Bioorganic Chemistry 44 (2012) 35–41

Contents lists available at SciVerse ScienceDirect

Bioorganic Chemistry

journal homepage: www.elsevier.com/locate/bioorg

Activity of 6-aryl-pyrrolo[2,3-*d*]pyrimidine-4-amines to *Tetrahymena*

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ARTICLE INFO

Article history:
Received 16 April 2012
Available online 6 July 2012

Keywords:
Pyrrolopyrimidine
Antiprotozoal agent
Tetrahymena
Kinase
Benzylamine

ABSTRACT

A series 6-aryl-pyrrolo[2,3-*d*]pyrimidine-4-amines (43 compounds), some of which are epidermal growth factor tyrosine kinase inhibitors, were tested for their protozoal toxicity using an environmental *Tetrahymena* strain as model organism. The protozoacidal activity of the analogues was found to be highly dependent on a 4-hydroxyl group at the 6-aryl ring, and a chiral 1-phenylethanamine substituent in position 4. Further, the potency was affected by the aromatic substitution pattern of the phenylethanamine: the unsubstituted, the *meta*-fluoro and the *para*-bromo substituted derivatives had the lowest minimum protozoacidal concentrations (8–16 μg/mL). Surprisingly, both enantiomers were found to have high potency suggesting that this compound class could have several modes of action. No correlation was found between the compounds protozoacidal activity and the *in vitro* epidermal growth factor receptor tyrosine kinase inhibitory potency. This suggests that the observed antimicrobial effects are related to other targets. Testing towards a panel of kinases indicated several alternative modes of action.

1. Introduction

Diseases caused by parasitic protozoa, as for instance malaria, dysentery, leishmaniasis, and human African trypanosomiasis are major causes of mortality throughout the world, thus, the study of effects of organic compounds on protozoa is important. Therapeutic agents are available [1,2] however, many of the drugs have critical side effects [3,4] and also resistance is emerging [5,6]. Therefore, identification of new lead compounds is required, and inhibition of cellular kinase activity has been recognised as a useful strategy [7–11]. Among others, tyrosine kinase inhibitors such as Erlotinib, Canertinib and Sunitinib designed for cancer chemotherapy have been identified as efficient antiprotozoal agents [11].

Tetrahymena is a genus of ciliated protozoa. Its members are easily grown and relatively safe to handle making them useful model systems for biochemical mechanistic studies in eukaryotes [12]. The motility behaviour of *Tetrahymena* is conveniently used to monitor bioactivity and cell toxicity of chemicals [13–15]. Compounds such as diphenols, aminophenols, diaminoaromatics, halogenated aromatic nitro compounds, aromatic aldehydes and α-haloketones are generally toxic to *Tetrahymena*. This is due to their ability to undergo various reactions with biomacromolecules [16–19]. *Tetrahymena* do not pose a serious threat to human health. However, *Legionella* in symbiosis with *Tetrahymena tropicalis* appears more resistant and aggressive [20,21]. In addition, infections attributed to members of this genus are a problem in closed fish farming. Low molecular weight compounds such as Menadione (**I**) [22], and anti-infective agents such as Niclosamide (**II**) have been proposed as treatment alternatives [23]. Other compounds with *in vitro* activity towards *Tetrahymena* include among others Climacostol (**III**) [24], known antimicrobial agents as Chloroquine [25] and Chloroamphenicol [26,27] and antineoplastics such as Necodazole [28], Fig. 1.

Tetrahymena are known to have epidermal growth factor (EGF)-like receptors which are involved in cell division [29], and cyst formation [30]. Also other processes such as chemotaxis [31], hormonal imprinting [32], cell division [33,34], stress response [34,35], and GTP signalling [36], are triggered and controlled by kinase activity. Using an environmental *Tetrahymena* isolate as model, we have evaluated the potency of a series of 6-aryl-7*H*-pyrrolo[2,3-*d*]pyrimidine-4-amines as antiprotozoal agents. One goal has been to identify new lead compounds for combating protozoa. Secondly, the study could shed light on the toxicity profile of this compound class since some of the derivatives are efficient inhibitors of the epidermal growth factor receptor tyrosine kinase (EGFR-TK) *in vitro* [37].

2. Materials and methods

2.1. General

^{1}H and ^{13}C NMR spectra were recorded with a Bruker Avance 400 spectrometer operating at 400 MHz and 100 MHz,

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0045-2068/$ - see front matter © 2012 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.bioorg.2012.06.003

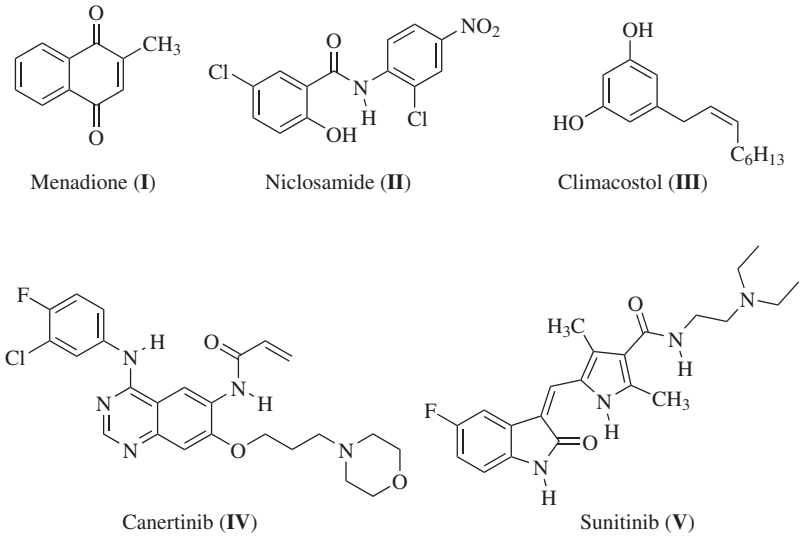


Fig. 1. Structure of compounds **I–III** with potency towards *Tetrahymena* and the kinase inhibitors Canertinib (**IV**) and Sunitinib (**V**).

respectively. ^{19}F NMR was performed on a Bruker Avance 600 operating at 564 MHz. The ^{19}F NMR shift values are relative to hexafluorobenzene. Coupling constants are in Hertz. HPLC (Agilent 110-Series) with a G1379A degasser, G1311A Quatpump, G1313A ALS autosampler and a G1315D Agilent detector (230 nm) was used to determine the purity of the synthesised compounds. Conditions: a Omrisphere 5 C18 (100 × 3.0 mm) column, flow rate 1.0 mL/min, elution starting with H_2O + 1% TFA/acetonitrile (98/2), linear gradient elution for 15 min. ending at acetonitrile/water+1% TFA (90/10), then 15 min isocratic elution. The software used with the HPLC was Agilent ChemStation. Accurate mass determination was performed with EI (70 eV) using a Finnigan MAT 95 XL. FTIR spectra were recorded on a Thermo Nicolet Avatar 330 infrared spectrophotometer. All melting points are uncorrected and measured by a Büchi melting point instrument. Optical rotation was measured with a PerkinElmer Instruments Model 341 Polarimeter.

2.2. Isolation and characterisation of Tetrahymena

The *Tetrahymena* strain used was originally isolated from pond water in Norway and was identified to the genus level based on its phenotype and on partial sequencing of the 18S rDNA-gene. The sequence had 100% identity with reported sequences for *Tetrahymena iwoffi*, *Tetrahymena tropicalis* and *Tetrahymena furgosoni*. The strain was maintained on non-nutrient agar (CCAP, Scotland) seeded with a thick suspension of pasteurised *Escherichia coli* prior to testing. The strain and further information on the sequencing studies can be made available on request.

2.3. Determination of minimum protozoacidal (MPC) concentrations

Stock solutions of the agents were made in DMSO at a concentration of 5120 μg/mL. Benzalkonium chloride (stock in water) was included as control. Water was used as dilutant producing doubling concentrations of the agents at 128–4 μg/mL. These intermediate dilutions (50 μL) were pipetted in triplicate into a 96-well, Nunc® round-bottomed microtiter plate system (Thermo Fischer Scientific, USA). Addition of 50 μL of the inoculum gave the final tested concentration range (2–64 μg/mL) and maximally 1.25% DMSO. A positive control (no agent), and a negative control (without Tetrahymena) tests were also included. *Tetrahymena* was grown on NNA seeded with a thick pasteurised suspension of *E. coli* for 48 h under a humidified atmosphere in the dark at 22 ± 2 °C. After incubation, protozoa were harvested and washed as previously described [38], and resuspended in pasteurised *E. coli* (corresponding to a MacFarland 0.5 standard) at 1×10^4 cells/mL. After incubation for 48 h at 22 ± 2 °C, wells were examined for motile cells using an inverted microscope. This approach enabled the whole content of the well to be visualised. The estimated minimum protozoacidal concentration (MPC; 48 h) was the lowest concentration at which no motile cells were seen. After examination in the microscope, the whole content of wells was transferred to culture dishes containing NNA/pasteurised *E. coli*. Cultures were examined over a 7-day period with an inverted microscope to see if a cell population developed. The MPC value measured (MPC; 7 days) was the lowest concentration that prevented the development of even a single viable cell in the 7-day period. Each test was performed in triplicate and the results were averaged to give the MPC value.

2.4. Kinase profiling

Compound (*R*)-**25e** was profiled utilising a panel of 124 protein kinases in the MRC National Centre for Protein Kinase Profiling Service at the University of Dundee (http://www.kinase-screen.mrc.ac.uk). The compound was tested *in vitro,* in duplicate, at a final concentration of 50 nM. For further details of the methodology see Bain et al. [39].

2.5. Synthesis

Detailed description of the synthesis and characterisation of most of the intermediates and tested compounds can be found elsewhere [37,40]. The synthesis and characterisation of the new chemical entities are given below.

2.5.1. General procedure thermal amination to ***20–24***

The following is representative: 4-chloro-6-(4-methoxyphenyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine (**14**) (275 mg, 1.06 mmol) and (*S*)-1-phenylethanamine ((*S*)-**19i**) (0.44 mL, ~3.5 mmol) were added to a dry round bottle flask containing 1-butanol (3.5 mL) under argon atmosphere. The mixture was heated at 145 °C for 24 h. The precipitate formed upon cooling to rt. was isolated by filtration, washed with diethyl ether (25 mL) and dried resulting in a solid.

*2.5.1.1. (S)-6-(4-Methoxyphenyl)-N-(1-phenylethyl)-7H-pyrrolo[2,3-d]pyrimidin-4-amine ((S)-**20e**).* The compound was prepared as described in Section 2.5.1 starting with 4-chloro-6-(4-methoxyphenyl)-7H-pyrrolo[2,3-*d*]pyrimidine (**14**) (159 mg, 0.61 mmol) and (*S*)-1-phenylethanamine (**19e**) (222 mg, 1.84 mmol). This gave 179 mg (0.52 mmol, 85%) of a white solid, mp. 226–228 °C, $[\alpha]_D^{20}$ = + 289 (*c* 0.17, DMSO). Spectroscopic properties were in correspondence with that reported previously for the (*R*)-enantiomer [40]. ^{1}H NMR (400 MHz, DMSO-d_6) δ: 11.92 (s, 1H, NH, H-7), 8.04 (s, 1H, H-2), 7.73 (m, 3H), 7.43 (m, 2H), 7.30 (m, 2), 7.19 (m, 1H), 7.02 (d, *J* = 8.8, 2H), 6.96 (bs, 1H, H-5), 5.50 (m, 1H), 3.80 (s, 3H), 1.53 (d, *J* = 7.0, 3H). HRMS (EI): 344.1634 (calcd $C_{21}H_{20}N_4O$, 344.1632, M^+).

*2.5.1.2. (R)-6-(4-Methoxyphenyl)-N-(1-(4-methoxyphenyl)ethyl)-7H-pyrrolo[2,3-d]pyrimidin-4-amine ((R)-**20h**).* The compound was prepared as described in Section 2.5.1 starting with 4-chloro-6-(4-metoxyphenyl)-7*H*-pyrrolo-[2,3-*d*]-pyrimidine (**14**) (238 mg, 0.92 mmol) and (*R*)-(4-methoxyphenyl)ethanamine (**19h**) (288 mg, 1.90 mmol). This gave 220 mg (0.59 mmol, 64%) of an off-white solid, mp. 249–251 °C, $[\alpha]_D^{20}$ = −330.1 (c 0.14, DMSO), purity > 99% (by HPLC). ^{1}H NMR (400 MHz, DMSO-d_6) δ: 11.89 (s, 1H, NH, H-7), 8.04 (s, 1H), 7.71 (d, *J* = 8.9, 2H), 7.64 (d, *J* = 8.4, 1H, NH), 7.34 (d, *J* = 8.7, 2H), 7.02 (d, *J* = 8.9, 2H), 6.94 (s, 1H, H-5), 6.86 (d, *J* = 8.7, 2H), 5.45 (m, 1H), 3.80 (s, 3H), 3.71 (s, 3H), 1.50 (d, *J* = 7.0, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ: 158.6, 157.9, 154.8, 151.3 (2C), 137.5, 133.4, 127.2 (2C), 125.9 (2C), 124.5, 114.4 (2C), 113.5 (2C), 103.9, 94.6, 55.2, 55.0, 48.0, 22.9. HRMS (ESI): 375.1814 (calcd $C_{22}H_{22}N_4O_2$, 375.1816, M + H^+). IR (neat, cm^{-1}): 3099, 2973, 1588, 1244, 830.

*2.5.1.3. (S)-N-(1-(4-Bromophenyl)ethyl)-6-(4-methoxyphenyl)-7H-pyrrolo[2,3-d]pyrimidin-4-amine ((S)-**20i**).* The compound was prepared as described in Section 2.5.1 starting with 4-chloro-6-(4-methoxyphenyl)-7*H*-pyrrolo-[2,3-*d*]-pyrimidine (**14**) (190 mg, 0.73 mmol) and (S)-1-(4-bromophenyl)ethanamine (**19i**) (439 mg, 2.19 mmol). This gave 245 mg (0.58 mmol, 79%) of a white solid, mp. 274–275 °C, $[\alpha]_D^{20}$ = +309 (*c* 0.21, DMSO). Spectroscopic properties were in correspondence with that reported previously for the (*R*)-enantiomer [37]. ^{1}H NMR (400 MHz, DMSO-d_6) δ: 11.93 (s, 1H, NH, H-7), 8.03 (s, 1H, H-2), 7.76 (s, 1H, NH), 7.73 (m, 2H), 7.49 (m, 2H), 7.38 (m, 2H), 7.02 (m, 2H), 6.94 (d, *J* = 1.8, 1H, H-5), 5.44 (m, 1H), 3.80 (s, 3H), 1.51 (d, *J* = 7.0, 3H). HRMS (EI): 422.0739 (calcd $C_{21}H_{19}BrN_4O$, 422.0737, M^+)

*2.5.1.4. 6-(4-Methoxyphenyl)-N-(1-naphthalen-1-ylmethyl)-7H-pyrrolo[2,3-d]pyrimidin-4-amine (**20o**).* The compound was prepared as described in Section 2.5.1 starting with 4-chloro-6-(4-methoxyphenyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine (**14**) (154 mg, 0.59 mmol) and naphthalen-1-ylmethanamine (**19o**) (280 mg, 1.78 mmol). This gave 173 mg (0.45 mmol, 77%) of a white solid, mp 278–281 °C. ^{1}H NMR (400 MHz, DMSO-d_6) δ: 11.98 (s, 1H, NH, H-7), 8.21–8.19 (m, 1H), 8.14 (s, 1H, H-2), 7.97–7.94 (m, 2H), 7.86–7.84 (m, 1H), 7.71–7.69 (m, 2H), 7.57–7.52 (m, 3 H), 7.49–7.46 (m, 1H), 7.01–7.00 (m, 2H), 6.89 (s, 1H, H-5), 5.20 (d, *J* = 5.6, 2H), 3.79 (s, 3H). ^{13}C NMR (100 MHz, DMSO-d_6), δ: 159.1, 155.8, 151.8 (2C, overlap), 135.7, 134.2, 133.8, 131.5, 128.9, 127.8, 126.6, 126.4 (2C), 126.2, 125.9, 125.7, 124.9, 124.0, 114.9 (2C), 104.4, 95.0, 55.6, 41.9. IR (neat, cm^{-1}): 3152, 1597,1254,769. HRMS (EI): 380.1632 (calcd $C_{24}H_{20}N_4O$, 380.1632, M^+).

*2.5.1.5. (R)-6-(4-Methoxyphenyl)-N-(1-(naphthalen-1-yl)ethyl)-7H-pyrrolo[2,3-d]pyrimidin-4-amine ((R)-**20p**).* The compound was prepared as described in Section 2.5.1 starting with 4-chloro-6-(4-methoxyphenyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine (**14**) (144 mg, 0.55 mmol) and (*R*)-1-(naphthalen-1-yl)ethanamine (**19p**) (285 mg, 1.66 mmol). This gave 162 mg (0.41 mmol, 74%) of a white solid, mp. 274–276 °C, $[\alpha]_D^{20}$ = −432 (*c* 0.37, DMSO). Spectroscopic properties were in correspondence with that reported previously for the racemate [37]. ^{1}H NMR (400 MHz, DMSO-d_6) δ: 11.93 (s, 1H, NH, H-7), 8.24 (d, *J* = 8.2, 1H), 8.04 (s, 1H, H-2), 7.94 (m, 1H), 7.87 (m, 1H), 7.81 (m, 1H), 7.71–7.64 (m, 3H), 7.59–7.45 (m, 3H), 7.01 (m, 2H), 6.97 (s, 1H, H-5), 6.27 (m, 1H), 3.79 (s, 3H), 1.67 (d, *J* = 6.8, 3H). IR (neat, cm^{-1}): 3131, 2962 1624, 1251, 828, 775. HRMS (EI): 394.1783 (calcd $C_{25}H_{22}N_4O$, 394.1794, M^+).

*2.5.1.6. (R)-N-(1-(Naphthalen-1-yl)ethyl)-6-phenyl-7H-pyrrolo[2,3-d]pyrimidin-4-amine ((R)-**21p**).* The compound was prepared as described in Section 2.5.1 starting with 4-chloro-6-(4-phenyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine (**15**) (87 mg, 0.38 mmol) and (R)-1-(naphthalen-1-yl)ethanamine (**19p**) (195 mg, 1.14 mmol). This gave 107 mg (0.29 mmol, 76%) of a white solid. The solid melted at 155–157 °C, but partly re-solidified to a solid melting at 200 °C, $[\alpha]_D^{20}$ = −481 (*c* 1.00, DMSO), purity: 98% (by HPLC). ^{1}H NMR (400 MHz, DMSO-d_6) δ: 12.07 (s, 1H, NH, H-7), 8.26–8.24 (m, 1H), 8.08 (s, 1H, H-2), 8.01–7.93 (m, 2H), 7.82–7.77 (m, 3H), 7.67–7.66 (m, 1H), 7.59–7.41 (m, 5H), 7.30–7.27 (m, 1H), 7.14 (s, 1H, H-5), 6.32–6.25 (m, 1H), 1.68 (d, *J* = 6.8, 3H). ^{13}C NMR (100 MHz, DMSO-d_6) δ: 155.3, 152.3, 152.0 141.3, 133.92, 133.87, 132.3, 131.1, 129.42 (2C), 129.1, 127.7, 127.6, 126.6, 126.0, 125.9, 124.9 (2C), 123.8, 122.7, 104.4, 60.2, 96.7, 22.3. IR (neat, cm^{-1}): 2976, 1586, 1471, 1311, 774, 749. HRMS (EI): 364.1683 (calcd $C_{24}H_{20}N_4$, 364.1682, M^+).

*2.5.1.7. (S)-N-(1-(Naphthalen-1-yl)ethyl)-6-phenyl-7H-pyrrolo[2,3-d]pyrimidin-4-amine ((S)-**21p**).* The compound was prepared as described in Section 2.5.1 starting with 4-chloro-6-(4-phenyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine (**15**) (70 mg, 0.30 mmol) and (*S*)-1-phenylethanamine (**19e**) (156 mg, 0.91 mmol). This gave 84 mg (23 mmol, 77%) of a white solid, mp. 162–166 °C, $[\alpha]_D^{20}$ = +422 (*c* 1.00, DMSO), purity: 98% (by HPLC). The spectroscopic properties corresponded with that reported for (*S*)-**21p** in Section 2.5.1.6. HRMS (EI): 364.1682 (calcd $C_{24}H_{20}N_4$, 364.1682, M^+).

*2.5.1.8. (R)-6-(4-Fluorophenyl)-N-(1-(naphthalen-1-yl)ethyl)-7H-pyrrolo[2,3-d]pyrimidin-4-amine ((R)-**22p**).* The compound was prepared as described in Section 2.5.1 starting with 4-chloro-6-(4-fluorophenyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine (**16**) (64 mg, 0.26 mmol) and (*R*)-1-(naphthalen-1-yl)ethanamine (**19p**) (133 mg, 0.78 mmol). This gave 70 mg (0.18 mmol, 70%) of a white solid, mp. 147–150 °C, $[\alpha]_D^{20}$ = −444 (*c* 0.40, DMSO), purity: 99% (by HPLC). ^{1}H NMR (400 MHz, DMSO-d_6) δ: 12.07 (s, 1H, NH, H-7), 8.26–8.24 (m, 1H), 8.08 (s, 1H, H-2), 7.99–7.93 (m, 2H), 7.82–7.80 (m, 3H), 7.67–7.65 (m, 1H), 7.58–7.45 (m, 3H), 7.31–7.27 (m, 2H), 7.09 (s, 1H, H-5), 6.31–6.25 (m, 1H), 1.68 (d, *J* = 6.8, 3H). ^{13}C NMR (100 MHz, DMSO-d_6), δ: 161.9 (d, *J* = 244.5), 155.3, 152.3 (2C), 152.0, 141.3, 139.9, 133.0, 131.1, 129.1, 128.9 (d, *J* = 2.9), 127.6, 126.9 (d, *J* = 7.9), 126.6, 126.0 (d, *J* = 3.5, 2C), 123.8, 122.7, 116.4 (d, *J* = 21.7, 2C), 104.4, 96.6, 60.2, 22.2. ^{19}F NMR (564 MHz, DMSO-d_6, C_6F_6) δ: −117.1 (m). IR (neat, cm^{-1}): 2985, 1585, 1496, 1312, 1233, 834, 774. HRMS (EI): 382.1585 (calcd $C_{24}H_{19}FN_4$, 382.1586, M^+).

2.5.1.9. (S)-6-(4-Fluorophenyl)-N-(1-(naphthalen-1-yl)ethyl)-7H-pyrrolo[2,3-d]pyrimidin-4-amine ((S)-22p). The compound was prepared as described in Section 2.5.1 starting with 4-chloro-6-(4-fluorophenyl)-7*H*-pyrrolo[2,3-*d*]pyrimidine (**16**) (66 mg, 0.27 mmol) and (*S*)-1-phenylethanamine (**19p**) (137 mg, 0.80 mmol). This gave 76 mg (0.20 mmol, 74%) of a white solid, mp. 149–152 °C, $[\alpha]_D^{20}$ = +380 (*c* 0.13, DMSO), purity: 98% (by HPLC). The spectroscopic properties corresponded with that reported for (*R*)-**22p** in Section 2.5.1.8.

*2.5.2. General procedure demethylation of **20–25***

The following is representative: (*S*)-6-(4-methoxyphenyl)-*N*-(1-phenylethyl)-7*H*-pyrrolo[2,3-*d*]pyrimidin-4-amine (**20i**) was dissolved in dry CH_2Cl_2 (2 mL) under argon atmosphere. BBr_3 (0.17 ml, ~1.8 mmol) in dry CH_2Cl_2 (1.5 mL) was added drop wise over 1 h. at 0 °C using a syringe pump. Then the mixture was allowed to react at 20 °C for 24 h. The reaction was quenched by addition of water (10 mL), and the mixture was extracted with EtOAc (3 × 25 mL). The combined organic phase was washed with brine (15 mL), dried over $MgSO_4$ and concentrated. The resulting residue was purified by precipitation from acetone (0.5 mL). The solid formed was isolated by filtration, washed with diethyl ether (10 mL) and dried.

*2.5.2.1. (S)-4-(4-(1-Phenylethylamino)-7H-pyrrolo[2,3-d]pyrimidin-6-yl)phenol hydrobromide ((S)-**25e**).* The compound was synthesised as described in Section 2.5.2 starting from (*S*)-6-(4-methoxyphenyl)-*N*-(1-phenylethyl)-7*H*-pyrrolo[2,3-*d*]-pyrimidin-4-amine (**20e**) (99 mg, 0.29 mmol). This gave 56 mg, (0.14 mmol, 47%) of a white solid, mp > 300 °C, $[\alpha]_D^{20}$ = +289 (*c* 0.17, DMSO). purity > 98% (by HPLC) Spectroscopic properties were in correspondence with that reported previously for the (*R*)-enantiomer [37]. ^{1}H NMR (400 MHz, DMSO-d_6) δ: 12.98 (s, 1H, NH, H-7), 9.83 (br s, 1H, OH), 9.55 (br s, 1H, NH), 8.30 (s, 1H, H-2), 7.66 (m, 2H), 7.50–7.48 (m, 2H), 7.39 (m, 2H), 7.32–7.29 (m, 1H), 7.24 (s, 1H, H-5), 6.89 (m, 2H), 5.37 (m, 1H), 1.66 (d, *J* = 6.5, 3H). HRMS (EI): 330.1475 (calcd $C_{20}H_{18}N_4O$, 330.1475, M^+).

*2.5.2.2. (S)-4-(4-(1-(4-bromophenyl)ethylamino)-7H-pyrrolo[2,3-d]pyrimidin-6-yl)phenol hydrobromide ((S)-**25i**).* The compound was synthesised as described in Section 2.5.2 starting from (*S*)-*N*-(1-(4-bromophenyl)ethyl)-6-(4-methoxyphenyl)-7*H*-pyrrolo[2,3-*d*]pyrimidin-4-amine (**20i**) (134 mg, 0.32 mol). This gave 83 mg (0.17 mmol, 52%) of a white solid, mp. 274–276 °C, $[\alpha]_D^{20}$ = +272 (*c* 0.28, DMSO), purity > 97% (by HPLC). Spectroscopic properties were in correspondence with that reported previously for the (*R*)-enantiomer [37]. ^{1}H NMR (400 MHz, DMSO-d_6) δ: 12.94 (s, 1H, NH, H-7), 9.82 (br s, 1H, OH), 9.47 (br s, 1H, NH), 8.29 (s, 1H, H-2), 7.65 (m, 2H), 7.58 (m, 2H), 7.44 (m, 2H), 7.16 (s, 1H, H-5), 6.88 (m, 2H), 5.37 (m, 1H), 1.63 (d, *J* = 6.6, 3H. HRMS (EI): 408.0581 (calcd $C_{20}H_{17}Br^{79}N_4O$, 408.0580, M^+).

*2.5.2.3. 4-(4-(Naphthalen-1-ylmethylamino)-7H-pyrrolo[2,3-d]pyrimidin-6-yl)phenol hydrobromide (**25o**).* The compound was synthesised as described in Section 2.5.2 starting from 6-(4-methoxyphenyl)-*N*-(naphthalen-1-ylmethyl)-7*H*-pyrrolo[2,3-*d*]-pyrimidin-4-amine (**20o**) (117 mg, 0.31 mmol) and BBr_3 (0.29 mL, 3.1 mmol). This gave 74 mg (0.20 mmol, 66%) of a white solid, mp > 300 °C. purity > 98% (by HPLC). ^{1}H NMR (400 MHz, DMSO-d_6) δ: 13.01 (s, 1H, H-7), 9.82 (s, 1H, OH), 8.36 (s, 1H, H-2), 8.15–8.13 (m, 1H), 8.04–8.02 (m, 1H), 7.97–7.95 (m, 1H), 7.66–7.60 (m, 4H), 7.54–7.7.50 (m, 2H), 7.17 (s, 1H, H-5), 6.87–6.89 (m, 2H), 5.26 (bs, 2H). ^{13}C NMR (100 MHz, DMSO-d_6) δ: 158.5, 149.9, 148.6, 142.8, 138.1, 133.9, 132.1, 131.3, 129.1, 128.9, 127.2 (2C), 127.1, 126.7, 126.1, 125.4, 124.1, 121.7, 116.4 (2C), 103.5, 96.8, 43.9. IR (neat, cm^{-1}): 3123, 1643, 1612, 1493, 1178, 757. HRMS (EI): 366.1471 (calcd $C_{23}H_{18}N_4O$, 366.1475, M^+).

*2.5.2.4. (R)-4-(4-(1-(naphthalen-1-yl)ethylamino)-7H-pyrrolo[2,3-d]pyrimidin-6-yl)phenol ((R)-**25p**).* The compound was synthesised as described in Section 2.5.2 starting (R)-6-(4-methoxyphenyl)-*N*-(1-(naphthalen-1-yl)ethyl)-7*H*-pyrrolo[2,3-*d*]pyrimidin-4-amine ((*R*)-**20p**) (113 mg, 0.29 mmol). This gave 58 mg (0.15 mmol, 53%) of a white solid, mp > 300 °C. $[\alpha]_D^{20}$ = −379 (*c* 0.26, DMSO) purity > 98% (by HPLC). Spectroscopic properties were in correspondence with that reported previously for the racemate [37]. ^{1}H NMR (400 MHz, DMSO-d_6) δ: 12.98 (s, 1H, NH, H-7), 9.82 (br s, 1H, OH), 9.55 (br s, 1H, NH), 8.30 (s, 1H), 8.14 (s, 1H, H-2), 8.00 (m, 1H), 7.91 (m, 1H), 7.64–7.57 (m, 5H), 7.54–7.50 (m, 1H), 7.26 (s, 1H, H-5), 6.89–6.87 (m, 2H), 6.09 (m, 1H), 1.78 (d, *J* = 6.5, 3H). HRMS (EI): 380.1635 (calcd $C_{24}H_{20}N_4O$, 380,1637, M^+).

*2.5.2.5. (S)-4-(4-(1-(Naphthalen-1-yl)ethylamino)-7H-pyrrolo[2,3-d]pyrimidin-6-yl)phenol hydrobromide ((S)-**25p**).* The compound was synthesised as described in Section 2.5.2 starting (S)-6-(4-methoxyphenyl)-*N*-(1-(naphthalen-1-yl)ethyl)-7*H*-pyrrolo[2,3-*d*]pyrimidin-4-amine ((*S*)-**20p**) (73 mg, 0.19 mmol). This gave 48 mg (0.13 mmol, 68%) of a white solid, mp > 300 °C. $[\alpha]_D^{20}$ = +389 (*c* 0.16, DMSO) purity > 99% (by HPLC). Spectroscopic properties were in correspondence with that reported previously for the racemate [37], and that described for (*R*)-**25p** in Section 2.5.2.4.

3. Result and discussion

3.1. Synthesis

The pyrrolopyrimidines were synthesised as described previously, Scheme 1 [37,41,42].

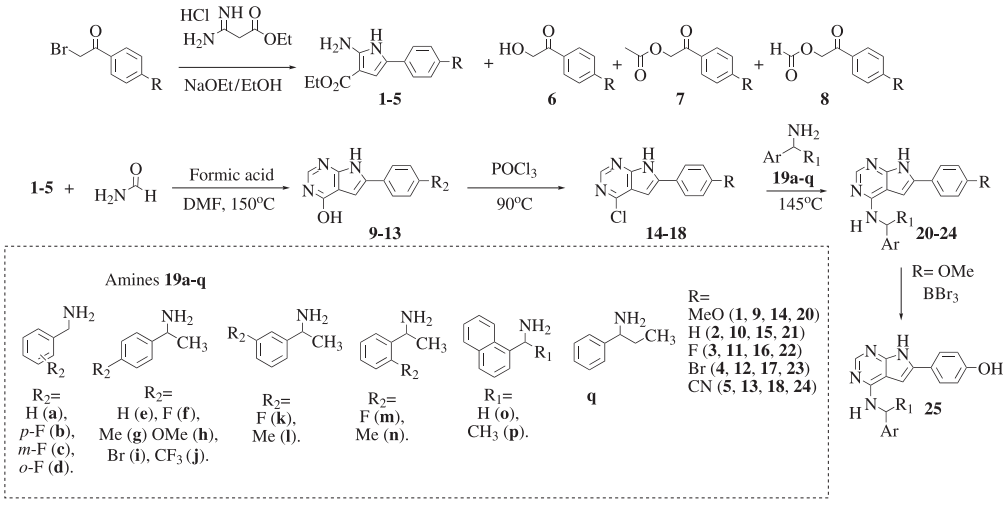
The first step forming the pyrroles **1**–**5** gave mediocre yields. We found that formation of **6**–**8** was the main reason for the loss in yield. The alcohol **6** may be caused by water generated in the pyrrole cyclisation, whereas the esters **7** and **8** most likely originate from fragmentation of the unstable aminoimidate. An increase in yield of **1**–**5** was seen when using >2 equivalents of the aminoimidate and 3 equivalents of sodium ethoxide. It has previously been suggested that such pyrroles are UV labile [42]. Discolouration of the products was seen on storage in DMSO for 1 day at room temperature. Cyclisation of **1**–**5** using formamide gave the 4-hydroxypyrrolopyrimidines **9**–**13** which all were crystalline and easily isolated. Standard chlorination gave **14**–**18**, which also were conveniently isolated and purified if full conversion was obtained in the reaction. In the next step, thermal nucleophilic aromatic substitution on **14**–**18** was performed using various amines. Compound **14** was reacted with **19a**–**q** giving **20a**–**q**, while the 4-chloropyrrolopyrimidines **15**–**18** were mainly substituted with **19e**–**f** and **19p**, giving the corresponding 4-amino derivatives **21**–**24**. Deprotection of the methoxy derivatives **20** with boron tribromide gave the phenolic compounds **25**. Twelve of the compounds reported in this study are new chemical entities.

3.2. Toxicity towards Tetrahymena

The *Tetrahymena* strain used in this study was originally isolated from pond water in Norway.

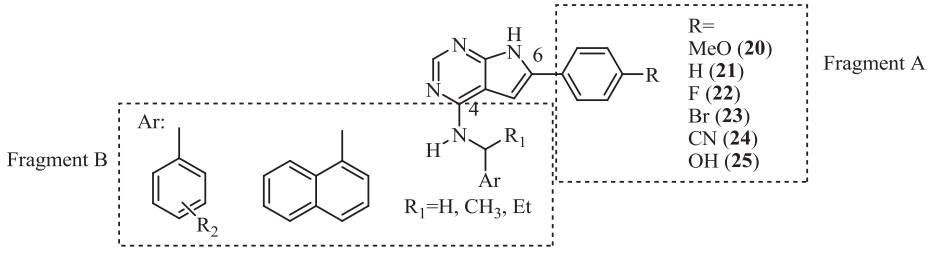
It was observed that this isolate grew faster and was more vigorous than several of our culture collection *Tetrahymena* strains. These observations were considered important when choosing it as a test strain for the present study. Benzylalkonium chloride was used as a control in the testing showing a MPC value of 8 μg/mL. We first investigated the effect of compounds having benzylamines, chiral 1-phenylethanamines and 1-naphthylethanamines as substituents in Fragment B (see Table 1), and methoxy, hydrogen, fluoro, bromo and cyano as R in Fragment A.

Most of the compounds were synthesised as their (*R*)-enantiomers, but the (*S*)-enantiomers of the methoxy substituted compound **20e**, and **20p**, **21p** and **22p** having a 1-naphthylethanamine substituent at C-4 were included to investigate the importance of stereochemistry. Testing revealed that the (*R*)-naphthyl derivative **20p** had an MPC-value of 32 (Table 1, entry 7), while other derivatives with R = OMe, H, F, Br and CN did not possess protozoacidal



Scheme 1. Synthesis of **20–25** using the amines **19a-q.**

Table 1
Activity of the pyrrolopyrimidines **20**–**24** and **25o**-**p** towards *Tetrahymena.*



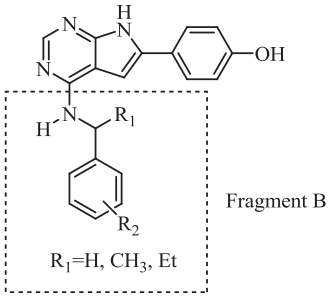
Entry	Substance	*R*	R_1	Ar/R_2	MPC μg/mL (48 h)[a]
1	**20a**	OMe	H	H	>64
2	**20b**	OMe	H	*p*-F	>64
3	(*R*)-**20e**	OMe	CH_3	H	>64
4	(*S*)-**20e**	OMe	CH_3	H	>64
5	(*R*)-**20h**	OMe	CH_3	*p*-MeO	>64
6	**20o**	OMe	H	$C_{10}H_7$	>64
7	(*R*)-**20p**	OMe	CH_3	$C_{10}H_7$	32[b]
8	(*S*)-**20p**	OMe	CH_3	$C_{10}H_7$	>64
9	(*R*)-**20r**	OMe	Et	H	>64
10	**21c**	H	H	*m*-F	>64
11	**21e**	H	CH_3	H	>64
12	(*R*)-**21f**	H	CH_3	*p*-F	>64
13	(*R*)-**21p**	H	CH_3	$C_{10}H_7$	>64
14	(*S*)-**21p**	H	CH_3	$C_{10}H_7$	>64
15	**22c**	F	H	*m*-F	>64
16	(*R*)-**22e**	F	CH_3	H	>64
17	(*R*)-**22f**	F	CH_3	*p*-F	>64
18	(*R*)-**22p**	F	CH_3	$C_{10}H_7$	>64
19	(*S*)-**22p**	F	CH_3	$C_{10}H_7$	>64
20	(*R*)-**23e**	Br	CH_3	H	>64
21	(*R*)-**23f**	Br	CH_3	p-F	>64
22	(*R*)-**24e**	CN	CH_3	H	>64
23	(*R*)-**24f**	CN	CH_3	*p*-F	>64
24	**25o**	OH	H	$C_{10}H_7$	64
25	(*rac*)-**25p**	OH	CH_3	$C_{10}H_7$	64
26	(*R*)-**25p**	OH	CH_3	$C_{10}H_7$	32[a]
27	(*S*)-**25p**	OH	CH_3	$C_{10}H_7$	64

[a] The MPC values were determined by averaging three parallel measurements.
[b] MPC = 32 also after 7 days.

activity with respect to *Tetrahymena* in the lower μg/mL concentration range.

Solubility challenges were encountered when some of these compounds were tested, the investigation was continued with the naphthylic compounds **25o**-**p** which had a hydrophilic phenolic group in fragment A, (Table 1, entries 24–27). However, no drastic improvement in potency was observed. The (*R*)-enantiomer of **25p** (Table 1, entry 26) was the most potent and gave a similar

Table 2
Activity of compounds **25** towards *Tetrahymena*.



Entry	Substance	*R*	R_2	MPC μg/ml (48 h)[a]	MPC μg/ml (7 days)[a]
1	**25a**	H	H	>64	>64
2	**25b**	H	*p*-F	>64	>64
3	**25c**	H	*m*-F	>64	>64
4	**25d**	H	*o*-F	>64	>64
5	(*R*)-**25e**	CH_3	H	8/16[b]	16/16[b]
6	(*R*)-**25f**	CH_3	*p*-F	32	32
7	(*R*)-**25g**	CH_3	*p*-CH_3	>64	>64
8	(*R*)-**25i**	CH_3	*p*-Br	8/8[b]	8/8[b]
9	(*rac*)-**25j**	CH_3	*p*-CF_3	32	32
10	(*R*)-**25k**	CH_3	*o*-F	64	>64
11	(*Rac*)-**25l**	CH_3	*o*-CH_3	64	>64
12	(*R*)-**25m**	CH_3	*m*-F	16	16
13	(*Rac*)-**25n**	CH_3	*m*-CH_3	32	32
14	(*R*)-**25q**	Et	H	32	32
15	(*S*)-**25e**	CH_3	H	8/16[b]	8/16[b]
16	(*S*)-**25i**	CH_3	Br	8	16

[a] The MPC values were determined by averaging three parallel measurements.
[b] Values given represent a second triplicate ground of testing.

MPC value to that of the methoxy derivative (*R*)-**20p** (Table 1, entry 7).

Then we decided to evaluate the effect of the substitution pattern in fragment B by varying R_1 (hydrogen, methyl and ethyl) and including mono *ortho*, *meta* or *para* R_2-groups, while keeping the phenolic unit in fragment A. The compounds tested and their potencies towards *Tetrahymena* are compiled in Table 2.

The unsubstituted benzylamine derivative **25a** and three fluoro substituted benzylamine derivatives, **25b-d**, were all inactive in the concentration range tested (Table 2, entries 1–4). However, to our satisfaction (*R*)-**25e**, PKI-166 [43], having a *para*-hydroxyphenyl at C-6 and a 1-phenylethanamine substituent as C-4, proved to be potent (MPC: 8–16 μg/mL Entry 5), indicating the importance of a chiral centre. Keeping the chiral R_1 group as methyl, and introducing rather conservative variations in the *para* position in terms of size and electronic properties, gave an MPC = 32 μg/mL for the fluoro derivative **25f**, while the methyl analogue **25g** was inactive. By changing the *para* substituent to bromo, (*R*)-**25i**, a MPC value of 8 μg/mL was obtained. Compared to the activity of the fluoro containing compound **25f** this indicates that a combination of both increased size and polarisability might be beneficial for achieving good potency. Also, the racemic trifluoromethyl derivative (*rac*)-**25j** showed activity (MPC = 32 μg/mL). *Ortho* and *meta* substitution by fluoro or a methyl substituent lowered the toxicity, but the *meta*-fluoro derivative **25m** showed appreciable protozoacidal activity (MPC: 16 μg/mL, entry 13). It was further investigated how the potency was affected by extending the chain length of R_1, but the result for **25q** containing a 1-phenylpropanamine substituent at C-4 (MPC = 32 μg/mL, entry 14) did not encourage further evaluation. To verify the importance of stereochemistry for the toxicity profile of these compounds we also synthesised and analysed for the effect of the (*S*)-enantiomers of the 1-phenylethanamine containing **25e** and its *para*-bromo substituted derivative **25i**. Both were found to be highly potent (Table 2, entries 15–16).

Some of the compounds evaluated in this study are efficient inhibitors of EGFR-TK *in vitro* [37]. These kinases depends on activation from the epidermal growth factor (EGF), which is a known signalling polypeptide in *Tetrahymena* [44]. However, we did not find any correlation between the *in vitro* activity towards EGFR-TK and the MPC values. This might indicate that receptors found in *Tetrahymena* are structurally different to the human version. To investigate if other kinases might be the target, the *para*-hydroxyphenyl derivative **25e** was evaluated against a panel of 124 kinases. Low inhibitory potency was observed in most cases (data not shown). Kinases which were inhibited to a degree of 25% or more at 50 nM are compiled in Fig. 2. Of these kinases, protein kinase B [45–47], calmodulin dependant enzymes [48,49], protein kinase C [9,50], and ERK1 type proteins [51] are found in protozoa and represent possible sites of action for the pyrrolopyrimidines.

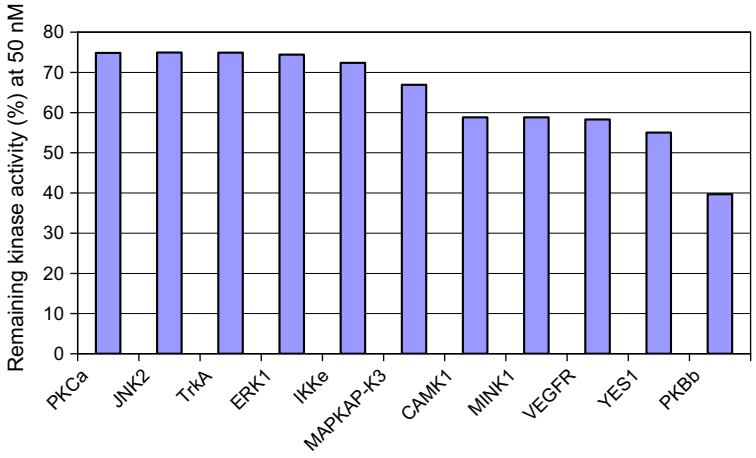


Fig. 2. Effect of **25e** (50 nM) on the activity of a selection of kinases. PKCα: Protein kinase C alpha; JNK2: c-Jun N-terminal kinase/mitogen-activated protein kinase, TrkA: Neurotrophic tyrosine kinase receptor type 1, ERK1: extracellular-signal-regulated kinase; IKKe: inhibitory κB kinase; MAPKAP-K3: MAPK-activated protein kinase 3; CAMK 1: calmodulin-dependent kinase: MINK1: misshapen-like kinase 1 VEGFR: vascular endothelial growth factor receptor, Yes 1: Yamaguchi sarcoma viral oncogene homologue. PKBb: protein kinase B.

The toxicity/potency of the compounds presented in this study against *Tetrahymena* crucially depended on the presence of a *para* phenolic group in fragment A. This might be due to better solubility and bioavailability than for **20**–**24**, or that the hydroxyl function engages in critical bonding interaction. In *Tetrahymena pyriformis* there is evidence for a transmembrane efflux pump as a detoxification mechanism, preferably excluding lipophilic compounds [52]. This might be an alternative explanation for the observed toxicity differences seen on introduction of the 4-hydroxyl group in fragment A. As *Tetrahymena* has only limited CYP-450 dependent metabolism activity [53], it is less likely that the toxicity is due to oxidation of the *para*-hydroxyphenyl unit of **25** leading to aromatic 1,2-dienones, which are typical Michael acceptors in reaction with bio macromolecules [16,18]. The low level of CYP-450 enzymes should also exclude the possible formation of active compounds from putative precursors such as the C-6 phenyl substituted derivative **21**. Furthermore, the MPC values were affected by the substitution pattern and the presence of a chiral centre in fragment B. All the above indicates that there is a specific mode of action involving a defined 3-dimentional receptor target. However, the fact that both enantiomers showed toxicity is suggesting that the pyrrolopyrimidines could have multiple modes of action, or that the target is rather flexible.

As a model for unspecific toxicity the study shows that introduction of a 4-hydroxyl group in fragment A could be problematic for EGFR-TK inhibitors, but also that the toxicity profile could be modulated by the substitution pattern both in fragment A and B. Human toxicity issues have in fact been seen for **25e** [54].

4. Conclusion

A series of pyrrolopyrimidines have been tested for their protozoacidal activity against *Tetrahymena*. Five compounds were found to be highly active (MPC 8–16 μg/mL). The identified compounds do not contain the typical groups which trigger non-specific toxicity effects. The presence of a *para* phenolic group in position 6 (fragment A), and a chiral centre in the 4-benzylamine (fragment B) enhanced the potency considerably. *Ortho*-substitution in fragment B, and an electron donating methyl group in the *para* position reduced the toxicity. There is no evidence that EGFR-TK kinases are targets for these compounds in *Tetrahymena*, however, kinase profiling identified other potential sites of action. The detailed mechanism will be investigated in continuing work. The presented structure–activity relationships could be used as guidelines for targeting other, medically more important protozoa.

Acknowledgments

The group is thankful to the Anders Jahres foundation for financial support. Roger Aarvik is thanked for technical support. Susana Villa Gonzalez is acknowledged for HRMS experiments.

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