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Synthesis of 5-hydroxymethylbenzopsoralen glucoside

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Benzopsoralen derivative, 5-hydroxymethyl-2*H*-benzofuro[3,2-g]-1-benzopyran-2-one (BP-OH, **1**) and its 5-bromomethyl analogue (BP-Br, **3**) were transformed to the corresponding glucoside, 5-(2,3,4,6-tetra-*O*-β-D-glucopyranosyloxymethyl)-2*H*-benzofuro[3,2-g]-1-benzopyran-2-one (benzopsoralen acetylated glucoside, BP-OAG, **7**), which after deacetylation yielded the free glucoside **8**. Different synthetic approaches were tried to accomplish glycosidation, including Ag_2CO_3, $HgO/HgCl_2$, $Hg(CN)_2$ or $BF_3 \cdot Et_2O$ as aglycone and carbohydrate moiety condensation promotors. $Hg(CN)_2$ was found to give significantly better yield (70%) on the product **7** than other mercury and silver salts or $BF_3 \cdot Et_2O$.

Keywords: benzopsoralen glucoside, 5-(β-D-glucopyranosyloxymethyl)-2*H*-benzofuro[3,2-g]-1-benzopyran-2-one, glucosidation, Koenigs-Knorr reaction

Psoriasis is a chronic skin disease characterized by cellular hyperproliferation. At present its main therapeutic cure is the combination of psoralen drugs by topical or oral administration and the exposure to the UVA light. This treatment is called PUVA therapy (from psoralen + UVA) and it is also used for the cure of several other skin diseases, such as *vitiligo, lichen planus, alopecia aerata, lupus erithematosus* etc. Generally, 8-methoxypsoralen (8-MOP) or 5-methoxypsoralen (5-MOP) are used, whereas the use of the synthetic 4,5,8-trimethylpsoralen is reserved to vitiligo (1–3). A more recent application of furocoumarin sensitization is the extracorporeal photochemotherapy (photopheresis). This therapy has been approved by Food and Drug Administration for the cure of cutaneous T-cell linphoma, but it is also employed for some autoimmune diseases and the prevention of rejection in organ transplantation (4, 5). However, psoralen therapy shows a number of side-effects: erythema and hyperpigmentation of skin, genotoxicity and at long-term, a risk of cancer and cataract (6–9). Numerous psoralen derivatives have been synthesized with the aim to increase the antiproliferative activity and to eliminate or decrease undesired effects (10–15). The condensation of benzene to the furan ring gave the compounds, active on DNA macromolecule, but with a scarce solubility in water and in common organic solvents (16–18). Since scarcely soluble compounds are of little value for eventual therapeutic use, an attempt to improve their solubility by an introduction of glucose unit in the structures has been planned. Consequently, the synthesis of 5-hydroxymethylbenzopsoralen glucoside starting from 5-hydroxymeth-

* Correspondence

yl-2*H*-benzofuro[3,2-g]-1-benzopyran-2-one (BP-OH, **1**) or from 5-bromomethyl analogue (BP-Br, **3**) has been tried and carried out. The carbohydrate moieties are known to influence the properties of the parent compound in many and diverse ways. Thus, glycosidation has been found to increase the water solubility, the absorption, decrease excretion, affects intracellular transport and provide protection against enzymatic degradation (19). In this paper efforts towards the synthesis of glucoside derivatives of the above-mentioned benzopsoralen compounds are described.

EXPERIMENTAL

Melting points were determined on a Boëtius Microheating Stage and remained uncorrected. Infrared spectra were recorded on a FT-IR Paragon 500 spectrometer (Perkin Elmer, UK) from KBr pelleted sample. ^{1}H and ^{13}C NMR spectra were recorded on a Varian Gemini 300 spectrometer (Varian, USA), operating at 75.5 MHz for the ^{13}C nucleus. Samples were measured from CD_3OD or DMSO-d_6 solutions at 20 °C in 5-mm NMR tubes. Chemical shifts (ppm) are referred to TMS. The Attached Proton Test (APT) ^{13}C spectrum of compound **8** was recorded from DMSO-d_6 at room temperature with delay time of 0.8 s. For thin layer chromatography, silica gel sheets Kieselgel 60 F_{254} (Merck, Germany) were used. Following solvent mixtures were used: a) chloroform/methanol (1:1); b) chloroform/methanol (7.5:2.5); c) ethyl acetate; d) cyclohexane/ethyl acetate (3:7); e) cyclohexane/ethyl acetate (1:1); and f) cyclohexane/ethyl acetate (7:3). For spot detection iodine vapours and methanol/sulphuric acid in 9:1 ratio were used. Preparative thin layer chromatography was performed on 2 mm thick silica gel sheets PSC Kieselgel 60 F_{254} (Merck, Germany) and column chromatography on silica gel (0.063–0.200 mm) (Kemika, Croatia) previously dried at 110 °C. Cyclohexane/ethyl acetate mixture (3:7) was used as eluent. All solvents were of analytical grade purity and dry.

5-(2,3,4,6-Tetra-O-acetyl-β-D-glucopyranosyloxymethyl)-2H-benzofuro[3,2-g]-1-benzopyran-2-one (benzopsoralen acetylated glucoside, BP-OAG, 7)

Method A. – From a solution of 0.240 g (0.90 mmol) BP-OH (**1**) in 20 mL of nitromethane and 20 mL benzene, approximately 10 mL of solvent was distilled (azeotropic removal of water). To the cold solution, 0.50 g freshly activated crushed 4Å molecular sieves, 0.470 g (1.70 mmol) freshly prepared Ag_2CO_3 and a solution of 0.383 g (0.93 mmol) ABG (**5**) in 12 mL benzene, were added. The reaction mixture was stirred at room temperature in the dark. After two days a new portion of ABG (0.191 g, 0.46 mmol) was added and stirring was continued for 7 days. TAG (**6**), unreacted BP-OH and the glucoside spot were monitored by TLC by eluting with the corresponding mixture. Insoluble material (inorganic salts and unreacted BP-OH) were filtered off and the mother liquor was evaporated and chromatographed on silica gel column. Yield: 0.054 g (10%).

Method B. – A suspension of 0.041 g (0.10 mmol) ABG (**5**), 0.024 g (0.09 mmol) BP-OH (**1**), 0.040 g (0.29 mmol) $CaSO_4$, 0.040 g (0.18 mmol) red HgO and a catalytic amount of $HgCl_2$ in 5 mL nitromethane was stirred in the dark for 10 days at room temperature. The reaction did not reach completeness within that period and the presence of the start-

ing compounds beside the new glucoside spot was detected by TLC. The product **7** was isolated by thick layer chromatography by eluting with cyclohexane/ethyl acetate (3:7) mixture. Yield: 0.008 g (15%).

Method C. – From a solution of 0.240 g (0.90 mmol) BP-OH (**1**) in 45 mL nitromethane and 45 mL benzene, approximately 20 mL of solvent was distilled. To the hot solution 0.50 g Drierite or freshly activated crushed 4Å molecular sieves, 0.227 g (0.90 mmol) $Hg(CN)_2$ and solution of 0.370 g (0.90 mmol) ABG (**5**) in 30 mL benzene were added. The reaction mixture was stirred at room temperature for 22 h, refluxed 6 h, evaporated and the residue purified by silica gel column chromatography. The isolated product **7** (0.375 g, 70%) was crystallized from tetrahydrofuran/petrolether.

Method D. – A suspension of 0.348 g (1.00 mmol) TAG (**6**), 0.329 g (1.00 mmol) BP-Br (**3**), 0.216 g (1.00 mmol) red HgO, a catalytic amount of $HgCl_2$ and 0.272 g (2.00 mmol) $CaSO_4$ in 5 mL nitromethane was stirred at room temperature for 8 days in the dark. The reaction did not reach completeness even after additional reflux for 6 h. Solvent was evaporated and the residue purified by column chromatography giving a small amount of product **7**. Yield: 0.059 g (5%).

Method E. – A suspension of 0.061g (0.19 mmol) BP-Br (**3**), 0.065 g (0.19 mmol) TAG (**6**), 0.045 g (0.18 mmol) $Hg(CN)_2$ and 0.10 g Drierite in 10 mL nitromethane and 10 mL benzene was refluxed for 10.5 h and additionally stirred five days at room temperature under nitrogen. Only starting compounds and no traces of glucoside **7** were detected on TLC.

Method F. – To a suspension of 0.320 g (1.20 mmol) BP-OH (**1**) and 0.507 g (1.30 mmol) PAG (**4**) in 90 mL chloroform a solution of 0.49 mL (3.90 mmol) $BF_3 \cdot Et_2O$ in 20 mL chloroform was added dropwise together with 0.60 g freshly activated crushed 4Å molecular sieves. The reaction mixture was stirred at room temperature for two days under nitrogen, evaporated and the residue purified by silica gel column chromatography giving the product **7**. Yield: 0.204 g (38%). m.p. 86–87 °C.

IR(KBr): ν_{max} 3030, 1745, 1650, 1615, 1580, 1455, 1375, 1225, 1155, 1135, 1080, 1040, 910, 825, 740 cm^{-1}.

^1H NMR (CD_3OD), δ (ppm): 8.69 (d, *J* = 10.2 Hz, 1H, H-4), 8.52 (d, *J* = 8.6 Hz, 1H, H-9), 7.73 (d, *J* = 8.6 Hz, 1H, H-6), 7.71 (s, 1H, H-11), 7.65 (t, *J* = 8.6 Hz, 1H, H-7), 7.55 (t, *J* = 8.6 Hz, 1H, H-8), 6.57 (d, *J* = 10.2 Hz, 1H, H-3), 5.73 (d, *J* = 12.0 Hz, 1H, H-12a), 5.63 (d, *J* = 12.0 Hz, 1H, H-12b), 4.71 (s, 12H, acetyls), 4.61–4.34 (m, 1H, H-3'), 4.56 (d, *J* = 7.1 Hz, 1H, H-1'), 4.47–4.39 (m, 1H, H-2'), 3.87–3.80 (m, 1H, H-4'), 3.67–3.62 (m, 1H, H-5') (the absorption of 6' protons is covered by hydrogen absorption from water).

Elemental analysis (%):	calcd.	C	60.40	H	4.73
$C_{30}H_{28}O_{13}$ (596.54)	found		60.65		4.92

5-(β-D-glucopyranosyloxymethyl)-2H-benzofuro[3,2-g]-1-benzopyran-2-one (benzopsoralen glucoside, BP-OG, 8)

To a solution of 0.029 g (0.049 mmol) benzopsoralen acetylated glucoside **7** in 3 mL methanol, 3 mL freshly prepared solution of sodium methoxide was added (0.13 g of sodium in 25 mL of methanol). When the reaction completed (20 h at room temperature plus 1 h reflux), Amberlite IR-120 (H^+) was added to make the solution neutral. The

resin was filtered off and the solution evaporated under reduced pressure. The crude product was washed several times with small portions of methanol. Yield: 0.019 g (90%). m.p. 248–250 °C.

IR (KBr): ν_{max} 3440, 3085, 2950, 2880, 1725, 1655, 1615, 1580, 1480, 1455, 1400, 1370, 1315, 1280, 1220, 1150, 1105, 1055, 1020, 830, 750 cm^{-1}.

^1H NMR (DMSO-d_6), δ (ppm): 8.69 (d, J = 10.2 Hz, 1H, H-4), 8.52 (d, J = 8.6 Hz, 1H, H-9), 7.86 (s, 1H, H-11), 7.76 (d, J = 8.6 Hz, 1H, H-6), 7.59 (t, J = 8.6 Hz, 1H, H-7), 7.46 (t, J = 8.6 Hz, 1H, H-8), 6.53 (d, J = 11.1 Hz, 1H, H-3), 5.53 (d, J = 12.9 Hz, 1H, H-12a), 5.41 (d, J = 12.9 Hz, 1H, H-12b), 4.98 (dd, J = 9.7, 5.3 Hz, 1H, H-5'), 4.74 (t, J = 6.3 Hz, 1H, 6'-OH), 4.40 (d, J = 8.5 Hz, 1H, H-1'), 4.11 (s, 3H, 2',3',4'-OH), 3.81–3.76 (m, 1H, H-2'), 3.56–3.48 (m, 1H, H-3'), 3.20–2.99 (m, 1H, H-4'), 2.73–2.67 (m, 2H, H-6').

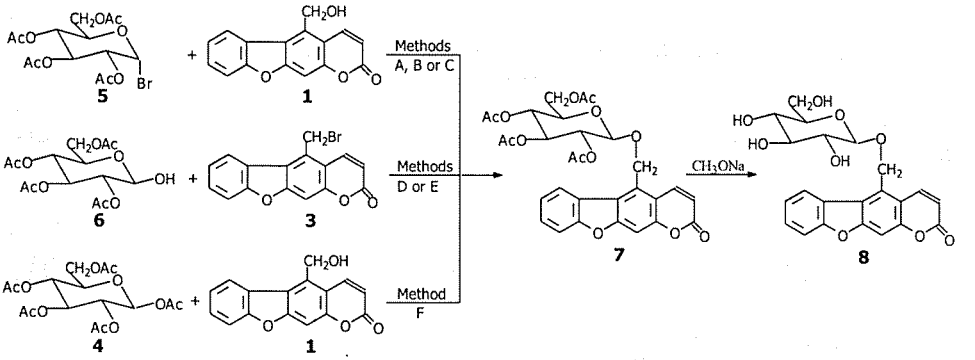
^{13}C NMR (DMSO-d_6), δ (ppm): 160.02 (C-2), 157.19 (C-10a), 156.69 (C-9a), 154.02 (C-11a), 142.12 (C-4), 130.10 (C-5), 128.38 (C-8), 124.24 (C-7), 124.18 (C-6), 122.51 (C-5b), 121.31 (C-5a), 115.01 (C-4a), 114.49 (C-3), 111.79 (C-9), 101.67 (C-1'), 100.28 (C-11), 77.34 (C-3'), 76.88 (C-5'), 73.39 (C-2'), 70.36 (C-4'), 61.81 (C-12) and 61.49 (C-6').

Elemental analysis (%):	calcd. C	61.68	H	4.71
$C_{22}H_{20}O_9$ (428.39)	found	62.01		4.40

RESULTS AND DISCUSSION

5-Bromomethyl-2*H*-benzofuro[3,2-g]-1-benzopyran-2-one (BP-Br, **3**) was synthesized by reacting 5-methyl-2*H*-benzofuro[3,2-g]-1-benzopyran-2-one with *N*-bromosuccinimide in the presence of benzoyl peroxide traces as catalyst (17). Compound **3** was transformed to 5-acetoxymethyl-2*H*-benzofuro[3,2-g]-1-benzopyran-2-one (BP-OA, **2**) in quantitative yield by acetylation with acetic anhydride in the presence of sodium acetate (17). Hydrolysis of **2** in alkaline medium afforded 5-hydroxymethyl-2*H*-benzofuro[3,2-g]-1-benzopyran-2-one (BP-OH, **1**) (17). 1,2,3,4,6-Penta-*O*-acetyl-β-D-glucopyranose (pentacetylglucose, PAG, **4**) was prepared by complete acetylation of glucose (20). 2,3,4,6-Tetra-*O*-acetyl-1-bromo-α-D-glucopyranose (acetobromoglucose, ABG, **5**) was obtained on bromination of **4** (21) and 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranose (tetraacetylglucose, TAG, **6**) was synthesized by hydrolysis of acetobromoglucose in the presence of Ag_2CO_3 (22). All melting points (m.p.) were identical to the published data except for pentacetylglucose (**4**). Its m.p. (104–105 °C) considerably differed from that reported in literature (20) (131–132 °C). This compound was chromatographically pure and was used with no further purification.

To accomplish glucosidation, different synthetic approaches has been examined, including Ag_2CO_3 (Method A), $HgO/HgCl_2$ (Methods B and D), $Hg(CN)_2$ (Method C and E) or $BF_3 \cdot Et_2O$ (Method F) as promotors of aglycone and carbohydrate moiety condensation. The methods used for glucosidation are shown in Scheme 1. The starting compounds were 5-hydroxymethylbenzopsoralen (**1**) and acetobromoglucose (**5**) for Methods A, B and C, 5-bromomethylbenzopsoralen (**3**) and tetraacetylglucose (**6**) for Methods D and E and 5-hydroxymethylbenzopsoralen (**1**) and pentaacetylglucose (**4**) for Method F. First three methods are the classic approaches to glycoside synthesis. They involve activation of anomeric centre of a suitably protected sugar by conversion to an α-haloether



Scheme 1

(compound **5**), which is highly prone to alcoholysis with inversion of the anomeric configuration to give derivatives of β-D-glucopyranoside (23). Initial attempts to couple BP-OH (**1**) with ABG (**5**) using silver reagents, such as Ag_2CO_3, gave unsatisfactory results (Koenigs-Knorr reaction). This suggests a greater rate of the solvolytic decomposition of the glucosyl bromide **5** to TAG (**6**) as compared with nucleophilic attack by the aglycone. However, the Helferich modification of the process employing $Hg(CN)_2$ furnished glucoside **7** in 70% yield. $Hg(CN)_2$ in nitromethane/benzene mixture (Method C) has been found to give significantly better yields than other mercury (Method B) or silver salts (Method A).

Attempt of condensation of the 5-bromomethylbenzopsoralen **3** with the tetraacetylglucose (**6**) failed (Methods D and E) (24). When the reaction was performed in the presence of pyridine 1-(5-methylene-2*H*-benzofuro[3,2-g]-1-benzopyran-2-one)pyridinium bromide (BPP, **9**) was obtained as the only product.

It is known that primary alcohols can be efficiently glycosylated by an acetylated sugar in the presence of Lewis acid. Jansson *et al.* have found boron trifluoride etherate ($BF_3 \cdot Et_2O$) as an optimal Lewis acid since it combines the desired high conservation of the anomeric stereostructure with high reaction rate and solubility in various solvents (25). The activated sugar derivative (fluoroborate ester, sugar-1-*O*-BF_2) is the primary product of the reaction, which then reacts with alcohol to give the corresponding glycoside. In the analogous way, the glycosidation of BP-OH (**1**) by peracetylglucose (PAG, **4**) as glycosyl donor was performed (Method F). This method gave the glycoside product in 38% yield.

Anhydrous conditions in all reactions were required and were assured by means of Drierite (anhydrous calcium sulfate), freshly activated crushed 4Å molecular sieves and/or by azeotropic removal of water with nitromethane/benzene mixture. Some reactions were performed under nitrogen and/or in the dark. Even under these strictly controlled conditions the yields of the condensation reactions were quite low except in the reaction C and the uncoupled sugars and the corresponding benzopsoralen derivative were detected by TLC. Attempts to increase the yields on glucoside **7** by increasing the reaction time or by raising the temperature have failed. The results of the glucosidation reactions are summarized in Table I.

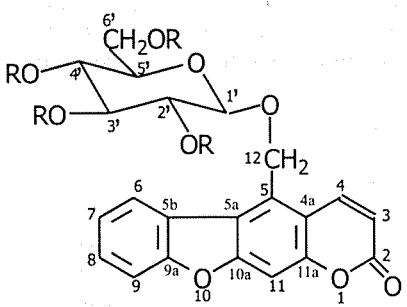
Table I. Reaction conditions for synthesis of 5-(2,3,4,6-tetra-O-acetyl-β-D-glucopyranosyloxymethyl)-2H-benzofuro[3,2-g]-1-benzopyran-2-one (BP-OAG, 7)

Method	Starting compounds		Condensation agent	Solvent	Drying agent	Temp.	Time (h)	Yield (%)
A	BP-OH (1)	ABG (5)	Ag_2CO_3	nitromethane/ benzene	4Å molecular sieves	r.t.[a]	216	10
B	BP-OH (1)	ABG (5)	HgO, $HgCl_2$	nitromethane	Drierite	r.t.	240	15
C	BP-OH (1)	ABG (5)	$Hg(CN)_2$	nitromethane/ benzene	Drierite or 4Å molecular sieves, N_2 atmosphere	r.t./ reflux	22/6	70
D	BP-Br (3)	TAG (6)	HgO, $HgCl_2$	nitromethane	Drierite	r.t./ reflux	192/6	5
E	BP-Br (3)	TAG (6)	$Hg(CN)_2$	nitromethane/ benzene	Drierite, N_2 atmosphere	reflux/ r.t.	10.5/ 120	
F	BP-OH (1)	PAG (4)	$BF_3 \cdot Et_2O$	chloroform	4Å molecular sieves, N_2 atmosphere	r.t.	48	38

[a] r.t. room temperature

Removal of the protecting groups from acetylated glucoside **7** produced the free glucoside **8**. Deacetylation step was performed with sodium methoxide/methanol at room temperature following the analogous literature procedure (26).

The products **7** and **8** were characterized by CHN analysis, IR, ^{1}H NMR and ^{13}C NMR spectra. Chemical structures of glucosides **7** and **8** are displayed in Fig.1. The assignments of ^{1}H and ^{13}C NMR spectra were performed using chemical and substituent shifts, H-H coupling constants, ^{1}H–^{1}H and ^{13}C–^{1}H connectivities, and by comparison with similar systems (27–29). ^{1}H NMR spectrum of glucoside **8** shows seventeen signals. Nine signals are from agluconic moiety. The protons H-12a and b are nonequivalent and



7 R = $COCH_3$
8 R = H

Fig. 1. Chemical structure and atom enumeration of 5-(2,3,4,6-tetra-O-acetyl-β-D-glucopyranosyloxymethyl)-2*H*-benzofuro[3,2-g]-1-benzopyran-2-one (BP-OAG, **7**) and 5-(β-D-glucopyranosyloxymethyl)-2*H*-benzofuro[3,2-g]-1-benzopyran-2-one (BP-OG, **8**).

they appeared in the spectrum as doublet of doublets (δ 5.53 and 5.41 ppm, J = 12.9 Hz). The remaining eight signals are from glucopyranosyl moiety. The APT ^{13}C NMR spectrum showed twenty two signals, ten from quaternary carbons or carbons carrying two protons and twelve from the carbons with one proton. The chemical shifts, integrals and multiplicities support the proposed structure. According to ^1H NMR spectrum the glucoside **8** is in β configuration since its anomeric H-1' appeared as doublet at δ 4.40 with a coupling constant of 8.5 Hz, which is in a good agreement with the previously reported data (δ 4.41 ppm, d, J = 7.9 Hz) (27). In addition, it is known that mercuric cyanide in nitromethane affords predominantly β-D-glycosides from acetylated α-D-glycosyl halides (23) and glycosidation mediated by $BF_3 \cdot Et_2O$ occurs with high conservation of the anomeric stereostructure (β-PAG gives β-glycosides) (25).

Abbreviations. – ABG, 2,3,4,6-tetra-*O*-acetyl-1-bromo-α-D-glucopyranose; APT, Attached Proton Test; BP-Br, 5-bromomethyl-2*H*-benzofuro[3,2-g]-1-benzopyran-2-one; BP-OA, 5-acetoxymethyl-2*H*-benzofuro[3,2-g]-1-benzopyran-2-one; BP-OAG, 5-(2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranosyloxymethyl)-2*H*-benzofuro[3,2-g]-1-benzopyran-2-one; BP-OG, 5-(β-D-glucopyranosyloxymethyl)-2*H*-benzofuro[3,2-g]-1-benzopyran-2-one; BP-OH, 5-hydroxymethyl-2*H*-benzofuro[3,2-g]-1-benzopyran-2-one; BPP, 1-(5-methylene-2*H*-benzofuro[3,2-g]-1-benzopyran-2-one)pyridinium bromide; FT-IR, Fourier Transform Infra Red Spectroscopy; NMR, Nuclear Magnetic Resonance Spectroscopy; PAG, 1,2,3,4,6-penta-*O*-acetyl-β-D-glucopyranose; TAG, 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranose; TLC, Thin Layer Chromatography.

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SAŽETAK

Sinteza glukozida 5-hidroksimetilbenzopsoralena

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Derivat benzopsoralena, 5-hidroksimetil-2*H*-benzofuro[3,2-g]-1-benzopiran-2-on (BP-OH, **1**) i njegov 5-brommetil analog (BP-Br, **3**) prevedeni su u odgovarajući glukozid, 5-(2,3,4,6-tetra-*O*-acetil-β-D-glukopiranoziloksimetil)-2*H*-benzofuro[3,2-g]-1-benzopiran-2-on (benzopsoralen acetilirani glukozid, BP-OAG, **7**), koji je nakon deacetilacije dao slobodni glukozid **8**. Istraženi su različiti sintetski pristupi u reakciji glikozidacije, upotrebljavajući Ag_2CO_3, $HgO/HgCl_2$, $Hg(CN)_2$ ili $BF_3 \cdot Et_2O$ kao promotore kondenzacije aglikona s monosaharidnim ostatkom. Najbolja iskorištenja na produktu **7** postignuta su pomoću $Hg(CN)_2$ (70 %) i $BF_3 \cdot Et_2O$ (38%).

Ključne riječi: glukozid benzopsoralena, 5-(β-D-glukopiranoziloksimetil)-2*H*-benzofuro[3,2-g]-1-benzopiran-2-on, glukozidacija, Koenigs-Knorrova reakcija

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