotropic) treatment of cell esds is used for estimating esds involving l.s. planes.

*Fractional atomic coordinates and isotropic or equivalent isotropic displacement parameters (Å²)*

| | *x* | *y* | *z* | $U_{iso}$*/$U_{eq}$ |
|---|---|---|---|---|
| O1 | 1.0511 (7) | 0.33866 (19) | 0.35954 (8) | 0.0346 (6) |
| C2 | 0.9792 (10) | 0.4552 (3) | 0.36548 (12) | 0.0331 (9) |
| C3 | 0.8510 (10) | 0.4728 (3) | 0.40944 (12) | 0.0356 (9) |
| C4 | 0.8335 (9) | 0.3665 (3) | 0.43395 (12) | 0.0307 (8) |
| C5 | 0.7327 (10) | 0.3302 (3) | 0.47925 (13) | 0.0356 (9) |
| H5 | 0.648929 | 0.381124 | 0.501555 | 0.043* |
| C6 | 0.7633 (10) | 0.2170 (3) | 0.48907 (12) | 0.0363 (9) |
| C7 | 0.8901 (10) | 0.1380 (3) | 0.45616 (13) | 0.0394 (10) |
| H7 | 0.905416 | 0.061294 | 0.464530 | 0.047* |
| C8 | 0.9913 (11) | 0.1730 (3) | 0.41188 (13) | 0.0383 (9) |
| H8 | 1.076432 | 0.121809 | 0.389793 | 0.046* |
| C9 | 0.9610 (9) | 0.2874 (3) | 0.40168 (12) | 0.0319 (8) |
| C10 | 1.0400 (10) | 0.5412 (3) | 0.33035 (12) | 0.0350 (9) |
| O11 | 0.9820 (8) | 0.6415 (2) | 0.34270 (9) | 0.0525 (8) |
| C12 | 1.1635 (9) | 0.5177 (3) | 0.28145 (12) | 0.0318 (8) |
| C13 | 1.2995 (10) | 0.6084 (3) | 0.25606 (13) | 0.0375 (9) |
| H13 | 1.319832 | 0.679808 | 0.270563 | 0.045* |
| C14 | 1.4041 (10) | 0.5935 (4) | 0.20979 (13) | 0.0433 (10) |
| H14 | 1.497366 | 0.653718 | 0.192927 | 0.052* |
| C15 | 1.3676 (11) | 0.4884 (4) | 0.18939 (13) | 0.0420 (10) |
| C16 | 1.2279 (10) | 0.3965 (3) | 0.21210 (13) | 0.0401 (10) |
| H16 | 1.200229 | 0.326544 | 0.196515 | 0.048* |
| C17 | 1.1296 (10) | 0.4116 (3) | 0.25904 (12) | 0.0372 (9) |
| H17 | 1.040261 | 0.350361 | 0.275726 | 0.045* |
| F18 | 1.4709 (7) | 0.4732 (2) | 0.14395 (7) | 0.0633 (8) |
| O19 | 0.7528 (9) | 0.5730 (2) | 0.42805 (11) | 0.0509 (8) |
| Br20 | 0.63812 (11) | 0.16145 (4) | 0.55017 (2) | 0.04886 (17) |
| H19 | 0.805 (12) | 0.618 (4) | 0.4097 (15) | 0.053 (15)* |

*Atomic displacement parameters (Å²)*

| | $U^{11}$ | $U^{22}$ | $U^{33}$ | $U^{12}$ | $U^{13}$ | $U^{23}$ |
|---|---|---|---|---|---|---|
| O1 | 0.0478 (16) | 0.0302 (12) | 0.0266 (13) | 0.0059 (13) | 0.0097 (11) | 0.0023 (10) |
| C2 | 0.041 (2) | 0.0301 (19) | 0.0289 (19) | 0.0024 (18) | 0.0076 (17) | −0.0044 (15) |
| C3 | 0.041 (2) | 0.032 (2) | 0.035 (2) | 0.0031 (19) | 0.0037 (18) | −0.0042 (16) |
| C4 | 0.031 (2) | 0.0329 (19) | 0.0286 (18) | 0.0021 (17) | 0.0047 (16) | −0.0016 (15) |

| | | | | | | |
|---|---|---|---|---|---|---|
| C5 | 0.037 (2) | 0.038 (2) | 0.0318 (19) | 0.003 (2) | 0.0079 (17) | −0.0037 (17) |
| C6 | 0.033 (2) | 0.042 (2) | 0.034 (2) | −0.002 (2) | 0.0049 (17) | 0.0035 (17) |
| C7 | 0.047 (3) | 0.032 (2) | 0.039 (2) | 0.0041 (19) | 0.0029 (19) | 0.0052 (16) |
| C8 | 0.052 (3) | 0.033 (2) | 0.030 (2) | 0.006 (2) | 0.0091 (18) | −0.0004 (16) |
| C9 | 0.034 (2) | 0.036 (2) | 0.0262 (18) | 0.0014 (18) | 0.0038 (16) | −0.0002 (16) |
| C10 | 0.044 (2) | 0.032 (2) | 0.0295 (19) | −0.0017 (19) | 0.0060 (17) | −0.0022 (16) |
| O11 | 0.088 (2) | 0.0311 (15) | 0.0398 (16) | 0.0041 (15) | 0.0131 (15) | −0.0022 (12) |
| C12 | 0.031 (2) | 0.0325 (19) | 0.0317 (19) | 0.0009 (17) | 0.0004 (16) | 0.0037 (15) |
| C13 | 0.044 (2) | 0.032 (2) | 0.037 (2) | 0.0002 (19) | 0.0028 (18) | 0.0031 (16) |
| C14 | 0.045 (3) | 0.049 (3) | 0.037 (2) | −0.002 (2) | 0.009 (2) | 0.0125 (19) |
| C15 | 0.041 (2) | 0.056 (3) | 0.029 (2) | 0.005 (2) | 0.0053 (18) | 0.0043 (18) |
| C16 | 0.053 (3) | 0.034 (2) | 0.033 (2) | 0.003 (2) | 0.0037 (19) | −0.0029 (17) |
| C17 | 0.047 (2) | 0.035 (2) | 0.030 (2) | −0.001 (2) | 0.0053 (18) | 0.0041 (16) |
| F18 | 0.090 (2) | 0.0692 (16) | 0.0332 (13) | 0.0089 (16) | 0.0262 (13) | 0.0011 (12) |
| O19 | 0.080 (2) | 0.0301 (15) | 0.0444 (17) | 0.0080 (16) | 0.0208 (16) | −0.0018 (14) |
| Br20 | 0.0552 (3) | 0.0534 (3) | 0.0396 (3) | 0.0052 (2) | 0.0172 (2) | 0.01369 (19) |

*Geometric parameters (Å, º)*

| | | | |
|---|---|---|---|
| O1—C2 | 1.406 (4) | C8—C9 | 1.374 (5) |
| O1—C9 | 1.374 (4) | C10—O11 | 1.249 (4) |
| C2—C3 | 1.355 (5) | C10—C12 | 1.486 (5) |
| C2—C10 | 1.429 (5) | C12—C13 | 1.393 (5) |
| C3—C4 | 1.422 (5) | C12—C17 | 1.393 (5) |
| C3—O19 | 1.345 (4) | C13—H13 | 0.9300 |
| C4—C5 | 1.400 (5) | C13—C14 | 1.376 (5) |
| C4—C9 | 1.397 (5) | C14—H14 | 0.9300 |
| C5—H5 | 0.9300 | C14—C15 | 1.360 (6) |
| C5—C6 | 1.358 (5) | C15—C16 | 1.373 (5) |
| C6—C7 | 1.406 (5) | C15—F18 | 1.353 (4) |
| C6—Br20 | 1.900 (3) | C16—H16 | 0.9300 |
| C7—H7 | 0.9300 | C16—C17 | 1.385 (5) |
| C7—C8 | 1.370 (5) | C17—H17 | 0.9300 |
| C8—H8 | 0.9300 | O19—H19 | 0.77 (4) |
| | | | |
| C9—O1—C2 | 105.3 (2) | C8—C9—C4 | 123.1 (3) |
| O1—C2—C10 | 124.4 (3) | C2—C10—C12 | 124.3 (3) |
| C3—C2—O1 | 109.7 (3) | O11—C10—C2 | 116.1 (3) |
| C3—C2—C10 | 125.9 (3) | O11—C10—C12 | 119.7 (3) |
| C2—C3—C4 | 108.9 (3) | C13—C12—C10 | 117.9 (3) |
| O19—C3—C2 | 127.0 (3) | C13—C12—C17 | 119.0 (3) |
| O19—C3—C4 | 124.1 (3) | C17—C12—C10 | 122.9 (3) |
| C5—C4—C3 | 135.8 (3) | C12—C13—H13 | 119.6 |
| C9—C4—C3 | 104.4 (3) | C14—C13—C12 | 120.8 (4) |
| C9—C4—C5 | 119.8 (3) | C14—C13—H13 | 119.6 |
| C4—C5—H5 | 121.6 | C13—C14—H14 | 120.9 |
| C6—C5—C4 | 116.8 (3) | C15—C14—C13 | 118.2 (4) |
| C6—C5—H5 | 121.6 | C15—C14—H14 | 120.9 |

| | | | |
|---|---|---|---|
| C5—C6—C7 | 122.9 (3) | C14—C15—C16 | 123.7 (3) |
| C5—C6—Br20 | 119.3 (3) | F18—C15—C14 | 118.5 (3) |
| C7—C6—Br20 | 117.8 (3) | F18—C15—C16 | 117.8 (4) |
| C6—C7—H7 | 119.7 | C15—C16—H16 | 121.1 |
| C8—C7—C6 | 120.7 (3) | C15—C16—C17 | 117.7 (3) |
| C8—C7—H7 | 119.7 | C17—C16—H16 | 121.1 |
| C7—C8—H8 | 121.6 | C12—C17—H17 | 119.8 |
| C7—C8—C9 | 116.8 (3) | C16—C17—C12 | 120.5 (3) |
| C9—C8—H8 | 121.6 | C16—C17—H17 | 119.8 |
| O1—C9—C4 | 111.6 (3) | C3—O19—H19 | 105 (3) |
| C8—C9—O1 | 125.3 (3) | | |

| | | | |
|---|---|---|---|
| O1—C2—C3—C4 | −0.2 (5) | C7—C8—C9—C4 | −0.2 (6) |
| O1—C2—C3—O19 | 179.9 (4) | C9—O1—C2—C3 | 0.0 (4) |
| O1—C2—C10—O11 | −175.6 (4) | C9—O1—C2—C10 | 178.9 (4) |
| O1—C2—C10—C12 | 4.6 (6) | C9—C4—C5—C6 | −0.6 (6) |
| C2—O1—C9—C4 | 0.3 (4) | C10—C2—C3—C4 | −179.2 (4) |
| C2—O1—C9—C8 | −179.4 (4) | C10—C2—C3—O19 | 1.0 (7) |
| C2—C3—C4—C5 | 178.8 (4) | C10—C12—C13—C14 | −177.1 (4) |
| C2—C3—C4—C9 | 0.4 (4) | C10—C12—C17—C16 | 175.6 (4) |
| C2—C10—C12—C13 | −163.1 (4) | O11—C10—C12—C13 | 17.1 (6) |
| C2—C10—C12—C17 | 20.9 (6) | O11—C10—C12—C17 | −158.9 (4) |
| C3—C2—C10—O11 | 3.2 (6) | C12—C13—C14—C15 | 0.7 (6) |
| C3—C2—C10—C12 | −176.6 (4) | C13—C12—C17—C16 | −0.4 (6) |
| C3—C4—C5—C6 | −178.8 (4) | C13—C14—C15—C16 | 0.9 (7) |
| C3—C4—C9—O1 | −0.4 (4) | C13—C14—C15—F18 | −179.8 (3) |
| C3—C4—C9—C8 | 179.3 (4) | C14—C15—C16—C17 | −2.1 (6) |
| C4—C5—C6—C7 | 0.2 (6) | C15—C16—C17—C12 | 1.8 (6) |
| C4—C5—C6—Br20 | 179.1 (3) | C17—C12—C13—C14 | −1.0 (6) |
| C5—C4—C9—O1 | −179.1 (3) | F18—C15—C16—C17 | 178.6 (3) |
| C5—C4—C9—C8 | 0.6 (6) | O19—C3—C4—C5 | −1.4 (8) |
| C5—C6—C7—C8 | 0.2 (6) | O19—C3—C4—C9 | −179.8 (4) |
| C6—C7—C8—C9 | −0.2 (6) | Br20—C6—C7—C8 | −178.7 (3) |
| C7—C8—C9—O1 | 179.5 (3) | | |

*Hydrogen-bond geometry (Å, º)*

| *D*—H···*A* | *D*—H | H···*A* | *D*···*A* | *D*—H···*A* |
|---|---|---|---|---|
| O19—H19···O11 | 0.77 (5) | 2.03 (4) | 2.692 (4) | 144 (4) |
| C17—H17···O1 | 0.93 | 2.32 | 2.942 (4) | 124 |
| C16—H16···O11$^{i}$ | 0.93 | 2.51 | 3.428 (4) | 170 |
| C5—H5···O19$^{ii}$ | 0.93 | 2.61 | 3.454 (5) | 150 |

Symmetry codes: (i) −*x*+2, *y*−1/2, −*z*+1/2; (ii) −*x*+1, −*y*+1, −*z*+1.

**(5-Bromo-3-hydroxybenzofuran-2-yl)(4-chlorophenyl)methanone (4b)**

*Crystal data*

$C_{15}H_8BrClO_3$
$M_r = 351.57$
Monoclinic, $P2_1/c$
$a = 26.4034$ (10) Å
$b = 3.9818$ (1) Å
$c = 26.2773$ (10) Å
$\beta = 104.605$ (4)°
$V = 2673.34$ (17) Å$^3$
$Z = 8$
$F(000) = 1392$
$D_x = 1.747$ Mg m$^{-3}$
Mo $K\alpha$ radiation, $\lambda = 0.71073$ Å
Cell parameters from 6124 reflections
$\theta = 3.1$–$24.1°$
$\mu = 3.28$ mm$^{-1}$
$T = 294$ K
Plate, yellow
0.4 × 0.15 × 0.05 mm

*Data collection*

Rigaku OD SuperNova Single source diffractometer with an Eos detector
Radiation source: micro-focus sealed X-ray tube, SuperNova (Mo) X-ray Source
Mirror monochromator
Detector resolution: 15.9631 pixels mm$^{-1}$
$\omega$ scans
Absorption correction: multi-scan (CrysAlis PRO; Rigaku OD, 2018)
$T_{min} = 0.572$, $T_{max} = 1.000$
27661 measured reflections
5419 independent reflections
3168 reflections with $I > 2\sigma(I)$
$R_{int} = 0.064$
$\theta_{max} = 26.4°$, $\theta_{min} = 2.4°$
$h = -33 \rightarrow 33$
$k = -4 \rightarrow 4$
$l = -32 \rightarrow 32$

*Refinement*

Refinement on $F^2$
Least-squares matrix: full
$R[F^2 > 2\sigma(F^2)] = 0.052$
$wR(F^2) = 0.102$
$S = 1.01$
5419 reflections
369 parameters
0 restraints
Primary atom site location: structure-invariant direct methods
Hydrogen site location: mixed
H atoms treated by a mixture of independent and constrained refinement
$w = 1/[\sigma^2(F_o^2) + (0.029P)^2 + 2.0591P]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{max} = 0.001$
$\Delta\rho_{max} = 0.56$ e Å$^{-3}$
$\Delta\rho_{min} = -0.42$ e Å$^{-3}$

*Special details*

**Geometry**. All esds (except the esd in the dihedral angle between two l.s. planes) are estimated using the full covariance matrix. The cell esds are taken into account individually in the estimation of esds in distances, angles and torsion angles; correlations between esds in cell parameters are only used when they are defined by crystal symmetry. An approximate (isotropic) treatment of cell esds is used for estimating esds involving l.s. planes.

*Fractional atomic coordinates and isotropic or equivalent isotropic displacement parameters (Å$^2$)*

| | $x$ | $y$ | $z$ | $U_{iso}$*/$U_{eq}$ |
|---|---|---|---|---|
| O1 | 0.74798 (10) | 0.1478 (6) | 0.20663 (11) | 0.0451 (7) |
| C2 | 0.76425 (16) | 0.2959 (10) | 0.25631 (16) | 0.0414 (10) |
| C3 | 0.72831 (17) | 0.2377 (11) | 0.28464 (18) | 0.0474 (11) |
| C4 | 0.68645 (16) | 0.0499 (10) | 0.25260 (17) | 0.0435 (10) |
| C5 | 0.63911 (17) | −0.0788 (11) | 0.25851 (19) | 0.0520 (12) |
| H5 | 0.628733 | −0.049134 | 0.289505 | 0.062* |
| C6 | 0.60870 (16) | −0.2499 (10) | 0.2169 (2) | 0.0506 (12) |
| C7 | 0.62345 (17) | −0.3027 (11) | 0.17041 (18) | 0.0522 (12) |

| | | | | |
|---|---|---|---|---|
| H7 | 0.601560 | −0.424167 | 0.143395 | 0.063* |
| C8 | 0.67037 (16) | −0.1771 (10) | 0.16363 (18) | 0.0488 (11) |
| H8 | 0.680793 | −0.210610 | 0.132745 | 0.059* |
| C9 | 0.70068 (16) | 0.0011 (9) | 0.20560 (17) | 0.0422 (11) |
| C10 | 0.81144 (17) | 0.4852 (10) | 0.27453 (19) | 0.0504 (12) |
| O11 | 0.82009 (13) | 0.5813 (8) | 0.32146 (13) | 0.0703 (9) |
| C12 | 0.84822 (16) | 0.5771 (10) | 0.24301 (17) | 0.0438 (10) |
| C13 | 0.89643 (17) | 0.7151 (11) | 0.26866 (18) | 0.0563 (12) |
| H13 | 0.905122 | 0.738409 | 0.305052 | 0.068* |
| C14 | 0.93111 (17) | 0.8166 (12) | 0.2408 (2) | 0.0614 (13) |
| H14 | 0.963255 | 0.907700 | 0.258215 | 0.074* |
| C15 | 0.91812 (16) | 0.7830 (11) | 0.18708 (19) | 0.0515 (12) |
| C16 | 0.87094 (18) | 0.6494 (11) | 0.16089 (18) | 0.0575 (12) |
| H16 | 0.862349 | 0.630215 | 0.124446 | 0.069* |
| C17 | 0.83643 (17) | 0.5441 (11) | 0.18891 (18) | 0.0520 (12) |
| H17 | 0.804676 | 0.449286 | 0.171240 | 0.062* |
| Cl18 | 0.96251 (5) | 0.9144 (4) | 0.15236 (6) | 0.0778 (4) |
| O19 | 0.73115 (15) | 0.3394 (9) | 0.33357 (14) | 0.0678 (10) |
| Br20 | 0.54377 (2) | −0.42670 (12) | 0.22329 (2) | 0.06821 (19) |
| O21 | 0.70963 (11) | 0.8529 (7) | 0.44584 (11) | 0.0543 (8) |
| C22 | 0.72238 (19) | 1.0222 (11) | 0.49411 (17) | 0.0510 (12) |
| C23 | 0.6799 (2) | 1.0408 (11) | 0.51387 (17) | 0.0540 (12) |
| C24 | 0.63657 (18) | 0.8860 (10) | 0.47749 (17) | 0.0481 (11) |
| C25 | 0.58370 (18) | 0.8345 (10) | 0.47435 (18) | 0.0537 (12) |
| H25 | 0.568715 | 0.905525 | 0.500961 | 0.064* |
| C26 | 0.55481 (17) | 0.6758 (11) | 0.43063 (19) | 0.0527 (12) |
| C27 | 0.57635 (19) | 0.5631 (11) | 0.39031 (18) | 0.0589 (13) |
| H27 | 0.555187 | 0.455037 | 0.361263 | 0.071* |
| C28 | 0.62855 (18) | 0.6108 (11) | 0.39319 (18) | 0.0571 (12) |
| H28 | 0.643551 | 0.534760 | 0.366871 | 0.069* |
| C29 | 0.65764 (18) | 0.7764 (11) | 0.43690 (17) | 0.0499 (11) |
| C30 | 0.77303 (19) | 1.1543 (11) | 0.51808 (19) | 0.0567 (13) |
| O31 | 0.77683 (13) | 1.2897 (9) | 0.56258 (13) | 0.0736 (10) |
| C32 | 0.81848 (18) | 1.1521 (11) | 0.49538 (18) | 0.0541 (12) |
| C33 | 0.8658 (2) | 1.2824 (12) | 0.52436 (19) | 0.0662 (14) |
| H33 | 0.867985 | 1.366531 | 0.557867 | 0.079* |
| C34 | 0.9090 (2) | 1.2900 (14) | 0.5049 (2) | 0.0784 (16) |
| H34 | 0.940408 | 1.375615 | 0.525226 | 0.094* |
| C35 | 0.90609 (19) | 1.1710 (13) | 0.4553 (2) | 0.0669 (14) |
| C36 | 0.8598 (2) | 1.0437 (13) | 0.4251 (2) | 0.0691 (14) |
| H36 | 0.857813 | 0.964976 | 0.391294 | 0.083* |
| C37 | 0.81681 (19) | 1.0340 (11) | 0.44501 (19) | 0.0631 (14) |
| H37 | 0.785654 | 0.946543 | 0.424512 | 0.076* |
| Cl38 | 0.96020 (6) | 1.1822 (5) | 0.42988 (7) | 0.1069 (6) |
| O39 | 0.67804 (16) | 1.1817 (9) | 0.55988 (14) | 0.0726 (11) |
| Br40 | 0.48242 (2) | 0.59410 (13) | 0.42371 (2) | 0.07029 (19) |
| H19 | 0.7620 (18) | 0.424 (12) | 0.343 (2) | 0.08 (2)* |
| H39 | 0.711 (2) | 1.268 (17) | 0.570 (3) | 0.14 (3)* |

*Atomic displacement parameters (Å²)*

| | $U^{11}$ | $U^{22}$ | $U^{33}$ | $U^{12}$ | $U^{13}$ | $U^{23}$ |
|---|---|---|---|---|---|---|
| O1 | 0.0443 (16) | 0.0494 (18) | 0.0441 (19) | 0.0027 (14) | 0.0158 (14) | −0.0022 (14) |
| C2 | 0.045 (2) | 0.047 (3) | 0.034 (3) | 0.007 (2) | 0.013 (2) | 0.003 (2) |
| C3 | 0.058 (3) | 0.049 (3) | 0.038 (3) | 0.012 (2) | 0.017 (2) | 0.006 (2) |
| C4 | 0.043 (2) | 0.042 (2) | 0.047 (3) | 0.012 (2) | 0.014 (2) | 0.007 (2) |
| C5 | 0.056 (3) | 0.048 (3) | 0.059 (3) | 0.016 (2) | 0.027 (3) | 0.011 (2) |
| C6 | 0.050 (3) | 0.037 (2) | 0.068 (4) | 0.007 (2) | 0.021 (3) | 0.005 (2) |
| C7 | 0.049 (3) | 0.046 (3) | 0.057 (3) | 0.004 (2) | 0.007 (2) | 0.000 (2) |
| C8 | 0.052 (3) | 0.045 (3) | 0.051 (3) | 0.003 (2) | 0.017 (2) | 0.000 (2) |
| C9 | 0.040 (2) | 0.040 (3) | 0.048 (3) | 0.0076 (19) | 0.012 (2) | 0.003 (2) |
| C10 | 0.052 (3) | 0.047 (3) | 0.050 (3) | 0.008 (2) | 0.008 (2) | 0.002 (2) |
| O11 | 0.073 (2) | 0.095 (3) | 0.042 (2) | −0.016 (2) | 0.0125 (18) | −0.0123 (19) |
| C12 | 0.042 (2) | 0.044 (2) | 0.043 (3) | 0.008 (2) | 0.006 (2) | −0.001 (2) |
| C13 | 0.056 (3) | 0.064 (3) | 0.043 (3) | 0.002 (3) | 0.001 (3) | −0.005 (2) |
| C14 | 0.044 (3) | 0.071 (3) | 0.063 (4) | −0.005 (2) | 0.002 (3) | −0.005 (3) |
| C15 | 0.045 (3) | 0.049 (3) | 0.059 (3) | 0.002 (2) | 0.010 (2) | 0.002 (2) |
| C16 | 0.062 (3) | 0.064 (3) | 0.044 (3) | −0.008 (3) | 0.008 (3) | −0.003 (2) |
| C17 | 0.045 (3) | 0.058 (3) | 0.051 (3) | −0.008 (2) | 0.008 (2) | −0.002 (2) |
| Cl18 | 0.0611 (8) | 0.0974 (10) | 0.0795 (10) | −0.0114 (7) | 0.0261 (7) | 0.0049 (8) |
| O19 | 0.070 (2) | 0.092 (3) | 0.044 (2) | −0.007 (2) | 0.0203 (19) | −0.0046 (19) |
| Br20 | 0.0535 (3) | 0.0522 (3) | 0.1076 (5) | 0.0021 (2) | 0.0364 (3) | 0.0067 (3) |
| O21 | 0.0570 (19) | 0.062 (2) | 0.042 (2) | −0.0063 (16) | 0.0098 (16) | −0.0054 (15) |
| C22 | 0.063 (3) | 0.056 (3) | 0.030 (3) | −0.005 (2) | 0.006 (2) | −0.001 (2) |
| C23 | 0.076 (3) | 0.055 (3) | 0.029 (3) | −0.001 (3) | 0.010 (3) | 0.007 (2) |
| C24 | 0.060 (3) | 0.045 (3) | 0.039 (3) | −0.001 (2) | 0.010 (2) | 0.006 (2) |
| C25 | 0.070 (3) | 0.047 (3) | 0.047 (3) | 0.004 (2) | 0.020 (3) | 0.007 (2) |
| C26 | 0.058 (3) | 0.047 (3) | 0.053 (3) | −0.003 (2) | 0.013 (3) | 0.013 (2) |
| C27 | 0.066 (3) | 0.058 (3) | 0.046 (3) | −0.008 (3) | 0.004 (3) | 0.000 (2) |
| C28 | 0.067 (3) | 0.061 (3) | 0.045 (3) | −0.004 (3) | 0.016 (3) | −0.006 (2) |
| C29 | 0.062 (3) | 0.049 (3) | 0.038 (3) | −0.005 (2) | 0.010 (2) | 0.002 (2) |
| C30 | 0.070 (3) | 0.051 (3) | 0.041 (3) | 0.000 (3) | 0.000 (3) | 0.003 (2) |
| O31 | 0.080 (2) | 0.088 (3) | 0.045 (2) | −0.006 (2) | 0.0018 (19) | −0.0140 (19) |
| C32 | 0.063 (3) | 0.050 (3) | 0.043 (3) | −0.005 (2) | 0.000 (3) | 0.000 (2) |
| C33 | 0.074 (3) | 0.066 (3) | 0.049 (3) | −0.012 (3) | −0.001 (3) | −0.011 (3) |
| C34 | 0.062 (3) | 0.090 (4) | 0.074 (4) | −0.019 (3) | 0.000 (3) | −0.010 (3) |
| C35 | 0.062 (3) | 0.073 (4) | 0.063 (4) | −0.012 (3) | 0.011 (3) | −0.004 (3) |
| C36 | 0.068 (3) | 0.086 (4) | 0.051 (3) | −0.017 (3) | 0.010 (3) | −0.014 (3) |
| C37 | 0.062 (3) | 0.071 (3) | 0.049 (3) | −0.016 (3) | 0.000 (3) | −0.006 (3) |
| Cl38 | 0.0789 (10) | 0.1375 (15) | 0.1097 (13) | −0.0319 (10) | 0.0336 (9) | −0.0211 (11) |
| O39 | 0.093 (3) | 0.084 (3) | 0.043 (2) | −0.009 (2) | 0.021 (2) | −0.0099 (18) |
| Br40 | 0.0627 (3) | 0.0649 (3) | 0.0813 (4) | −0.0056 (3) | 0.0145 (3) | 0.0078 (3) |

*Geometric parameters (Å, º)*

| | | | |
|---|---|---|---|
| O1—C2 | 1.398 (4) | O21—C22 | 1.400 (5) |
| O1—C9 | 1.373 (4) | O21—C29 | 1.367 (5) |

| | | | |
|---|---|---|---|
| C2—C3 | 1.366 (5) | C22—C23 | 1.352 (6) |
| C2—C10 | 1.431 (6) | C22—C30 | 1.427 (6) |
| C3—C4 | 1.421 (6) | C23—C24 | 1.432 (6) |
| C3—O19 | 1.332 (5) | C23—O39 | 1.345 (5) |
| C4—C5 | 1.395 (5) | C24—C25 | 1.393 (6) |
| C4—C9 | 1.392 (5) | C24—C29 | 1.392 (6) |
| C5—H5 | 0.9300 | C25—H25 | 0.9300 |
| C5—C6 | 1.364 (6) | C25—C26 | 1.364 (6) |
| C6—C7 | 1.389 (6) | C26—C27 | 1.397 (6) |
| C6—Br20 | 1.899 (4) | C26—Br40 | 1.902 (4) |
| C7—H7 | 0.9300 | C27—H27 | 0.9300 |
| C7—C8 | 1.389 (5) | C27—C28 | 1.374 (6) |
| C8—H8 | 0.9300 | C28—H28 | 0.9300 |
| C8—C9 | 1.384 (5) | C28—C29 | 1.378 (6) |
| C10—O11 | 1.256 (5) | C30—O31 | 1.268 (5) |
| C10—C12 | 1.473 (6) | C30—C32 | 1.469 (6) |
| C12—C13 | 1.394 (5) | C32—C33 | 1.388 (6) |
| C12—C17 | 1.383 (5) | C32—C37 | 1.395 (6) |
| C13—H13 | 0.9300 | C33—H33 | 0.9300 |
| C13—C14 | 1.369 (6) | C33—C34 | 1.365 (6) |
| C14—H14 | 0.9300 | C34—H34 | 0.9300 |
| C14—C15 | 1.373 (6) | C34—C35 | 1.369 (6) |
| C15—C16 | 1.370 (6) | C35—C36 | 1.376 (6) |
| C15—Cl18 | 1.738 (5) | C35—Cl38 | 1.724 (5) |
| C16—H16 | 0.9300 | C36—H36 | 0.9300 |
| C16—C17 | 1.374 (6) | C36—C37 | 1.366 (6) |
| C17—H17 | 0.9300 | C37—H37 | 0.9300 |
| O19—H19 | 0.86 (5) | O39—H39 | 0.90 (6) |

| | | | |
|---|---|---|---|
| C9—O1—C2 | 105.2 (3) | C29—O21—C22 | 105.3 (3) |
| O1—C2—C10 | 124.8 (4) | O21—C22—C30 | 124.2 (4) |
| C3—C2—O1 | 110.2 (4) | C23—C22—O21 | 109.9 (4) |
| C3—C2—C10 | 125.0 (4) | C23—C22—C30 | 125.9 (4) |
| C2—C3—C4 | 108.0 (4) | C22—C23—C24 | 108.7 (4) |
| O19—C3—C2 | 126.6 (4) | O39—C23—C22 | 126.1 (4) |
| O19—C3—C4 | 125.3 (4) | O39—C23—C24 | 125.2 (5) |
| C5—C4—C3 | 135.4 (4) | C25—C24—C23 | 136.3 (5) |
| C9—C4—C3 | 104.8 (4) | C29—C24—C23 | 103.9 (4) |
| C9—C4—C5 | 119.8 (4) | C29—C24—C25 | 119.8 (4) |
| C4—C5—H5 | 121.4 | C24—C25—H25 | 121.4 |
| C6—C5—C4 | 117.2 (4) | C26—C25—C24 | 117.2 (4) |
| C6—C5—H5 | 121.4 | C26—C25—H25 | 121.4 |
| C5—C6—C7 | 122.8 (4) | C25—C26—C27 | 122.7 (4) |
| C5—C6—Br20 | 118.5 (4) | C25—C26—Br40 | 119.7 (4) |
| C7—C6—Br20 | 118.8 (4) | C27—C26—Br40 | 117.7 (4) |
| C6—C7—H7 | 119.5 | C26—C27—H27 | 119.7 |
| C8—C7—C6 | 121.0 (4) | C28—C27—C26 | 120.6 (4) |
| C8—C7—H7 | 119.5 | C28—C27—H27 | 119.7 |

| | | | |
|---|---|---|---|
| C7—C8—H8 | 122.0 | C27—C28—H28 | 121.5 |
| C9—C8—C7 | 116.0 (4) | C27—C28—C29 | 116.9 (4) |
| C9—C8—H8 | 122.0 | C29—C28—H28 | 121.5 |
| O1—C9—C4 | 111.8 (4) | O21—C29—C24 | 112.1 (4) |
| O1—C9—C8 | 125.0 (4) | O21—C29—C28 | 125.0 (4) |
| C8—C9—C4 | 123.2 (4) | C28—C29—C24 | 122.8 (4) |
| C2—C10—C12 | 125.8 (4) | C22—C30—C32 | 126.1 (4) |
| O11—C10—C2 | 114.6 (4) | O31—C30—C22 | 114.3 (5) |
| O11—C10—C12 | 119.6 (4) | O31—C30—C32 | 119.6 (4) |
| C13—C12—C10 | 118.5 (4) | C33—C32—C30 | 119.3 (4) |
| C17—C12—C10 | 123.0 (4) | C33—C32—C37 | 117.1 (5) |
| C17—C12—C13 | 118.4 (4) | C37—C32—C30 | 123.6 (4) |
| C12—C13—H13 | 119.7 | C32—C33—H33 | 119.2 |
| C14—C13—C12 | 120.7 (4) | C34—C33—C32 | 121.6 (5) |
| C14—C13—H13 | 119.7 | C34—C33—H33 | 119.2 |
| C13—C14—H14 | 120.2 | C33—C34—H34 | 120.1 |
| C13—C14—C15 | 119.6 (4) | C33—C34—C35 | 119.8 (5) |
| C15—C14—H14 | 120.2 | C35—C34—H34 | 120.1 |
| C14—C15—Cl18 | 119.0 (4) | C34—C35—C36 | 120.4 (5) |
| C16—C15—C14 | 121.0 (4) | C34—C35—Cl38 | 120.4 (4) |
| C16—C15—Cl18 | 120.1 (4) | C36—C35—Cl38 | 119.2 (4) |
| C15—C16—H16 | 120.3 | C35—C36—H36 | 120.3 |
| C15—C16—C17 | 119.4 (4) | C37—C36—C35 | 119.4 (5) |
| C17—C16—H16 | 120.3 | C37—C36—H36 | 120.3 |
| C12—C17—H17 | 119.5 | C32—C37—H37 | 119.2 |
| C16—C17—C12 | 121.0 (4) | C36—C37—C32 | 121.6 (4) |
| C16—C17—H17 | 119.5 | C36—C37—H37 | 119.2 |
| C3—O19—H19 | 102 (4) | C23—O39—H39 | 99 (4) |

| | | | |
|---|---|---|---|
| O1—C2—C3—C4 | −1.0 (4) | O21—C22—C23—C24 | −1.3 (5) |
| O1—C2—C3—O19 | 179.5 (4) | O21—C22—C23—O39 | 179.0 (4) |
| O1—C2—C10—O11 | −176.3 (4) | O21—C22—C30—O31 | −177.9 (4) |
| O1—C2—C10—C12 | 5.1 (6) | O21—C22—C30—C32 | 3.6 (7) |
| C2—O1—C9—C4 | −0.1 (4) | C22—O21—C29—C24 | −0.6 (5) |
| C2—O1—C9—C8 | −179.6 (4) | C22—O21—C29—C28 | 179.4 (4) |
| C2—C3—C4—C5 | −178.8 (4) | C22—C23—C24—C25 | −177.8 (5) |
| C2—C3—C4—C9 | 0.8 (4) | C22—C23—C24—C29 | 0.9 (5) |
| C2—C10—C12—C13 | −169.9 (4) | C22—C30—C32—C33 | −178.1 (4) |
| C2—C10—C12—C17 | 12.6 (6) | C22—C30—C32—C37 | 3.8 (7) |
| C3—C2—C10—O11 | 4.6 (6) | C23—C22—C30—O31 | 2.3 (7) |
| C3—C2—C10—C12 | −174.0 (4) | C23—C22—C30—C32 | −176.2 (4) |
| C3—C4—C5—C6 | 179.7 (4) | C23—C24—C25—C26 | 178.5 (5) |
| C3—C4—C9—O1 | −0.5 (4) | C23—C24—C29—O21 | −0.1 (5) |
| C3—C4—C9—C8 | 179.1 (4) | C23—C24—C29—C28 | 179.9 (4) |
| C4—C5—C6—C7 | 1.0 (6) | C24—C25—C26—C27 | 0.7 (6) |
| C4—C5—C6—Br20 | −179.6 (3) | C24—C25—C26—Br40 | 179.6 (3) |
| C5—C4—C9—O1 | 179.3 (3) | C25—C24—C29—O21 | 178.8 (4) |
| C5—C4—C9—C8 | −1.2 (6) | C25—C24—C29—C28 | −1.2 (7) |

| | | | |
|---|---|---|---|
| C5—C6—C7—C8 | −1.0 (7) | C25—C26—C27—C28 | −0.3 (7) |
| C6—C7—C8—C9 | −0.1 (6) | C26—C27—C28—C29 | −0.8 (7) |
| C7—C8—C9—O1 | −179.4 (3) | C27—C28—C29—O21 | −178.4 (4) |
| C7—C8—C9—C4 | 1.2 (6) | C27—C28—C29—C24 | 1.6 (7) |
| C9—O1—C2—C3 | 0.7 (4) | C29—O21—C22—C23 | 1.1 (5) |
| C9—O1—C2—C10 | −178.5 (4) | C29—O21—C22—C30 | −178.7 (4) |
| C9—C4—C5—C6 | 0.1 (6) | C29—C24—C25—C26 | 0.0 (6) |
| C10—C2—C3—C4 | 178.2 (4) | C30—C22—C23—C24 | 178.6 (4) |
| C10—C2—C3—O19 | −1.3 (7) | C30—C22—C23—O39 | −1.2 (7) |
| C10—C12—C13—C14 | −177.4 (4) | C30—C32—C33—C34 | −179.2 (5) |
| C10—C12—C17—C16 | 176.6 (4) | C30—C32—C37—C36 | 178.5 (4) |
| O11—C10—C12—C13 | 11.6 (6) | O31—C30—C32—C33 | 3.5 (7) |
| O11—C10—C12—C17 | −166.0 (4) | O31—C30—C32—C37 | −174.6 (4) |
| C12—C13—C14—C15 | 0.2 (7) | C32—C33—C34—C35 | 0.9 (8) |
| C13—C12—C17—C16 | −1.0 (6) | C33—C32—C37—C36 | 0.4 (7) |
| C13—C14—C15—C16 | 0.0 (7) | C33—C34—C35—C36 | 0.0 (8) |
| C13—C14—C15—Cl18 | 179.8 (4) | C33—C34—C35—Cl38 | 179.4 (4) |
| C14—C15—C16—C17 | −0.8 (7) | C34—C35—C36—C37 | −0.6 (8) |
| C15—C16—C17—C12 | 1.3 (7) | C35—C36—C37—C32 | 0.4 (8) |
| C17—C12—C13—C14 | 0.3 (6) | C37—C32—C33—C34 | −1.0 (7) |
| Cl18—C15—C16—C17 | 179.5 (3) | Cl38—C35—C36—C37 | 180.0 (4) |
| O19—C3—C4—C5 | 0.7 (8) | O39—C23—C24—C25 | 2.0 (8) |
| O19—C3—C4—C9 | −179.6 (4) | O39—C23—C24—C29 | −179.4 (4) |
| Br20—C6—C7—C8 | 179.6 (3) | Br40—C26—C27—C28 | −179.2 (3) |

*Hydrogen-bond geometry (Å, º)*

| *D*—H···*A* | *D*—H | H···*A* | *D*···*A* | *D*—H···*A* |
|---|---|---|---|---|
| O19—H19···O11 | 0.86 (5) | 1.87 (5) | 2.631 (5) | 147 (5) |
| C17—H17···O1 | 0.93 | 2.29 | 2.951 (5) | 128 |
| O39—H39···O31 | 0.91 (6) | 1.80 (6) | 2.627 (6) | 150 (7) |
| C37—H37···O21 | 0.93 | 2.25 | 2.926 (6) | 129 |
| C36—H36···O11 | 0.93 | 2.40 | 3.235 (6) | 149 |
| C8—H8···O39$^{i}$ | 0.93 | 2.67 | 3.434 (6) | 140 |

Symmetry code: (i) $x$, $-y+1/2$, $z-1/2$.

### (5-Bromo-3-hydroxybenzofuran-2-yl)(4-bromophenyl)methanone (4c)

*Crystal data*

$C_{15}H_8Br_2O_3$
$M_r$ = 396.03
Triclinic, $P\overline{1}$
$a$ = 7.0725 (4) Å
$b$ = 7.0884 (5) Å
$c$ = 14.6069 (8) Å
$\alpha$ = 92.230 (5)°
$\beta$ = 103.091 (5)°
$\gamma$ = 101.219 (6)°
$V$ = 696.98 (8) Å$^3$

$Z$ = 2
$F(000)$ = 384
$D_x$ = 1.887 Mg m$^{-3}$
Mo $K\alpha$ radiation, $\lambda$ = 0.71073 Å
Cell parameters from 3969 reflections
$\theta$ = 2.9–25.0°
$\mu$ = 5.82 mm$^{-1}$
$T$ = 294 K
Plate, yellow
0.35 × 0.15 × 0.05 mm

*Data collection*

Rigaku OD SuperNova Single source diffractometer with an Eos detector
Radiation source: micro-focus sealed X-ray tube, SuperNova (Mo) X-ray Source
Mirror monochromator
Detector resolution: 15.9631 pixels mm$^{-1}$
$\omega$ scans
Absorption correction: multi-scan (CrysAlis PRO; Rigaku OD, 2018)
$T_{min}$ = 0.523, $T_{max}$ = 1.000
14183 measured reflections
2840 independent reflections
1867 reflections with $I > 2\sigma(I)$
$R_{int}$ = 0.046
$\theta_{max}$ = 26.4°, $\theta_{min}$ = 2.9°
$h$ = −8→8
$k$ = −8→8
$l$ = −18→18

*Refinement*

Refinement on $F^2$
Least-squares matrix: full
$R[F^2 > 2\sigma(F^2)]$ = 0.046
$wR(F^2)$ = 0.109
$S$ = 1.03
2840 reflections
185 parameters
0 restraints
Hydrogen site location: mixed
H atoms treated by a mixture of independent and constrained refinement
$w = 1/[\sigma^2(F_o^2) + (0.0415P)^2 + 0.4345P]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{max}$ = 0.001
$\Delta\rho_{max}$ = 0.44 e Å$^{-3}$
$\Delta\rho_{min}$ = −0.40 e Å$^{-3}$

*Special details*

**Geometry**. All esds (except the esd in the dihedral angle between two l.s. planes) are estimated using the full covariance matrix. The cell esds are taken into account individually in the estimation of esds in distances, angles and torsion angles; correlations between esds in cell parameters are only used when they are defined by crystal symmetry. An approximate (isotropic) treatment of cell esds is used for estimating esds involving l.s. planes.

*Fractional atomic coordinates and isotropic or equivalent isotropic displacement parameters (Å$^2$)*

| | $x$ | $y$ | $z$ | $U_{iso}$*/$U_{eq}$ |
|---|---|---|---|---|
| O1 | 0.2698 (4) | 0.5503 (4) | 0.38600 (19) | 0.0488 (7) |
| C2 | 0.2236 (6) | 0.3699 (6) | 0.4205 (3) | 0.0451 (10) |
| C3 | 0.1893 (6) | 0.2269 (6) | 0.3496 (3) | 0.0492 (10) |
| C4 | 0.2133 (6) | 0.3147 (6) | 0.2657 (3) | 0.0467 (10) |
| C5 | 0.1950 (6) | 0.2465 (7) | 0.1721 (3) | 0.0538 (11) |
| H5 | 0.162112 | 0.115376 | 0.152601 | 0.065* |
| C6 | 0.2283 (6) | 0.3842 (8) | 0.1110 (3) | 0.0603 (13) |
| C7 | 0.2745 (7) | 0.5815 (8) | 0.1380 (3) | 0.0644 (13) |
| H7 | 0.294088 | 0.668302 | 0.093245 | 0.077* |
| C8 | 0.2919 (7) | 0.6517 (7) | 0.2302 (3) | 0.0583 (12) |
| H8 | 0.322333 | 0.783073 | 0.249141 | 0.070* |
| C9 | 0.2605 (6) | 0.5113 (6) | 0.2925 (3) | 0.0470 (10) |
| C10 | 0.2117 (6) | 0.3412 (6) | 0.5157 (3) | 0.0471 (10) |
| O11 | 0.1679 (5) | 0.1689 (4) | 0.5325 (2) | 0.0672 (9) |
| C12 | 0.2445 (5) | 0.4957 (6) | 0.5920 (3) | 0.0432 (10) |
| C13 | 0.2243 (6) | 0.4393 (7) | 0.6802 (3) | 0.0528 (11) |
| H13 | 0.190559 | 0.308580 | 0.688378 | 0.063* |
| C14 | 0.2529 (6) | 0.5720 (7) | 0.7550 (3) | 0.0562 (12) |
| H14 | 0.239823 | 0.532483 | 0.813584 | 0.067* |
| C15 | 0.3015 (6) | 0.7652 (7) | 0.7422 (3) | 0.0516 (11) |
| C16 | 0.3218 (6) | 0.8272 (7) | 0.6564 (3) | 0.0538 (11) |

| | | | | |
|---|---|---|---|---|
| H16 | 0.354165 | 0.958359 | 0.648961 | 0.065* |
| C17 | 0.2934 (6) | 0.6921 (6) | 0.5815 (3) | 0.0485 (10) |
| H17 | 0.307233 | 0.732746 | 0.523116 | 0.058* |
| Br18 | 0.34142 (8) | 0.94907 (8) | 0.84645 (4) | 0.0757 (2) |
| O19 | 0.1385 (5) | 0.0365 (5) | 0.3552 (3) | 0.0671 (9) |
| Br20 | 0.20857 (10) | 0.30111 (10) | −0.01643 (4) | 0.0906 (3) |
| H19 | 0.127 (9) | 0.030 (8) | 0.411 (4) | 0.10 (2)* |

*Atomic displacement parameters (Å²)*

| | $U^{11}$ | $U^{22}$ | $U^{33}$ | $U^{12}$ | $U^{13}$ | $U^{23}$ |
|---|---|---|---|---|---|---|
| O1 | 0.0533 (18) | 0.0470 (17) | 0.0475 (16) | 0.0062 (14) | 0.0175 (13) | 0.0085 (13) |
| C2 | 0.044 (2) | 0.044 (3) | 0.048 (2) | 0.008 (2) | 0.0135 (19) | 0.009 (2) |
| C3 | 0.051 (3) | 0.048 (3) | 0.053 (3) | 0.011 (2) | 0.020 (2) | 0.010 (2) |
| C4 | 0.038 (2) | 0.053 (3) | 0.052 (3) | 0.011 (2) | 0.0147 (19) | 0.009 (2) |
| C5 | 0.051 (3) | 0.056 (3) | 0.055 (3) | 0.010 (2) | 0.015 (2) | 0.002 (2) |
| C6 | 0.054 (3) | 0.084 (4) | 0.044 (2) | 0.016 (3) | 0.012 (2) | 0.006 (3) |
| C7 | 0.064 (3) | 0.075 (4) | 0.056 (3) | 0.011 (3) | 0.019 (2) | 0.021 (3) |
| C8 | 0.067 (3) | 0.057 (3) | 0.052 (3) | 0.007 (2) | 0.021 (2) | 0.014 (2) |
| C9 | 0.040 (2) | 0.057 (3) | 0.046 (2) | 0.008 (2) | 0.0142 (19) | 0.007 (2) |
| C10 | 0.045 (3) | 0.049 (3) | 0.048 (2) | 0.010 (2) | 0.0123 (19) | 0.013 (2) |
| O11 | 0.099 (3) | 0.0453 (19) | 0.0565 (19) | 0.0070 (18) | 0.0227 (17) | 0.0145 (15) |
| C12 | 0.036 (2) | 0.052 (3) | 0.043 (2) | 0.010 (2) | 0.0116 (18) | 0.013 (2) |
| C13 | 0.056 (3) | 0.054 (3) | 0.053 (3) | 0.011 (2) | 0.018 (2) | 0.018 (2) |
| C14 | 0.056 (3) | 0.069 (3) | 0.047 (3) | 0.011 (2) | 0.018 (2) | 0.014 (2) |
| C15 | 0.046 (3) | 0.060 (3) | 0.049 (3) | 0.008 (2) | 0.013 (2) | 0.002 (2) |
| C16 | 0.055 (3) | 0.047 (3) | 0.058 (3) | 0.006 (2) | 0.013 (2) | 0.008 (2) |
| C17 | 0.050 (3) | 0.052 (3) | 0.044 (2) | 0.009 (2) | 0.0131 (19) | 0.011 (2) |
| Br18 | 0.0838 (4) | 0.0774 (4) | 0.0631 (3) | 0.0050 (3) | 0.0248 (3) | −0.0112 (3) |
| O19 | 0.102 (3) | 0.046 (2) | 0.059 (2) | 0.0128 (18) | 0.031 (2) | 0.0083 (16) |
| Br20 | 0.1167 (5) | 0.1131 (5) | 0.0462 (3) | 0.0303 (4) | 0.0227 (3) | 0.0072 (3) |

*Geometric parameters (Å, º)*

| | | | |
|---|---|---|---|
| O1—C2 | 1.399 (5) | C7—C8 | 1.387 (6) |
| O1—C9 | 1.368 (5) | C8—C9 | 1.394 (6) |
| C2—C3 | 1.367 (6) | C10—O11 | 1.248 (5) |
| C2—C10 | 1.432 (5) | C10—C12 | 1.478 (6) |
| C3—C4 | 1.425 (5) | C12—C13 | 1.394 (5) |
| C3—O19 | 1.338 (5) | C12—C17 | 1.391 (6) |
| C4—C5 | 1.400 (6) | C13—C14 | 1.365 (6) |
| C4—C9 | 1.387 (6) | C14—C15 | 1.376 (6) |
| C5—C6 | 1.370 (6) | C15—C16 | 1.372 (6) |
| C6—C7 | 1.393 (7) | C15—Br18 | 1.899 (4) |
| C6—Br20 | 1.896 (4) | C16—C17 | 1.379 (6) |
| | | | |
| C9—O1—C2 | 105.3 (3) | O1—C9—C4 | 112.3 (3) |
| O1—C2—C10 | 124.7 (4) | O1—C9—C8 | 124.3 (4) |

| | | | |
|---|---|---|---|
| C3—C2—O1 | 109.8 (3) | C4—C9—C8 | 123.4 (4) |
| C3—C2—C10 | 125.5 (4) | C2—C10—C12 | 125.6 (4) |
| C2—C3—C4 | 108.2 (4) | O11—C10—C2 | 114.9 (4) |
| O19—C3—C2 | 127.2 (4) | O11—C10—C12 | 119.5 (4) |
| O19—C3—C4 | 124.6 (4) | C13—C12—C10 | 117.3 (4) |
| C5—C4—C3 | 135.0 (4) | C17—C12—C10 | 124.5 (3) |
| C9—C4—C3 | 104.4 (4) | C17—C12—C13 | 118.2 (4) |
| C9—C4—C5 | 120.6 (4) | C14—C13—C12 | 121.3 (4) |
| C6—C5—C4 | 116.2 (4) | C13—C14—C15 | 119.0 (4) |
| C5—C6—C7 | 123.1 (4) | C14—C15—Br18 | 118.7 (3) |
| C5—C6—Br20 | 118.2 (4) | C16—C15—C14 | 121.6 (4) |
| C7—C6—Br20 | 118.7 (4) | C16—C15—Br18 | 119.6 (3) |
| C8—C7—C6 | 121.5 (4) | C15—C16—C17 | 119.0 (4) |
| C7—C8—C9 | 115.2 (5) | C16—C17—C12 | 120.8 (4) |

| | | | |
|---|---|---|---|
| O1—C2—C3—C4 | 0.0 (5) | C7—C8—C9—C4 | −0.6 (6) |
| O1—C2—C3—O19 | −179.0 (4) | C9—O1—C2—C3 | 0.5 (4) |
| O1—C2—C10—O11 | 179.8 (4) | C9—O1—C2—C10 | −178.7 (4) |
| O1—C2—C10—C12 | 0.5 (6) | C9—C4—C5—C6 | 0.6 (6) |
| C2—O1—C9—C4 | −0.8 (4) | C10—C2—C3—C4 | 179.2 (4) |
| C2—O1—C9—C8 | 178.3 (4) | C10—C2—C3—O19 | 0.2 (7) |
| C2—C3—C4—C5 | −178.7 (4) | C10—C12—C13—C14 | 179.6 (4) |
| C2—C3—C4—C9 | −0.4 (4) | C10—C12—C17—C16 | −179.9 (4) |
| C2—C10—C12—C13 | 179.3 (4) | O11—C10—C12—C13 | 0.0 (6) |
| C2—C10—C12—C17 | −0.6 (6) | O11—C10—C12—C17 | −179.9 (4) |
| C3—C2—C10—O11 | 0.7 (6) | C12—C13—C14—C15 | 0.4 (6) |
| C3—C2—C10—C12 | −178.6 (4) | C13—C12—C17—C16 | 0.2 (6) |
| C3—C4—C5—C6 | 178.7 (4) | C13—C14—C15—C16 | 0.0 (6) |
| C3—C4—C9—O1 | 0.8 (4) | C13—C14—C15—Br18 | −179.9 (3) |
| C3—C4—C9—C8 | −178.4 (4) | C14—C15—C16—C17 | −0.3 (6) |
| C4—C5—C6—C7 | −1.1 (6) | C15—C16—C17—C12 | 0.2 (6) |
| C4—C5—C6—Br20 | 179.3 (3) | C17—C12—C13—C14 | −0.5 (6) |
| C5—C4—C9—O1 | 179.4 (3) | Br18—C15—C16—C17 | 179.7 (3) |
| C5—C4—C9—C8 | 0.2 (6) | O19—C3—C4—C5 | 0.3 (7) |
| C5—C6—C7—C8 | 0.7 (7) | O19—C3—C4—C9 | 178.6 (4) |
| C6—C7—C8—C9 | 0.2 (7) | Br20—C6—C7—C8 | −179.7 (3) |
| C7—C8—C9—O1 | −179.7 (4) | | |

*Hydrogen-bond geometry (Å, º)*

| *D*—H···*A* | *D*—H | H···*A* | *D*···*A* | *D*—H···*A* |
|---|---|---|---|---|
| O19—H19···O11 | 0.84 (6) | 1.93 (6) | 2.669 (5) | 146 (5) |
| C17—H17···O1 | 0.93 | 2.28 | 2.948 (5) | 129 |
| O19—H19···O11$^{i}$ | 0.84 (6) | 2.60 (6) | 3.174 (5) | 127 |
| C14—H14···Br20$^{ii}$ | 0.93 | 3.05 | 3.959 (5) | 165 |
| C16—H16···O11$^{iii}$ | 0.93 | 2.61 | 3.287 (6) | 130 |

Symmetry codes: (i) −*x*, −*y*, −*z*+1; (ii) *x*, *y*, *z*+1; (iii) *x*, *y*+1, *z*.

**(4-Bromophenyl)(3-hydroxy-5-iodobenzofuran-2-yl)methanone (4h)**

*Crystal data*

$C_{15}H_8BrIO_3$
$M_r = 443.02$
Monoclinic, $I2/a$
$a = 26.4214$ (8) Å
$b = 4.76309$ (13) Å
$c = 46.6213$ (14) Å
$\beta = 106.034$ (3)°
$V = 5638.9$ (3) Å$^3$
$Z = 16$
$F(000) = 3360$
$D_x = 2.087$ Mg m$^{-3}$
Mo $K\alpha$ radiation, $\lambda = 0.71073$ Å
Cell parameters from 11835 reflections
$\theta = 2.7$–$27.2°$
$\mu = 5.11$ mm$^{-1}$
$T = 293$ K
Needle, yellow
0.35 × 0.15 × 0.05 mm

*Data collection*

Rigaku OD SuperNova Single source diffractometer with an Eos detector
Radiation source: micro-focus sealed X-ray tube, SuperNova (Mo) X-ray Source
Mirror monochromator
Detector resolution: 15.9631 pixels mm$^{-1}$
$\omega$ scans
Absorption correction: gaussian (CrysAlis PRO; Rigaku OD, 2018)
$T_{min} = 0.582$, $T_{max} = 1.000$
30966 measured reflections
5733 independent reflections
4448 reflections with $I > 2\sigma(I)$
$R_{int} = 0.036$
$\theta_{max} = 26.4°$, $\theta_{min} = 2.7°$
$h = -32 \rightarrow 33$
$k = -5 \rightarrow 5$
$l = -58 \rightarrow 58$

*Refinement*

Refinement on $F^2$
Least-squares matrix: full
$R[F^2 > 2\sigma(F^2)] = 0.048$
$wR(F^2) = 0.123$
$S = 1.07$
5733 reflections
369 parameters
2 restraints
Primary atom site location: dual
Hydrogen site location: mixed
H atoms treated by a mixture of independent and constrained refinement
$w = 1/[\sigma^2(F_o^2) + (0.0486P)^2 + 38.6563P]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{max} = 0.002$
$\Delta\rho_{max} = 1.78$ e Å$^{-3}$
$\Delta\rho_{min} = -1.21$ e Å$^{-3}$

*Special details*

**Geometry**. All esds (except the esd in the dihedral angle between two l.s. planes) are estimated using the full covariance matrix. The cell esds are taken into account individually in the estimation of esds in distances, angles and torsion angles; correlations between esds in cell parameters are only used when they are defined by crystal symmetry. An approximate (isotropic) treatment of cell esds is used for estimating esds involving l.s. planes.

*Fractional atomic coordinates and isotropic or equivalent isotropic displacement parameters (Å$^2$)*

| | $x$ | $y$ | $z$ | $U_{iso}$*/$U_{eq}$ |
|---|---|---|---|---|
| O1 | 0.31437 (17) | −0.1296 (9) | 0.62348 (9) | 0.0509 (10) |
| C2 | 0.3471 (2) | 0.0161 (13) | 0.60926 (12) | 0.0440 (14) |
| C3 | 0.3360 (2) | −0.0703 (13) | 0.58016 (13) | 0.0442 (14) |
| C4 | 0.2954 (2) | −0.2773 (12) | 0.57509 (12) | 0.0423 (13) |
| C5 | 0.2670 (2) | −0.4364 (13) | 0.55069 (14) | 0.0501 (15) |
| H5 | 0.274146 | −0.425178 | 0.532280 | 0.060* |
| C6 | 0.2279 (3) | −0.6110 (14) | 0.55498 (14) | 0.0519 (16) |
| C7 | 0.2174 (3) | −0.6343 (15) | 0.58299 (16) | 0.0606 (18) |
| H7 | 0.191032 | −0.755200 | 0.585119 | 0.073* |

| | | | | |
|---|---|---|---|---|
| C8 | 0.2457 (3) | −0.4804 (15) | 0.60729 (15) | 0.0592 (18) |
| H8 | 0.239390 | −0.496240 | 0.625887 | 0.071* |
| C9 | 0.2837 (3) | −0.3023 (13) | 0.60254 (14) | 0.0489 (15) |
| C10 | 0.3842 (2) | 0.2278 (13) | 0.62289 (13) | 0.0426 (13) |
| O11 | 0.40906 (18) | 0.3384 (10) | 0.60636 (9) | 0.0561 (11) |
| C12 | 0.3956 (2) | 0.3180 (12) | 0.65444 (13) | 0.0434 (13) |
| C13 | 0.4331 (3) | 0.5229 (15) | 0.66462 (15) | 0.0568 (17) |
| H13 | 0.449736 | 0.602010 | 0.651387 | 0.068* |
| C14 | 0.4469 (3) | 0.6151 (15) | 0.69416 (15) | 0.0577 (17) |
| H14 | 0.473533 | 0.746849 | 0.700905 | 0.069* |
| C15 | 0.4200 (3) | 0.5055 (14) | 0.71317 (13) | 0.0505 (15) |
| C16 | 0.3822 (3) | 0.3006 (14) | 0.70382 (14) | 0.0536 (16) |
| H16 | 0.365082 | 0.225725 | 0.717047 | 0.064* |
| C17 | 0.3699 (3) | 0.2079 (14) | 0.67478 (15) | 0.0533 (16) |
| H17 | 0.344307 | 0.070224 | 0.668447 | 0.064* |
| Br18 | 0.43363 (3) | 0.64613 (18) | 0.75258 (2) | 0.0687 (2) |
| O19 | 0.3584 (2) | 0.0240 (12) | 0.55955 (10) | 0.0569 (12) |
| I20 | 0.18141 (2) | −0.84287 (11) | 0.51858 (2) | 0.06610 (17) |
| O21 | 0.59407 (16) | 0.3302 (9) | 0.61452 (9) | 0.0479 (10) |
| C22 | 0.5739 (2) | 0.3006 (13) | 0.63934 (13) | 0.0447 (14) |
| C23 | 0.5344 (2) | 0.1034 (13) | 0.63325 (13) | 0.0450 (14) |
| C24 | 0.5269 (2) | 0.0073 (12) | 0.60347 (13) | 0.0448 (14) |
| C25 | 0.4916 (2) | −0.1762 (14) | 0.58424 (13) | 0.0481 (14) |
| H25 | 0.466170 | −0.274141 | 0.590511 | 0.058* |
| C26 | 0.4964 (3) | −0.2045 (14) | 0.55608 (14) | 0.0507 (15) |
| C27 | 0.5355 (3) | −0.0663 (15) | 0.54646 (14) | 0.0560 (16) |
| H27 | 0.538039 | −0.097817 | 0.527223 | 0.067* |
| C28 | 0.5702 (3) | 0.1147 (15) | 0.56484 (15) | 0.0571 (17) |
| H28 | 0.596072 | 0.208781 | 0.558524 | 0.069* |
| C29 | 0.5646 (2) | 0.1500 (13) | 0.59361 (13) | 0.0459 (14) |
| C30 | 0.5924 (2) | 0.4426 (14) | 0.66678 (13) | 0.0473 (14) |
| O31 | 0.57006 (18) | 0.3832 (11) | 0.68662 (10) | 0.0601 (12) |
| C32 | 0.6364 (2) | 0.6516 (13) | 0.67412 (13) | 0.0456 (14) |
| C33 | 0.6541 (3) | 0.7459 (17) | 0.70387 (15) | 0.066 (2) |
| H33 | 0.637978 | 0.682757 | 0.718059 | 0.079* |
| C34 | 0.6958 (3) | 0.9338 (17) | 0.71181 (16) | 0.069 (2) |
| H34 | 0.707602 | 0.996950 | 0.731405 | 0.082* |
| C35 | 0.7195 (2) | 1.0266 (14) | 0.69098 (15) | 0.0523 (16) |
| C36 | 0.7020 (3) | 0.9403 (15) | 0.66182 (16) | 0.0592 (17) |
| H36 | 0.717881 | 1.008713 | 0.647729 | 0.071* |
| C37 | 0.6611 (3) | 0.7523 (14) | 0.65349 (14) | 0.0504 (15) |
| H37 | 0.649775 | 0.691805 | 0.633777 | 0.061* |
| Br38 | 0.77726 (3) | 1.27828 (18) | 0.70198 (2) | 0.0785 (3) |
| O39 | 0.50813 (19) | 0.0169 (11) | 0.65218 (11) | 0.0583 (12) |
| I40 | 0.43898 (2) | −0.44310 (11) | 0.52517 (2) | 0.06144 (16) |
| H39 | 0.521 (4) | 0.109 (19) | 0.6664 (11) | 0.14 (5)* |
| H19 | 0.372 (4) | 0.16 (2) | 0.566 (2) | 0.12 (4)* |

*Atomic displacement parameters (Å²)*

| | $U^{11}$ | $U^{22}$ | $U^{33}$ | $U^{12}$ | $U^{13}$ | $U^{23}$ |
|---|---|---|---|---|---|---|
| O1 | 0.063 (3) | 0.050 (3) | 0.040 (2) | −0.011 (2) | 0.016 (2) | −0.0027 (19) |
| C2 | 0.050 (3) | 0.047 (4) | 0.035 (3) | 0.001 (3) | 0.012 (3) | 0.002 (3) |
| C3 | 0.046 (3) | 0.043 (3) | 0.044 (3) | 0.010 (3) | 0.012 (3) | 0.008 (3) |
| C4 | 0.047 (3) | 0.040 (3) | 0.038 (3) | 0.008 (3) | 0.008 (3) | 0.003 (2) |
| C5 | 0.052 (4) | 0.048 (4) | 0.047 (3) | 0.014 (3) | 0.009 (3) | 0.006 (3) |
| C6 | 0.050 (4) | 0.045 (4) | 0.052 (4) | 0.003 (3) | 0.000 (3) | −0.002 (3) |
| C7 | 0.063 (4) | 0.053 (4) | 0.064 (4) | −0.009 (3) | 0.014 (4) | 0.001 (3) |
| C8 | 0.075 (5) | 0.055 (4) | 0.051 (4) | −0.013 (4) | 0.022 (3) | −0.004 (3) |
| C9 | 0.058 (4) | 0.041 (4) | 0.048 (3) | 0.000 (3) | 0.014 (3) | −0.001 (3) |
| C10 | 0.047 (3) | 0.041 (3) | 0.043 (3) | 0.006 (3) | 0.017 (3) | 0.007 (3) |
| O11 | 0.060 (3) | 0.063 (3) | 0.047 (2) | −0.010 (2) | 0.016 (2) | 0.003 (2) |
| C12 | 0.041 (3) | 0.039 (3) | 0.050 (3) | −0.002 (3) | 0.013 (3) | 0.003 (3) |
| C13 | 0.058 (4) | 0.059 (4) | 0.055 (4) | −0.011 (3) | 0.020 (3) | 0.000 (3) |
| C14 | 0.061 (4) | 0.058 (4) | 0.054 (4) | −0.015 (3) | 0.017 (3) | −0.006 (3) |
| C15 | 0.061 (4) | 0.047 (4) | 0.041 (3) | 0.005 (3) | 0.009 (3) | −0.001 (3) |
| C16 | 0.061 (4) | 0.058 (4) | 0.046 (3) | −0.009 (3) | 0.021 (3) | 0.000 (3) |
| C17 | 0.058 (4) | 0.048 (4) | 0.055 (4) | −0.010 (3) | 0.017 (3) | 0.000 (3) |
| Br18 | 0.0813 (5) | 0.0782 (5) | 0.0436 (4) | −0.0039 (4) | 0.0122 (3) | −0.0089 (3) |
| O19 | 0.061 (3) | 0.070 (3) | 0.041 (2) | −0.005 (3) | 0.016 (2) | −0.003 (2) |
| I20 | 0.0611 (3) | 0.0597 (3) | 0.0616 (3) | 0.0046 (2) | −0.0096 (2) | −0.0056 (2) |
| O21 | 0.047 (2) | 0.052 (3) | 0.047 (2) | −0.009 (2) | 0.0178 (19) | −0.005 (2) |
| C22 | 0.046 (3) | 0.045 (4) | 0.042 (3) | 0.000 (3) | 0.011 (3) | 0.003 (3) |
| C23 | 0.044 (3) | 0.047 (4) | 0.046 (3) | 0.001 (3) | 0.016 (3) | 0.008 (3) |
| C24 | 0.047 (3) | 0.038 (3) | 0.048 (3) | 0.001 (3) | 0.011 (3) | 0.005 (3) |
| C25 | 0.045 (3) | 0.049 (4) | 0.047 (3) | −0.001 (3) | 0.009 (3) | 0.002 (3) |
| C26 | 0.050 (4) | 0.045 (4) | 0.050 (4) | 0.001 (3) | 0.003 (3) | −0.005 (3) |
| C27 | 0.061 (4) | 0.063 (4) | 0.045 (3) | −0.004 (3) | 0.016 (3) | −0.006 (3) |
| C28 | 0.062 (4) | 0.062 (4) | 0.054 (4) | −0.009 (3) | 0.025 (3) | −0.010 (3) |
| C29 | 0.047 (3) | 0.044 (3) | 0.047 (3) | −0.005 (3) | 0.015 (3) | −0.003 (3) |
| C30 | 0.046 (3) | 0.049 (4) | 0.046 (3) | 0.005 (3) | 0.012 (3) | 0.003 (3) |
| O31 | 0.065 (3) | 0.072 (3) | 0.046 (2) | −0.007 (2) | 0.020 (2) | 0.003 (2) |
| C32 | 0.044 (3) | 0.042 (3) | 0.048 (3) | 0.003 (3) | 0.008 (3) | −0.004 (3) |
| C33 | 0.079 (5) | 0.076 (5) | 0.045 (4) | −0.009 (4) | 0.021 (4) | −0.015 (4) |
| C34 | 0.069 (5) | 0.080 (5) | 0.050 (4) | −0.005 (4) | 0.006 (4) | −0.030 (4) |
| C35 | 0.044 (3) | 0.049 (4) | 0.061 (4) | 0.006 (3) | 0.011 (3) | −0.014 (3) |
| C36 | 0.059 (4) | 0.055 (4) | 0.068 (4) | −0.010 (3) | 0.025 (4) | −0.010 (3) |
| C37 | 0.054 (4) | 0.053 (4) | 0.045 (3) | −0.004 (3) | 0.016 (3) | −0.007 (3) |
| Br38 | 0.0571 (4) | 0.0704 (5) | 0.1037 (6) | −0.0097 (4) | 0.0152 (4) | −0.0352 (5) |
| O39 | 0.066 (3) | 0.060 (3) | 0.051 (3) | −0.012 (2) | 0.019 (2) | 0.004 (2) |
| I40 | 0.0614 (3) | 0.0613 (3) | 0.0563 (3) | −0.0061 (2) | 0.0073 (2) | −0.0138 (2) |

*Geometric parameters (Å, º)*

| | | | |
|---|---|---|---|
| O1—C2 | 1.410 (7) | O21—C22 | 1.409 (7) |
| O1—C9 | 1.360 (7) | O21—C29 | 1.369 (7) |

| | | | |
|---|---|---|---|
| C2—C3 | 1.370 (8) | C22—C23 | 1.373 (9) |
| C2—C10 | 1.427 (9) | C22—C30 | 1.410 (9) |
| C3—C4 | 1.427 (9) | C23—C24 | 1.423 (8) |
| C3—O19 | 1.339 (7) | C23—O39 | 1.330 (7) |
| C4—C5 | 1.400 (9) | C24—C25 | 1.404 (9) |
| C4—C9 | 1.402 (8) | C24—C29 | 1.385 (8) |
| C5—H5 | 0.9300 | C25—H25 | 0.9300 |
| C5—C6 | 1.383 (9) | C25—C26 | 1.360 (9) |
| C6—C7 | 1.412 (10) | C26—C27 | 1.399 (9) |
| C6—I20 | 2.111 (6) | C26—I40 | 2.112 (6) |
| C7—H7 | 0.9300 | C27—H27 | 0.9300 |
| C7—C8 | 1.383 (9) | C27—C28 | 1.373 (9) |
| C8—H8 | 0.9300 | C28—H28 | 0.9300 |
| C8—C9 | 1.379 (9) | C28—C29 | 1.400 (9) |
| C10—O11 | 1.258 (7) | C30—O31 | 1.260 (7) |
| C10—C12 | 1.481 (8) | C30—C32 | 1.495 (9) |
| C12—C13 | 1.379 (9) | C32—C33 | 1.409 (9) |
| C12—C17 | 1.410 (8) | C32—C37 | 1.388 (9) |
| C13—H13 | 0.9300 | C33—H33 | 0.9300 |
| C13—C14 | 1.395 (9) | C33—C34 | 1.388 (11) |
| C14—H14 | 0.9300 | C34—H34 | 0.9300 |
| C14—C15 | 1.383 (9) | C34—C35 | 1.367 (10) |
| C15—C16 | 1.378 (9) | C35—C36 | 1.372 (9) |
| C15—Br18 | 1.894 (6) | C35—Br38 | 1.897 (7) |
| C16—H16 | 0.9300 | C36—H36 | 0.9300 |
| C16—C17 | 1.375 (9) | C36—C37 | 1.376 (9) |
| C17—H17 | 0.9300 | C37—H37 | 0.9300 |
| O19—H19 | 0.78 (11) | O39—H39 | 0.79 (2) |

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|---|---|---|---|
| C9—O1—C2 | 106.3 (4) | C29—O21—C22 | 104.6 (4) |
| O1—C2—C10 | 125.0 (5) | O21—C22—C30 | 125.5 (5) |
| C3—C2—O1 | 109.0 (5) | C23—C22—O21 | 109.7 (5) |
| C3—C2—C10 | 126.0 (6) | C23—C22—C30 | 124.7 (6) |
| C2—C3—C4 | 108.6 (5) | C22—C23—C24 | 108.4 (5) |
| O19—C3—C2 | 126.4 (6) | O39—C23—C22 | 125.5 (6) |
| O19—C3—C4 | 125.1 (6) | O39—C23—C24 | 126.1 (6) |
| C5—C4—C3 | 135.9 (6) | C25—C24—C23 | 135.4 (6) |
| C5—C4—C9 | 119.5 (6) | C29—C24—C23 | 104.3 (5) |
| C9—C4—C3 | 104.6 (5) | C29—C24—C25 | 120.3 (6) |
| C4—C5—H5 | 121.2 | C24—C25—H25 | 121.4 |
| C6—C5—C4 | 117.5 (6) | C26—C25—C24 | 117.2 (6) |
| C6—C5—H5 | 121.2 | C26—C25—H25 | 121.4 |
| C5—C6—C7 | 121.8 (6) | C25—C26—C27 | 122.4 (6) |
| C5—C6—I20 | 119.4 (5) | C25—C26—I40 | 118.2 (5) |
| C7—C6—I20 | 118.9 (5) | C27—C26—I40 | 119.3 (5) |
| C6—C7—H7 | 119.5 | C26—C27—H27 | 119.3 |
| C8—C7—C6 | 121.1 (7) | C28—C27—C26 | 121.4 (6) |
| C8—C7—H7 | 119.5 | C28—C27—H27 | 119.3 |

| | | | |
|---|---|---|---|
| C7—C8—H8 | 121.7 | C27—C28—H28 | 121.8 |
| C9—C8—C7 | 116.6 (6) | C27—C28—C29 | 116.3 (6) |
| C9—C8—H8 | 121.7 | C29—C28—H28 | 121.8 |
| O1—C9—C4 | 111.5 (5) | O21—C29—C24 | 113.1 (5) |
| O1—C9—C8 | 124.9 (6) | O21—C29—C28 | 124.5 (6) |
| C8—C9—C4 | 123.6 (6) | C24—C29—C28 | 122.4 (6) |
| C2—C10—C12 | 125.0 (5) | C22—C30—C32 | 125.5 (6) |
| O11—C10—C2 | 115.7 (5) | O31—C30—C22 | 116.2 (6) |
| O11—C10—C12 | 119.3 (6) | O31—C30—C32 | 118.3 (6) |
| C13—C12—C10 | 118.4 (5) | C33—C32—C30 | 117.6 (6) |
| C13—C12—C17 | 117.7 (6) | C37—C32—C30 | 123.7 (5) |
| C17—C12—C10 | 123.8 (6) | C37—C32—C33 | 118.7 (6) |
| C12—C13—H13 | 119.0 | C32—C33—H33 | 120.3 |
| C12—C13—C14 | 122.0 (6) | C34—C33—C32 | 119.4 (7) |
| C14—C13—H13 | 119.0 | C34—C33—H33 | 120.3 |
| C13—C14—H14 | 120.9 | C33—C34—H34 | 119.8 |
| C15—C14—C13 | 118.3 (6) | C35—C34—C33 | 120.3 (6) |
| C15—C14—H14 | 120.9 | C35—C34—H34 | 119.8 |
| C14—C15—Br18 | 119.6 (5) | C34—C35—C36 | 120.8 (6) |
| C16—C15—C14 | 121.4 (6) | C34—C35—Br38 | 120.3 (5) |
| C16—C15—Br18 | 118.9 (5) | C36—C35—Br38 | 118.8 (5) |
| C15—C16—H16 | 120.3 | C35—C36—H36 | 120.1 |
| C17—C16—C15 | 119.4 (6) | C35—C36—C37 | 119.9 (7) |
| C17—C16—H16 | 120.3 | C37—C36—H36 | 120.1 |
| C12—C17—H17 | 119.4 | C32—C37—H37 | 119.6 |
| C16—C17—C12 | 121.1 (6) | C36—C37—C32 | 120.8 (6) |
| C16—C17—H17 | 119.4 | C36—C37—H37 | 119.6 |
| C3—O19—H19 | 104 (8) | C23—O39—H39 | 101 (4) |

| | | | |
|---|---|---|---|
| O1—C2—C3—C4 | −0.3 (7) | O21—C22—C23—C24 | −2.1 (7) |
| O1—C2—C3—O19 | 178.9 (6) | O21—C22—C23—O39 | 177.5 (6) |
| O1—C2—C10—O11 | −178.5 (5) | O21—C22—C30—O31 | −178.4 (6) |
| O1—C2—C10—C12 | 2.8 (10) | O21—C22—C30—C32 | 0.7 (10) |
| C2—O1—C9—C4 | 0.5 (7) | C22—O21—C29—C24 | 0.0 (7) |
| C2—O1—C9—C8 | −179.4 (6) | C22—O21—C29—C28 | 178.5 (6) |
| C2—C3—C4—C5 | 178.4 (7) | C22—C23—C24—C25 | −175.9 (7) |
| C2—C3—C4—C9 | 0.6 (7) | C22—C23—C24—C29 | 2.0 (7) |
| C2—C10—C12—C13 | 179.0 (6) | C22—C30—C32—C33 | −172.1 (6) |
| C2—C10—C12—C17 | −1.4 (10) | C22—C30—C32—C37 | 6.6 (10) |
| C3—C2—C10—O11 | −1.4 (9) | C23—C22—C30—O31 | −1.0 (9) |
| C3—C2—C10—C12 | 179.9 (6) | C23—C22—C30—C32 | 178.1 (6) |
| C3—C4—C5—C6 | −177.0 (6) | C23—C24—C25—C26 | 177.4 (7) |
| C3—C4—C9—O1 | −0.7 (7) | C23—C24—C29—O21 | −1.2 (7) |
| C3—C4—C9—C8 | 179.2 (6) | C23—C24—C29—C28 | −179.8 (6) |
| C4—C5—C6—C7 | −1.4 (9) | C24—C25—C26—C27 | 2.1 (10) |
| C4—C5—C6—I20 | 177.3 (4) | C24—C25—C26—I40 | −173.4 (4) |
| C5—C4—C9—O1 | −178.9 (5) | C25—C24—C29—O21 | 177.1 (5) |
| C5—C4—C9—C8 | 1.0 (10) | C25—C24—C29—C28 | −1.5 (10) |

| | | | |
|---|---|---|---|
| C5—C6—C7—C8 | 0.6 (11) | C25—C26—C27—C28 | −2.5 (11) |
| C6—C7—C8—C9 | 0.9 (11) | C26—C27—C28—C29 | 0.7 (10) |
| C7—C8—C9—O1 | 178.2 (6) | C27—C28—C29—O21 | −177.1 (6) |
| C7—C8—C9—C4 | −1.7 (11) | C27—C28—C29—C24 | 1.2 (10) |
| C9—O1—C2—C3 | −0.1 (7) | C29—O21—C22—C23 | 1.3 (6) |
| C9—O1—C2—C10 | 177.4 (6) | C29—O21—C22—C30 | 179.0 (6) |
| C9—C4—C5—C6 | 0.6 (9) | C29—C24—C25—C26 | −0.2 (9) |
| C10—C2—C3—C4 | −177.8 (6) | C30—C22—C23—C24 | −179.8 (6) |
| C10—C2—C3—O19 | 1.4 (10) | C30—C22—C23—O39 | −0.2 (10) |
| C10—C12—C13—C14 | −178.6 (6) | C30—C32—C33—C34 | 178.2 (7) |
| C10—C12—C17—C16 | −179.9 (6) | C30—C32—C37—C36 | −178.7 (6) |
| O11—C10—C12—C13 | 0.4 (9) | O31—C30—C32—C33 | 7.0 (9) |
| O11—C10—C12—C17 | 179.9 (6) | O31—C30—C32—C37 | −174.3 (6) |
| C12—C13—C14—C15 | −3.2 (11) | C32—C33—C34—C35 | 0.0 (12) |
| C13—C12—C17—C16 | −0.3 (10) | C33—C32—C37—C36 | 0.0 (10) |
| C13—C14—C15—C16 | 3.1 (11) | C33—C34—C35—C36 | 1.2 (11) |
| C13—C14—C15—Br18 | −175.1 (5) | C33—C34—C35—Br38 | −178.9 (6) |
| C14—C15—C16—C17 | −1.7 (10) | C34—C35—C36—C37 | −1.7 (11) |
| C15—C16—C17—C12 | 0.3 (10) | C35—C36—C37—C32 | 1.1 (11) |
| C17—C12—C13—C14 | 1.8 (10) | C37—C32—C33—C34 | −0.6 (11) |
| Br18—C15—C16—C17 | 176.5 (5) | Br38—C35—C36—C37 | 178.3 (5) |
| O19—C3—C4—C5 | −0.8 (11) | O39—C23—C24—C25 | 4.5 (12) |
| O19—C3—C4—C9 | −178.6 (6) | O39—C23—C24—C29 | −177.6 (6) |
| I20—C6—C7—C8 | −178.1 (6) | I40—C26—C27—C28 | 173.0 (5) |

*Hydrogen-bond geometry (Å, º)*

| *D*—H···*A* | *D*—H | H···*A* | *D*···*A* | *D*—H···*A* |
|---|---|---|---|---|
| O19—H19···O11 | 0.76 (10) | 2.05 (9) | 2.680 (7) | 140 (9) |
| C17—H17···O1 | 0.93 | 2.24 | 2.919 (8) | 129 |
| O39—H39···O31 | 0.79 (7) | 1.90 (9) | 2.617 (7) | 151 |
| C37—H37···O21 | 0.93 | 2.28 | 2.950 (8) | 128 |
| C13—H13···O39$^{i}$ | 0.93 | 2.50 | 3.231 (9) | 135 |

Symmetry code: (i) *x*, *y*+1, *z*.