Preparation and Photosynthesis-Inhibiting Activity of 1-[(2-Nitrophenyl)carbamoyl]naphthalen-2-yl Alkylcarbamates

Tomas Gonec[1,*], Josef Stranik[1], Matus Pesko[2], Jiri Kos[1], Michal Oravec[3], Katarina Kralova[4], Josef Jampilek[5,*]

[1] Department of Chemical Drugs, Faculty of Pharmacy, University of Veterinary and Pharmaceutical Sciences, Palackeho 1, 612 42 Brno, Czech Republic; e-mail: t.gonec@seznam.cz

[2] Department of Environmental Ecology, Faculty of Natural Sciences, Comenius University, Mlynska dolina Ch-2, 842 15 Bratislava, Slovakia

[3] Global Change Research Institute CAS, Belidla 986/4a, 603 00 Brno, Czech Republic

[4] Institute of Chemistry, Faculty of Natural Sciences, Comenius University, Mlynska dolina Ch-2, 842 15 Bratislava, Slovakia

[5] Department of Pharmaceutical Chemistry, Faculty of Pharmacy, Comenius University, Odbojarov 10, 83232 Bratislava, Slovakia; e-mail: josef.jampilek@gmail.com

* Authors to whom correspondence should be addressed.

Abstract: In this study, a series of eight 1-[(2-nitrophenyl)carbamoyl]naphthalen-2-yl alkylcarbamates was prepared and characterized. The discussed compounds were prepared by microwave-assisted and conventional synthesis. The compounds were tested for their activity related to inhibition of photosynthetic electron transport (PET) in spinach (*Spinacia oleracea* L.) chloroplasts. The PET-inhibiting activity of the compounds was relatively low; the corresponding IC_{50} values ranged from 0.233 to 0.487 mmol/L and the highest activity within the series of compounds was observed for 1-[(2-nitrophenyl)carbamoyl]naphthalen-2-yl pentylcarbamate. The compounds were found to inhibit PET in photosystem II.

Keywords: Alkylcarbamates; Hydroxynaphthalene-carboxamides; PET inhibition; Spinach chloroplasts; Structure-activity relationships.

INTRODUCTION

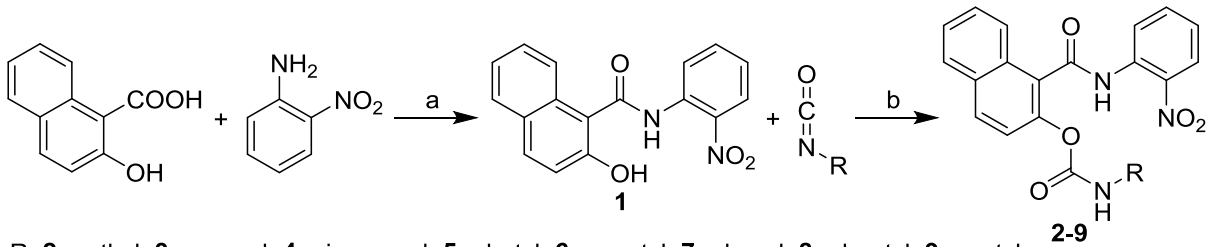
The presence of an amide or carbamate (–CONH–, –OCONH–) group with hydrophobic residue in its close vicinity is characteristic not only of a number of clinically used drugs [1] but also of many applied pesticides [2]. These moieties are important functional groups that are able, due to their electron properties, to interact and bind with a number of

enzymes/receptors and, by means of these target sites, affect the biological response. The properties of the amide and the carbamate moieties can be easily modified by various substitutions [3,4]. These groups are characteristic of a number of herbicides acting as inhibitors of photosynthetic electron transport (PET) in photosystem (PS) II [5–21]. Moreover, in the middle of the 1970's it was found that salicylanilides belong to effective uncoupling agents of oxidative phosphorylation [22–24], and acceleration of the deactivation reactions of water splitting enzyme system Y by 3-*tert*-butyl-5-chloro-*N*-(2-chloro-4-nitrophenyl)-2-hydroxybenzamide was observed [23]. Substituted salicylanilides or their bioisosteres inhibited PET [14–21,25–28] and reduced chlorophyll content in green alga, *Chlorella vulgaris* [25–27]. It is important to note that in addition to the above-mentioned herbicidal activity, the wide spectrum of biological effects of salicylanilides includes, for example, antibacterial, antimycobacterial, antifungal and anthelmintic activity; however, their mechanism of action is still under investigation [29 and refs. therein].
In the context of the above-mentioned facts, 1-[(2-nitrophenyl)-carbamoyl]naphthalen-2-yl alkylcarbamates were prepared [30] and some of them tested were for their photosynthesis-inhibiting activity – the inhibition of photosynthetic electron transport (PET) in spinach chloroplasts (*Spinacia oleracea* L.).

RESULTS AND DISCUSSION

All the studied compounds were prepared according to Scheme 1 [30]. In the first step, *N*-(2-nitrophenyl)-2-hydroxynaphthalene-1-carboxamide (**1**) was synthesized by the microwave-assisted method [18]. In the second step, a modified method using triethylamine for activation of the phenolic group was used [16]. The addition of activated compound **1** to appropriate alkyl isocyanates yielded a series of eight 1-[(2-nitrophenyl)carbamoyl]-naphthalen-2-yl alkylcarbamates **2**–**9**.

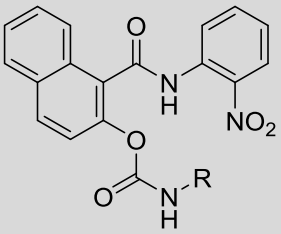
Scheme 1. Synthesis of 1-[(2-nitrophenyl)carbamoyl]naphthalen-2-yl alkylcarbamates **2**–**9** [30]: (a) PCl_3, chlorobenzene, MW; (b) TEA, acetonitrile, ambient temperature.



R: **2** = ethyl; **3** = propyl; **4** = isopropyl; **5** = butyl; **6** = pentyl; **7** = hexyl; **8** = heptyl; **9** = octyl

All the predicted molecular descriptors (lipophilicity, hydrophobic distributive parameters, molar volumes and surface) were calculated using the ACD/Percepta ver. 2012 program (Advanced Chemistry Development, Toronto, ON, Canada), see Table 1. The lipophilicity of compounds **2**–**9**, expressed as log *P* values, ranged from 3.58 (compound **2**, R = C_2H_5) to 7.22 (compound **9**, R = C_8H_{17}). Logically, lipophilicity increases with lengthening of the alkyl tail. Isopropyl showed lower lipophilicity value than propyl. For individual substituents – alkyl chains of the discussed compounds – also hydrophobic properties expressed as distributive parameters π were predicted; they ranged from 0.99 to 4.18. Bulkiness (i.e. tail length/branching) of individual substituents expressed as molar volume MV [cm^{-3}] and surface activity expressed as surface tension ST [dyne/cm] of the discussed carbamates were determined as other parameters that could influence PET-inhibiting activity.

Table 1. Structure of 1-[(2-nitrophenyl)carbamoyl]naphthalen-2-yl alkylcarbamates **2**–**9**, calculated values of log *P* and surface tension (ST [dyne/cm]) of compounds and hydrophobic distributive parameters π and molar volume MV [cm^{-3}] of R substituents (calculated using ACD/Percepta ver. 2012) and IC_{50} [mmol/L] values related to PET inhibition in spinach chloroplasts of tested compounds in comparison with 3-(3,4-dichlorophenyl)-1,1-dimethyl-urea (DCMU).



Comp.	R	log *P*	π	MV [cm^3]	ST [dyne/cm]	PET inhibition IC_{50} [mmol/L]
2	C_2H_5	3.58	0.99	47.29	61.24	0.450
3	C_3H_7	3.96	1.52	63.80	59.35	0.365
4	$CH(CH_3)_2$	3.80	1.34	64.18	58.30	0.664
5	C_4H_9	4.32	2.05	80.31	57.71	0.274
6	C_5H_{11}	5.15	2.58	96.81	56.26	0.233
7	C_6H_{13}	5.71	3.12	113.32	54.97	0.283
8	C_7H_{15}	6.81	3.65	129.83	53.82	0.352
9	C_8H_{17}	7.22	4.18	146.33	52.79	0.487
DCMU	–	–	–	–	–	0.002

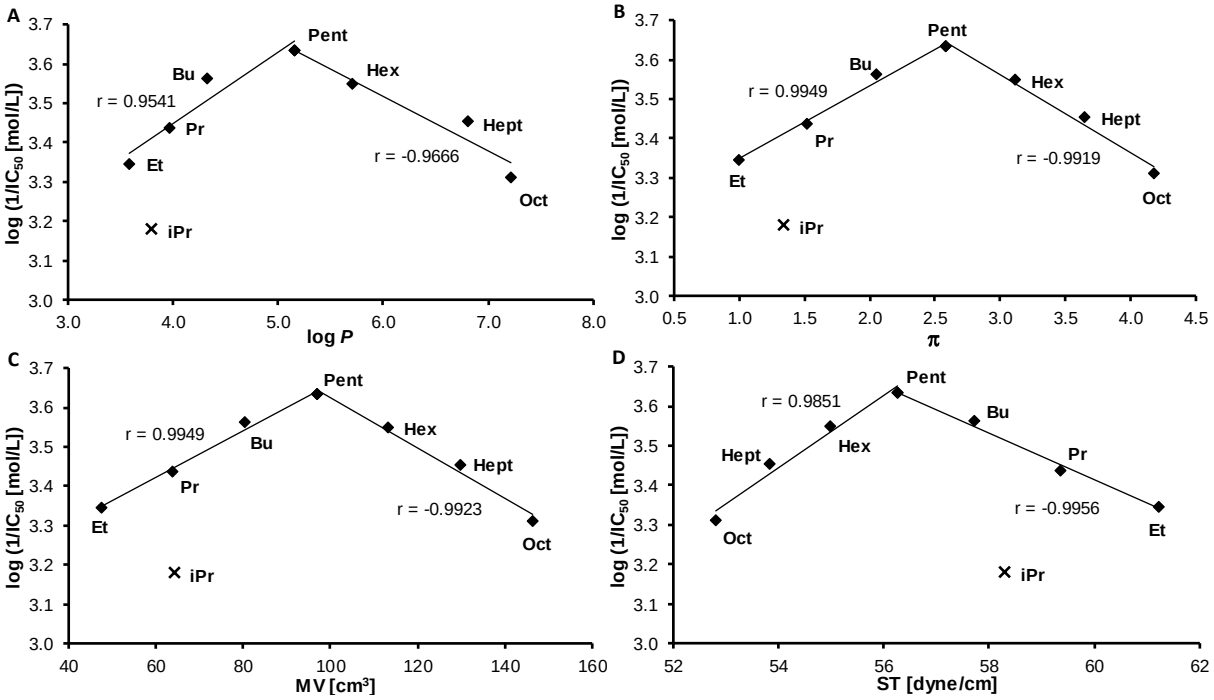
The PET-inhibiting activity was expressed by negative logarithm of IC_{50} value (compound concentration in mol/L causing 50% inhibition of PET). The evaluated 1-[(2-nitrophenyl)-carbamoyl]naphthalen-2-yl alkylcarbamates showed relatively low activity related to PET inhibition in spinach (*Spinacia oleracea* L.) chloroplasts with IC_{50} values ranging from 0.233 to 0.487 mmol/L, see Table 1. 1-[(2-Nitrophenyl)carbamoyl]naphthalen-2-yl pentylcarbamate (**6**) had the highest PET-inhibiting activity (IC_{50} = 0.233 mmol/L) within the investigated series.

The dependences of the PET-inhibiting activity log(1/IC_{50} [mol/L]) of compounds **2**–**9** in spinach chloroplasts on lipophilicity (expressed as log *P*), hydrophobicity (expressed as distributive parameter π) and bulkiness expressed as molar volume MV of the alkyl tails as well as on surface activity expressed as surface tension ST of compounds are illustrated in Figures 1A–1D. Bilinear dependences of activity on individual descriptors can be observed in all Figures. The PET-inhibiting activity within the series linearly increased with the increase of log *P* values (as lipophilicity of the whole structure including intramolecular interactions, correlation coefficient r = 0.9541, n = 4, Fig. 1A), distributive parameter (influence of substituent R hydrophobicity, r = 0.9949, n = 4, Fig. 1B), molar volume (influence of substituent R bulkiness, r = 0.9949, n = 4, Fig. 1C) and with increasing surface tension (i.e. with a decrease of surface activity, r = 0.9851, n = 4, Fig. 1D) up to pentyl derivative **6**. After this optimum, activity linearly decreased with the subsequent increase of lipophilicity (r = -0.9666, n = 4, Fig. 1A), distributive parameter (r = -0.9919, n = 4, Fig. 1B), molar volume (r = -0.9923, n = 4, Fig. 1C) and surface tension (i.e. with a surface activity decrease, r = -0.9956, n = 4, Fig. 1D). A better correlation coefficient estimated for the dependence of log(1/IC_{50}) on distributive parameter π characterizing the hydrophobicity of R substituent compared to that of log(1/IC_{50}) on log *P* characterizing

the lipophilicity of the whole molecule indicates that the inhibitory activity is dominantly affected by R substituent causing perturbation of thylakoid membranes. On the other hand, in general limited PET-inhibiting activity of the compounds can be caused by possible interactions of amide and carbamate groups (responsible also for interactions with photosynthetic apparatus) with the spatially close NO_2 moiety in the *ortho* position of anilide ring [16–19,31].

An increase of PET-inhibiting activity with the prolongation of the alkyl tail estimated for compounds **2**, **3**, **5**, **6** is connected with the fact that a longer alkyl chain can be incorporated in the thylakoid membrane to a greater extent and subsequently causes membrane damage. This biological activity is connected with the surface activity of these compounds (they can be considered as non-ionic surfactants) and with the alkyl tail length (molar volume), which is again reflected in lipophilicity. Nevertheless, besides the above-mentioned physicochemical parameters, also the appropriate concentration of the compound at the site of action in the photosynthetic apparatus is important for PET-inhibiting activity. Consequently, a compound having poor water solubility cannot pass through the hydrophilic regions of the thylakoid membrane to reach the site of action, which results in a significant decrease of inhibitory activity. The solubility of hexyl derivative **7** and especially derivatives **8** and **9** with longer alkyl chains was significantly lower than that of pentyl derivative **6**, which resulted in a notable activity decrease. From the aspect of PET-inhibiting activity, the lipophilicity optimum can be found for C_5, see Fig. 1. With the further elongation of the alkyl chain (hydrophobic part) to octyl, so called 'cut-off' effect, i.e. the loss of biological activity with the increasing lipophilicity of the compounds usually observed for amphiphilic compounds was manifested [5,28,32–34].

Figure 1. Dependence of PET-inhibiting activity log(1/IC_{50} [mol/L]) of compounds **2**–**9** in spinach chloroplasts on lipophilicity of compounds expressed as log *P* (**A**), hydrophobic distributive parameters π of R substituents (**B**), bulkiness of R substituents expressed as molar volume MV [cm^{-3}] of alkyl tail (**C**) and surface tension (ST [dyne/cm]) (**D**) of compounds.



The application of 2,5-diphenylcarbazide (DPC, artificial electron donor) that supplies electrons in the site of $Z^{\bullet}/D^{\bullet}$ intermediate, i.e. tyrosine radicals Tyr_Z and Tyr_D (or their surroundings) that are situated in D_1 and D_2 proteins on the donor side of PS II [10], to chloroplasts, the activity of which was inhibited by the most active compound **6** (up to 30% of

the control), caused practically complete PET restoration already at addition of 3-fold DPC concentration with regard to the applied concentration of compound **6**. Therefore it can be concluded that the site of action of the studied 1-[(2-nitrophenyl)carbamoyl]naphthalen-2-yl alkylcarbamates is situated mainly on the donor side of PS II. The site of action situated on the donor side of PS II was found also for 2-alkylthio-6-R-benzothiazoles (R = 6-formamido-, 6-acetamido-, and 6-benzoylamino-) [35], anilides of 2-alkylpyridine-4-carboxylic acids [36], cationic surfactants [37,38] acting in the intermediates $Z^{\bullet}/D^{\bullet}$ and 2-alkylsulphanyl-4-pyridinecarbothioamides acting in the $D^{\bullet}$ intermediate [39].

EXPERIMENTAL

General

All reagents were purchased from Aldrich (Sigma-Aldrich, St. Louis, MO, USA) and Alfa (Alfa-Aesar, Ward Hill, Massachusetts, USA). TLC experiments were performed on alumina-backed silica gel 60 F254 plates (Merck, Darmstadt, Germany). The plates were illuminated under UV (254 nm) and evaluated in iodine vapour. The melting points were determined on a Kofler hot-plate apparatus HMK (Franz Kustner Nacht KG, Dresden, Germany) and are uncorrected. Infrared (IR) spectra were recorded on a Smart MIRacle™ ATR ZnSe for Nicolet™ Impact 410 FT-IR spectrometer (Thermo Scientific, West Palm Beach, FL, USA). The spectra were obtained by accumulation of 256 scans with 2 cm^{-1} resolution in the region of 4000–650 cm^{-1}. All ^{1}H- and ^{13}C-NMR spectra were recorded on a JEOL ECZR 400 MHz NMR spectrometer (400 MHz for ^{1}H and 100 MHz for ^{13}C, JEOL, Tokyo, Japan) in DMSO-d_6. ^{1}H and ^{13}C chemical shifts (δ) are reported in ppm. High-resolution mass spectra were measured using a high-performance liquid chromatograph Dionex UltiMate® 3000 (Thermo Scientific) coupled with a LTQ Orbitrap XL™ Hybrid Ion Trap-Orbitrap Fourier Transform Mass Spectrometer (Thermo Scientific) with injection into HESI II in the positive mode. The lipophilicity (log *P*) of the final compounds, the surface tension and the molar volume of R substituents were predicted using ACD/Percepta ver. 2012 (Advanced Chemistry Development, Inc., Toronto, ON, Canada).

Synthesis

The synthetic pathway and the characterization of *N*-(2-nitrophenyl)-2-hydroxynaphthalene-1-carboxamide (**1**) were described by Gonec *et al.* [18]. The characterizations of target 1-[(2-nitrophenyl)carbamoyl]naphthalen-2-yl alkylcarbamates **2**–**9** were published recently [30], nevertheless, for the complexity of the studies, the analytical data of individual discussed compounds are mentioned below.

General procedure for synthesis of alkylcarbamates **2**–**9**: *N*-(2-nitrophenyl)-2-hydroxynaphthalene-1-carboxamide (**1**, 1.0 mmol) and triethylamine (1.1 mmol) were suspended in dry acetonitrile (10 mL). The solution of the appropriate alkyl isocyanate (1.2 mmol) in acetonitrile (5 mL) was added in four portions within 2 h, and the reacting mixture was stirred for 24 h at ambient temperature. The solvent was evaporated under reduced pressure, and the solid residue was washed with methanol and ethyl acetate to give pure product. Studied compounds **2**–**9** are presented in Table 1.

1-[(2-Nitrophenyl)carbamoyl]naphthalen-2-yl ethylcarbamate (**2**). Yield 40%; Mp 157–159 °C; IR (cm^{-1}): 3320, 3216, 2963, 2917, 2843, 1743, 1705, 1656, 1645, 1608, 1580, 1532, 1504, 1462, 1432, 1357, 1341, 1294, 1270, 1250, 1216, 1199, 1162, 1144, 1079, 1034, 993, 822, 791, 779, 732, 667; ^{1}H-NMR (DMSO-d_6) δ: 10.94 (s, 1H), 8.07 (d, J = 9.1 Hz, 1H), 8.01–8.05 (m, 3H), 7.71–7.80 (m, 3H), 7.65 (ddd, J = 8.2 Hz, 6.9 Hz, 1.4 Hz, 1H), 7.59 (ddd, J = 8.2 Hz, 6.9 Hz, 1.4 Hz, 1H), 7.41–7.48 (m, 2H), 3.04–3.11 (m, 2H), 1.03 (t, J = 7.1 Hz, 3H); ^{13}C-NMR (DMSO-d_6), δ: 164.12, 153.71, 145.56, 142.98, 133.89, 130.62, 130.51, 130.33,

130.26, 128.10, 127.42, 125.91, 125.82, 125.70, 124.96, 124.90, 124.43, 122.62, 35.39, 14.75; HR-MS: for $C_{20}H_{16}O_5N_3$ $[M + H]^+$ calculated 378.10845, found 378.10934 *m/z.*

1-[(2-Nitrophenyl)carbamoyl]naphthalen-2-yl propylcarbamate (**3**). Yield 75%; Mp 153–155 °C; IR (cm^{-1}): 3298, 3223, 2960, 2930, 2873, 1727, 1717, 1662, 1589, 1537, 1520, 1505, 1488, 1463, 1440, 1353, 1285, 1257, 1224, 1146, 1106, 1051, 996, 981, 914, 865, 818, 779, 731, 666; ^{1}H-NMR (DMSO-d_6) δ: 10.93 (s, 1H), 8.07 (d, *J* = 9.1 Hz, 1H), 8.01–8.05 (m, 3H), 7.72–7.82 (m, 3H), 7.65 (ddd, *J* = 8.2 Hz, 6.9 Hz, 1.4 Hz, 1H), 7.59 (ddd, *J* = 8.2 Hz, 6.9 Hz, 1.4 Hz, 1H), 7.41–7.48 (m, 2H), 3.00 (q, *J* = 6.5 Hz, 2H), 1.42 (sx, *J* = 7.1 Hz, 2H), 0.80 (t, *J* = 7.3 Hz, 3H); ^{13}C-NMR (DMSO-d_6), δ: 164.14, 153.94, 145.61, 142.89, 133.91, 130.69, 130.53, 130.33, 130.33, 128.11, 127.43, 125.93, 125.79, 125.72, 125.64, 124.91, 124.46, 122.62, 42.29, 22.37, 11.10; HR-MS: for $C_{21}H_{18}O_5N_3$ $[M + H]^+$ calculated 392.12410, found 392.12521 *m/z.*

1-[(2-Nitrophenyl)carbamoyl]naphthalen-2-yl isoproylcarbamate (**4**). Yield 69%; Mp 172–176 °C; IR (cm^{-1}): 3355, 3320, 2974, 1738, 1665, 1586, 1532, 1505, 1489, 1440, 1362, 1245, 1213, 1173, 1149, 1056, 1018, 953, 924, 826, 778, 763, 732; ^{1}H-NMR (DMSO-d_6) δ: 10.93 (s, 1H), 8.07 (d, *J* = 9.1 Hz, 1H), 8.01–8.05 (m, 3H), 7.75–7.80 (m, 3H), 7.66 (ddd, *J* = 8.2 Hz, 6.9 Hz, 1.4 Hz, 1H), 7.59 (ddd, *J* = 8.2 Hz, 6.9 Hz, 1.4 Hz, 1H), 7.46 (td, *J* = 8.2 Hz, 1.4 Hz, 1H), 7.42 (d, *J* = 9.1 Hz, 1H), 3.65 (sx, *J* = 6.4 Hz, 2H), 1.07 (d, *J* = 6.4 Hz, 6H); ^{13}C-NMR (DMSO-d_6), δ: 164.18, 153.10, 145.61, 142.94, 133.92, 130.69, 130.54, 130.37, 130.33, 128.14, 127.46, 125.96, 125.85, 125.80, 125.72, 124.94, 124.46, 122.71, 42.86, 22.32; HR-MS: for $C_{21}H_{18}O_5N_3$ $[M + H]^+$ calculated 394.13975, found 394.14058 *m/z.*

1-[(2-Nitrophenyl)carbamoyl]naphthalen-2-yl butylcarbamate (**5**). Yield 82%; Mp 171–174 °C; IR (cm^{-1}): 3293, 3222, 2957, 2873, 1724, 1661, 1589, 1549, 1532, 1520, 1505, 1471, 1463, 1439, 1350, 1279, 1257, 1227, 1145, 1109, 1006, 914, 865, 818, 779, 769, 731, 680, 667; ^{1}H-NMR (DMSO-d_6) δ: 10.92 (s, 1H), 8.07 (d, *J* = 9.1 Hz, 1H), 8.01–8.05 (m, 3H), 7.73–7.80 (m, 3H), 7.65 (ddd, *J* = 8.2 Hz, 6.9 Hz, 1.4 Hz, 1H), 7.58 (ddd, *J* = 8.2 Hz, 6.9 Hz, 1.4 Hz, 1H), 7.45 (td, *J* = 8.2 Hz, 1.4 Hz, 1H), 7.38 (d, *J* = 9.1 Hz, 1H), 3.03 (q, *J* = 6.2 Hz, 2H), 1.38 (qi, *J* = 7.0 Hz, 2H), 1.23 (sx, *J* = 7.0 Hz, 2H), 0.81 (t, *J* = 7.1 Hz, 3H); ^{13}C-NMR (DMSO-d_6), δ: 164.13, 153.91, 145.58, 142.77, 133.91, 130.74, 130.52, 130.32, 130.31, 128.10, 127.41, 125.91, 125.74, 125.73, 125.56, 124.91, 124.44, 122.59, 40.18, 31.23, 19.27, 13.58; HR-MS: for $C_{22}H_{20}O_5N_3$ $[M + H]^+$ calculated 406.13975, found 406.14081 *m/z.*

1-[(2-Nitrophenyl)carbamoyl]naphthalen-2-yl pentylcarbamate (**6**). Yield 70%; Mp 141–143 °C; IR (cm^{-1}): 3298, 3226, 2935, 2874, 1723, 1667, 1588, 1548, 1532, 1519, 1505, 1485, 1475, 1436, 1347, 1322, 1284, 1253, 1226, 1142, 1108, 1037, 1025, 996, 913, 866, 819, 778, 767, 730, 680, 660; ^{1}H-NMR (DMSO-d_6) δ: 10.93 (s, 1H), 8.07 (d, *J* = 9.1 Hz, 1H), 8.01–8.05 (m, 3H), 7.75–7.81 (m, 3H), 7.65 (ddd, *J* = 8.2 Hz, 6.9 Hz, 1.4 Hz, 1H), 7.58 (ddd, *J* = 8.2 Hz, 6.9 Hz, 1.4 Hz, 1H), 7.45 (td, *J* = 8.2 Hz, 1.4 Hz, 1H), 7.41 (d, *J* = 9.1 Hz, 1H), 3.02 (q, *J* = 6.4 Hz, 2H), 1.40 (qi, *J* = 7.0 Hz, 2H), 1.09–1.33 (m, 4H), 0.82 (t, *J* = 6.2 Hz, 3H); ^{13}C-NMR (DMSO-d_6), δ: 164.12, 153.89, 145.58, 142.80, 133.88, 130.72, 130.51, 130.31, 130.30, 128.10, 127.42, 125.91, 125.74, 125.72, 125.58, 124.91, 124.44, 122.61, 40.47, 28.77, 28.29, 21.76, 13.83; HR-MS: for $C_{23}H_{22}O_5N_3$ $[M + H]^+$ calculated 420.15540, found 420.15643 *m/z.*

1-[(2-Nitrophenyl)carbamoyl]naphthalen-2-yl hexylcarbamate (**7**). Yield 58%; Mp 122–123 °C; IR (cm^{-1}): 3332, 3272, 2929, 2868, 1709, 1665, 1609, 1589, 1541, 1514, 1472, 1443, 1352, 1295, 1250, 1215, 1205, 1158, 1148, 1113, 1046, 993, 978, 911, 863, 825, 779, 761, 738, 697, 672; ^{1}H-NMR (DMSO-d_6) δ: 10.93 (s, 1H), 8.07 (d, *J* = 9.1 Hz, 1H), 8.01–8.05 (m, 3H), 7.75–7.81 (m, 3H), 7.65 (ddd, *J* = 8.2 Hz, 6.9 Hz, 1.4 Hz, 1H), 7.58 (ddd, *J* = 8.2 Hz, 6.9 Hz, 1.4 Hz, 1H), 7.45 (td, *J* = 8.2 Hz, 1.4 Hz, 1H), 7.41 (d, *J* = 9.1 Hz, 1H), 3.02 (q, *J* = 6.0 Hz, 2H), 1.38 (qi, *J* = 6.4 Hz, 2H), 1.18–1.25 (m, 6H), 0.83 (t, *J* = 6.6 Hz, 3H); ^{13}C-NMR

(DMSO-d_6), δ: 164.65, 154.44, 146.08, 143.25, 134.42, 131.24, 131.04, 130.83, 130.82, 128.61, 127.94, 126.44, 126.23, 126.23, 126.06, 125.42, 124.94, 123.10, 41.03, 31.42, 29.56, 26.28, 22.49, 14.38; HR-MS: for $C_{24}H_{24}O_5N_3$ $[M + H]^+$ calculated 434.17105, found 434.17236 *m/z*.

1-[(2-Nitrophenyl)carbamoyl]naphthalen-2-yl heptylcarbamate (**8**). Yield 46%; Mp 101–102 °C; IR (cm^{-1}): 3333, 3265, 2957, 2925, 2852, 1709, 1665, 1652, 1609, 1588, 1541, 1511, 1472, 1464, 1441, 1350, 1294, 1250, 1215, 1205, 1148, 1045, 979, 911, 824, 779, 755, 737, 696, 667; ^{1}H-NMR (DMSO-d_6) δ: 10.93 (s, 1H), 8.07 (d, *J* = 9.1 Hz, 1H), 8.01–8.05 (m, 3H), 7.75–7.81 (m, 3H), 7.65 (ddd, *J* = 8.2 Hz, 6.9 Hz, 1.4 Hz, 1H), 7.58 (ddd, *J* = 8.2 Hz, 6.9 Hz, 1.4 Hz, 1H), 7.45 (td, *J* = 8.2 Hz, 1.4 Hz, 1H), 7.41 (d, *J* = 9.1 Hz, 1H), 3.02 (q, *J* = 6.3 Hz, 2H), 1.39 (qi, *J* = 6.4 Hz, 2H), 1.17–1.28 (m, 8H), 0.85 (t, *J* = 6.6 Hz, 3H); ^{13}C-NMR (DMSO-d_6), δ: 164.12, 153.89, 145.58, 142.77, 133.88, 130.74, 130.53, 130.31, 130.31, 128.10, 127.42, 125.91, 125.73, 125.72, 125.58, 124.90, 124.44, 122.61, 40.50, 31.16, 29.11, 28.36, 26.07, 22.04, 13.93; HR-MS: for $C_{25}H_{26}O_5N_3$ $[M + H]^+$ calculated 448.18670, found 448.18848 *m/z*.

1-[(2-Nitrophenyl)carbamoyl]naphthalen-2-yl octylcarbamate (**9**). Yield 37%; Mp 92–94 °C; IR (cm^{-1}): 3315, 3230, 2924, 2850, 1704, 1653, 1589, 1528, 1508, 1485, 1463, 1435, 1360, 1293, 1271, 1251, 1219, 915, 834, 780, 759, 736, 701, 667; ^{1}H-NMR (DMSO-d_6) δ: 10.93 (s, 1H), 8.07 (d, *J* = 9.1 Hz, 1H), 8.01–8.05 (m, 3H), 7.75–7.81 (m, 3H), 7.65 (ddd, *J* = 8.2 Hz, 6.9 Hz, 1.4 Hz, 1H), 7.59 (ddd, *J* = 8.2 Hz, 6.9 Hz, 1.4 Hz, 1H), 7.46 (td, *J* = 8.2 Hz, 1.4 Hz, 1H), 7.41 (d, *J* = 9.1 Hz, 1H), 3.03 (q, *J* = 5.5 Hz, 2H), 1.39 (qi, *J* = 6.0 Hz, 2H), 1.18–1.29 (m, 10H), 0.86 (t, *J* = 6.4 Hz, 3H); ^{13}C-NMR (DMSO-d_6), δ: 164.12, 153.89, 145.58, 142.79, 133.86, 130.72, 130.51, 130.32, 130.31, 128.10, 127.42, 125.91, 125.75, 125.72, 125.58, 124.90, 124.44, 122.59, 40.50, 31.22, 29.09, 28.67, 28.59, 26.12, 22.07, 13.95; HR-MS: for $C_{26}H_{28}O_5N_3$ $[M + H]^+$ calculated 462.20235, found 462.20410 *m/z*.

Study of photosynthetic electron transport (PET) inhibition in spinach chloroplasts

Chloroplasts were prepared from spinach (*Spinacia oleracea* L.) according to Masarovicova and Kralova [40]. The inhibition of photosynthetic electron transport (PET) in spinach chloroplasts was determined spectrophotometrically (Genesys 6, Thermo Scientific), using the artificial electron acceptor 2,6-dichlorophenol-indophenol (DCPIP) according to Kralova *et al*. [41], and the rate of photosynthetic electron transport was monitored as a photoreduction of DCPIP. The measurements were carried out in phosphate buffer (0.02 mol/L, pH 7.2) containing sucrose (0.4 mol/L), $MgCl_2$ (0.005 mol/L) and NaCl (0.015 mol/L). The chlorophyll content was 30 mg/L in these experiments, and the samples were irradiated (~100 W/m^2 with 10 cm distance) with a halogen lamp (250 W) using a 4 cm water filter to prevent warming of the samples (suspension temperature ~4 °C). The studied compounds were dissolved in DMSO due to their limited water solubility. The applied DMSO concentration (up to 4%) did not affect the photochemical activity in spinach chloroplasts. The inhibitory efficiency of the studied compounds was expressed by IC_{50} values, i.e. by molar concentration of the compounds causing a 50% decrease in the oxygen evolution rate relative to the untreated control. The comparable IC_{50} value for the selective herbicide 3-(3,4-dichlorophenyl)-1,1-dimethylurea, DCMU (Diuron®), was about 0.002 mmol/L. The results are summarized in Table 1.

ACKNOWLEDGEMENTS

This study was supported by IGA VFU Brno 320/2015/FaF and by the Slovak Research and Development Agency (Grant No. APVV-0516-12). The HPLC/HRMS system forms a part of the National Infrastructure CzeCOS (LM2015061); Michal Oravec was supported by the National Sustainability Program (NPU I; Grant No. LO1415 POLYMAT).

REFERENCES

1. Steinhilber, D.; Schubert-Zsilavecz, M.; Roth, H.J. *Medizinische Chemie: Targets, Arzneistoffe, Chemische Biologie*. Deutscher Apotheker Verlag, Stutgart, Germany; 2010.
2. US Environmental Protection Agency – *Pesticide Registration: Pesticide Data Submitters List (PDSL)*, 2016. Available online: https://www.epa.gov/sites/production/files/2016-04/documents/dslchem_0.pdf (accessed on 25 September 2016).
3. Pattabiraman, V. R. Bode, J. W. Rethinking amide bond synthesis. *Nature* **2011**, *480*, 471–479.
4. Ghosh, A.K.; Brindisi, M. Organic carbamates in drug design and medicinal chemistry. *J. Med. Chem.* **2015**, *58*, 2895–2940.
5. Good, N.E. Inhibitors of the Hill reaction. *Plant Physiol.* **1961**, *36*, 788–803.
6. Draber, W.; Tietjen, K.; Kluth, J.F.; Trebst, A. Herbicides in photosynthesis research. *Angew. Chem.* **1991**, *3*, 1621–1633.
7. Tischer, W.; Strotmann, H. Relationship between inhibitor binding by chloroplasts and inhibition of photosynthetic electron-transport. *Biochim. Biophys. Acta* **1977**, *460*, 113–125.
8. Trebst, A.; Draber, W. Structure activity correlations of recent herbicides in photosynthetic reactions. In: *Advances in Pesticide Science*; Greissbuehler, H., Ed.; Pergamon Press: Oxford, 1979; pp. 223–234.
9. Bowyer, J.R.; Camilleri, P.; Vermaas, W.F.J. Photosystem II and its interaction with herbicides. In: *Herbicides, Topics in Photosynthesis*, Baker, N.R.; Percival, M.P., Eds.; Elsevier Science B.V: Amsterdam, 1991; Vol. 10, pp. 27–85.
10. Izawa, S. Acceptors and donors for chloroplast electron transport. In *Methods in Enzymology*, Vol. 69, Part C, Colowick, P., Kaplan, N.O., Eds.; Academic Press: New York – London, UK, 1980; pp. 413–434.
11. Kralova, K.; Sersen, F.; Cizmarik, J. Inhibitory effect of piperidinoethylesters of alkoxyphenylcarbamic acids on photosynthesis. *Gen. Physiol. Biophys.* **1992**, *11*, 261–267.
12. Kralova, K.; Sersen, F.; Kubicova, L.; Waisser, K. Inhibitory effects of substituted benzanilides on photosynthetic electron transport in spinach chloroplasts. *Chem. Pap.* **1999**, *53*, 328–331.
13. Kralova, K.; Sersen, F.; Kubicova, L.; Waisser, K. Inhibition of photosynthetic electron transport in spinach chloroplasts by 3- and 4-halogeno substituted benzanilides and thiobenzanilides. *J. Trace Microprobe Technol.* **2000**, *18*, 251–256.
14. Otevrel, J.; Mandelova, Z.; Pesko, M.; Guo, J.; Kralova, K.; Sersen, F.; Vejsova, M.; Kalinowski, D.; Kovacevic, Z.; Coffey, A.; Csollei, J.; Richardson, D.R.; Jampilek, J. Investigating the spectrum of biological activity of ring-substituted salicylanilides and carbamoylphenylcarbamates. *Molecules* **2010**, *15*, 8122–8142.
15. Imramovsky, A.; Pesko, M.; Kralova, K.; Vejsova, M.; Stolarikova, J.; Vinsova, J.; Jampilek, J. Investigating spectrum of biological activity of 4- and 5-chloro-2-hydroxy-N-[2-(arylamino)-1-alkyl-2-oxoethyl]benzamides. *Molecules* **2011**, *16*, 2414–2430.
16. Imramovsky, A.; Pesko, M.; Monreal-Ferriz, J.; Kralova, K.; Vinsova, J.; Jampilek, J. Photosynthesis-inhibiting efficiency of 4-chloro-2-(chlorophenylcarbamoyl)phenyl alkyl-carbamates. *Bioorg. Med. Chem. Lett.* **2011**, *21*, 4564–4567.
17. Kos, J.; Zadrazilova, I.; Pesko, M.; Keltosova, S.; Tengler, J.; Gonec, T.; Bobal, P.; Kauerova, T.; Oravec, M.; Kollar, P.; Cizek, A.; Kralova, K.; Jampilek, J. Antibacterial and herbicidal activity of ring-substituted 3-hydroxynaphthalene-2-carboxanilides. *Molecules* **2013**, *18*, 7977–7997.
18. Gonec, T.; Kos, J.; Zadrazilova, I.; Pesko, M.; Govender, R.; Keltosova, S.; Chambel, B.; Pereira, D.; Kollar, P.; Imramovsky, A.; O´Mahony, J.; Coffey, A.; Cizek, A.; Kralova, K.; Jampilek, J. Antibacterial and herbicidal activity of ring-substituted 2-hydroxynaphthalene-1-carboxanilides. *Molecules* **2013**, *18*, 9397–9419.

19. Gonec, T.; Kos, J.; Zadrazilova, I.; Pesko, M.; Keltosova, S.; Tengler, J.; Bobal, P.; Kollar, P.; Cizek, A.; Kralova, K.; Jampilek, J. Antimycobacterial and herbicidal activity of ring-substituted 1-hydroxynaphthalene-2-carboxanilides. *Bioorg. Med. Chem.* **2013**, *21*, 6531–6541.
20. Gonec, T.; Zadrazilova, I.; Nevin, E.; Kauerova, T.; Pesko, M.; Kos, J.; Oravec, M.; Kollar, P.; Coffey, A.; O´Mahony, J.; Cizek, A.; Kralova, K.; Jampilek, J. Synthesis and biological evaluation of *N*-alkoxyphenyl-3-hydroxynaphthalene-2-carboxanilides. *Molecules* **2015**, *20*, 9767–9787.
21. Kralova, K.; Perina, M.; Waisser, K.; Jampilek, J. Structure-activity relationships of N-benzyl-salicylamides for inhibition of photosynthetic electron transport. *Med. Chem.* **2015**, 11, 156–164.
22. Williamson, R.L.; Metcalf, R.L. Salicylanilides: A new group of active uncouplers of oxidative phosphorylation. *Science* **1967**, *158*, 1694–1695.
23. Renger, G. The action of 5-chloro-3-tert-butyl-2´-chloro-4´-nitro-salicylanilide and α,α-bis(hexafluoroacetonyl)aceton on the water-splitting enzyme system Y in spinach chloroplasts. *FEBS Lett.* **1975**, *52*, 30–32.
24. Black, C.C. Photosynthetic phosphorylation and associated reactions in the presence of a new group of uncouplers: Salicylanilides. *Biochim. Biophys. Acta* **1968**, *162*, 294–296.
25. Jampilek, J.; Dolezal, M.; Kunes, J.; Buchta, V.; Silva, L.; Kralova, K. Quinaldine derivatives: Preparation and biological activity. *Med. Chem.* **2005**, *1*, 591–599.
26. Musiol, R.; Jampilek, J.; Kralova, K.; Richardson, D.R.; Kalinowski, D.; Podeszwa, B.; Finster, J.; Niedbala, H.; Palka, A.; Polanski, J. Investigating biological activity spectrum for novel quinoline analogues. *Bioorg. Med. Chem.* **2007**, *15*, 1280–1288.
27. Musiol, R.; Tabak, D.; Niedbala, H.; Podeszwa, B.; Jampilek, J.; Kralova, K.; Dohnal, J.; Finster, J.; Mencel, A.; Polanski, J. Investigating biological activity spectrum for novel quinoline analogues 2: Hydroxyquinolinecarboxamides with photosynthesis inhibiting activity. *Bioorg. Med. Chem.* **2008**, *16*, 4490–4499.
28. Jampilek, J.; Kralova, K.; Pesko, M.; Kos, J. Ring-substituted 8-hydroxyquinoline-2-carboxanilides as photosystem II inhibitors. *Bioorg. Med. Chem. Lett.* **2016**, *26*, 3862–3865.
29. Zadrazilova, I.; Pospisilova, S.; Masarikova, M.; Imramovsky, A.; Monreal-Ferriz, J.; Vinsova, J.; Cizek, A.; Jampilek, J. Salicylanilide carbamates: Promising antibacterial agents with high in vitro activity against methicillin-resistant Staphylococcus aureus. *Eur. J. Pharm. Sci.* **2015**, *77*, 197–207.
30. Gonec, T.; Pospisilova, S.; Holanova, L.; Stranik, J.; Cernikova, A.; Pudelkova, V.; Kos, J.; Oravec, M.; Kollar, P.; Cizek, A.; Jampilek, J. Synthesis and antimicrobial evaluation of 1-[(2-substituted phenyl)carbamoyl]naphthalen-2-yl carbamates. *Molecules* **2016**, *21*, 1189.
31. Gonec, T.; Stranik, J.; Pesko, M.; Kos, J.; Oravec, M.; Kralova, K.; Jampilek, J. Preparation and photosynthesis-inhibiting activity of 1-[(2-chlorophenyl)carbamoyl]naphthalen-2-yl alkylcarbamates. *ECSOC-19*, **2015**, November 1-30, b006, http://sciforum.net/conference/80/paper/3079.
32. Balgavy, P.; Devinsky, F. Cut-off effects in biological activities of surfactants. *Adv. Colloid Interfac.* **1996**, *66*, 23–63.
33. Przestalski, S.; Sarapuk, J.; Kleszczynska, H.; Gabrielska, J.; Hladyszowski, J.; Trela, Z.; Kuczera, J. Influence of amphiphilic compounds on membranes. *Acta Biochim. Pol.* **2000**, *47*, 627–638.
34. Sarapuk, J.; Kubica, K. Cut-off phenomenon. *Cell. Mol. Biol. Lett.* **1998**, *5*, 261–269.
35. Kralova, K.; Sersen, F.; Sidoova, E. Effects of 2-alkylthio-6-aminobenzothiazoles and their 6-N-substituted derivatives on photosynthesis inhibition in Chlorella vulgaris and spinach chloroplasts. *Gen. Phys. Biophys.* **1993**, *12*, 421–427.

36. Kralova, K.; Sersen, F.; Miletin, M.; Hartl, J. Inhibition of photosynthetic electron transport by some anilides of 2-alkylpyridine-4-carboxylic acids in spinach chloroplasts. *Chem. Pap.* **1998**, *52*, 52–58.
37. Kralova, K.; Sersen, F. Long chain bisquaternary ammonium salts - effective inhibitors of photosynthesis. *Tenside Surfact. Det.* **1994**, *31*, 192–194.
38. Kralova, K.; Sersen, F.; Devinsky, F.; Lacko, I. Photosynthesis-inhibiting effects of cationic biodegradable gemini surfactants. *Tenside Surfact. Det.* **2010**, *47*, 288–293.
39. Kralova, K.; Sersen, F.; Klimesova, V.; Waisser, K. 2-Alkylsulphanyl-4-pyridine-carbothioamides–inhibitors of oxygen evolution in freshwater alga Chlorella vulgaris. *Chem. Pap.* **2011**, *65*, 909–912.
40. Masarovicova, E.; Kralova, K. Approaches to measuring plant photosynthesis activity. In *Handbook of Photosynthesis*, 2nd ed.; Pessarakli, M., Ed.; Taylor & Francis Group: Boca Raton, FL, USA, 2005; pp. 617–656.
41. Kralova, K.; Sersen, F.; Sidoova, E. Photosynthesis inhibition produced by 2-alkylthio-6-R-benzothiazoles. *Chem. Pap.* **1992**, *46*, 348–350.