Hindawi Publishing Corporation
Journal of Chemistry
Volume 2013, Article ID 686242, 5 pages
http://dx.doi.org/10.1155/2013/686242

Research Article

Synthesis of Magnolignan, a New Pigment Lightening Component, via a Suzuki-Miyaura Reaction

Shuhei Narita, Tetsuhiro Ogura, and Toyonobu Usuki

Department of Materials and Life Sciences, Faculty of Science and Technology, Sophia University, 7-1 Kioicho, Chiyoda-ku, Tokyo 102-8554, Japan

Correspondence should be addressed to Toyonobu Usuki; t-usuki@sophia.ac.jp

Received 25 April 2012; Revised 10 July 2012; Accepted 10 July 2012

Academic Editor: Lorenzo Cerretani

Copyright © 2013 Shuhei Narita et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Magnolignan, 2,2′-dihydroxy-5,5′-dipropyl-biphenyl (**1**), is a down-regulator of melanin synthesis that inhibits the maturation of tyrosinase. In this study, a concise total synthesis of **1** was achieved in five steps with 50% overall yield starting from commercially available *trans*-anethole (**2**) via a Suzuki-Miyaura reaction.

1. Introduction

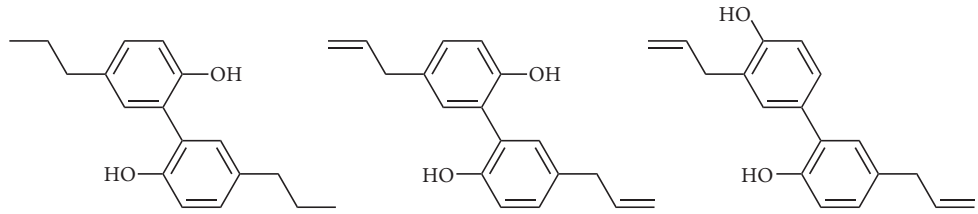
Various treatments with melanin synthesis inhibitors, lasers, and chemical peels have been investigated to achieve lightening effects for pigmented skin in the field of cosmetics. In particular, melanin synthesis inhibitors, such as hydroquinone, have been shown to be an effective treatment of melasma and a prophylactic agent for hyperpigmentation [1]. Melanin synthesis inhibitors have been widely used as lightening components in cosmetic formulations. While hydroquinone has a remarkable lightening effect, its strong bleaching action causes skin irritation. Therefore, alternative hydroquinone derivatives that have a mild or nonirritating effect have been investigated.

Researchers at Kanebo Cosmetics Co. Ltd., Japan, have proved that compounds with a biphenol framework are extraordinarily effective as melanin synthesis inhibitors [2]. Structure-activity relationship (SAR) studies of biphenol compounds strongly suggested that 2,2′-dihydroxy-5,5′-dipropyl-biphenyl (**1**, Figure 1), also known as magnolignan or tetrahydromagnolol, has a greater lightening effect than the natural products magnolol and honokiol, which are isolated from the bark of *Magnolia officinalis* or *M. obovata* [3]. The lightening effect of magnolignan **1** was validated by several bioassays, such as the de novo melanin synthesis [4], the tyrosine hydroxylase assay [5], and melanin measurements [6]. For these studies, the new lightening compound **1** was synthesized using the oxidative coupling method previously reported by Sartori and co-workers [7]. Here, in this paper, a concise total synthesis of magnolignan **1** is described. The key step in the synthesis is a Suzuki-Miyaura reaction [8] in water.

2. Experimental

2.1. General Procedures. All nonaqueous reactions were conducted under an atmosphere of nitrogen with magnetic stirring. Tetrahydrofuran (THF), dichloromethane (CH_2Cl_2), acetonitrile (MeCN), and diethyl ether (Et_2O) were dried by distillation and stored over activated molecular sieves. Dehydrated methanol (MeOH) was purchased from Kanto Chemical (Tokyo, Japan). Dimethyl sulfoxide (DMSO) was purchased from Wako Pure Chemical Industries (Osaka, Japan). All reagents were obtained from commercial suppliers and used without further purification unless otherwise stated. Analytical thin layer chromatography (TLC) was performed on silica gel 60 F_{254} plates produced by Merck. Column chromatography was performed with acidic Silica gel 60 (spherical, 40–50 μm) or neutral Silica gel 60N (spherical, 40–50 μm) produced by Kanto Chemical.

Melting point was measured by an AS one ATM-01 apparatus. Infrared (IR) spectra were recorded on a JASCO FT-IR 4100 spectrometer and are reported in wavenumbers (cm^{-1}).



Magnolignan (**1**) Magnolol Honokiol

Figure 1: Structures of magnolignan (**1**), magnolol, and honokiol.

^{1}H and ^{13}C NMR spectra were recorded on a JEOL JNM-EXC 300 spectrometer (300 MHz) or on a JEOL JNM-ECA 500 spectrometer (500 MHz). ^{1}H NMR data are reported as follows: chemical shift (δ, ppm), integration, multiplicity (s, singlet; d, doublet; t, triplet; m, multiplet), coupling constants (J) in Hz, and assignments. ^{13}C NMR data are reported in terms of chemical shift (δ, ppm). EI-LRMS (GC-MS) spectra were recorded on a Shimadzu GCMS QP-5050 instrument. EI-HRMS spectra were recorded on a JEOL JMS-700 instrument.

*2.2. 1-Methoxy-4-Propylbenzene (***3**). To a suspension of 10% Pd/C (0.101 g) in MeOH (30 mL) under atmosphere of hydrogen was added 1-methoxy-4-(1-propenyl)benzene **2** (1.00 g, 6.75 mmol). After stirring for 3 h at room temperature, the reaction mixture was filtered through a pad of Celite with MeOH. Concentration *in vacuo* afforded **3** (0.957 g, 6.37 mmol, 94%) as a colorless oil; R_f 0.48 (hexane/EtOAc = 20 : 1); IR (neat) ν_{max} 2947, 2063, 1879, 1610, 1509, 1456, 1248, 1179, 1110, 1038, 821, 748, 699, 553 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.10 (2H, d, J = 8.5 Hz, ArH), 6.83 (2H, d, J = 8.6 Hz, ArH), 3.87 (3H, s, OMe), 2.51 (2H, t, J = 7.4 Hz, CH_2), 1.54–1.64 (2H, m, CH_2), 0.92 (3H, t, J = 7.4 Hz, CH_3); ^{13}C NMR (75 MHz, $CDCl_3$) δ 157.8, 134.9, 129.4, 113.7, 55.3, 37.2, 24.9, 13.9; GC-MS (m/z) calcd for $C_{10}H_{14}O$ $[M]^+$ 150.10, found 150.05.

2.3. 2-Bromo-1-Methoxy-4-Propylbenzene (**4**). To a solution of *N*-bromosuccinimide (0.498 g, 2.80 mmol, 1.2 eq) in MeCN (8.75 mL) was added 1-methoxy-4-propylbenzene **3** (0.351 g, 2.34 mmol, 1.0 eq). After stirring for 3 h at room temperature, the reaction mixture was concentrated *in vacuo*, and washed with CCl_4. Concentration *in vacuo* afforded **4** (0.521 g, 2.27 mmol, 97%) as a colorless oil; R_f 0.61 (hexane/EtOAc = 20 : 1); IR (neat) ν_{max} 2957, 1602, 1495, 1262, 1187, 1150, 1054, 887, 808, 747, 714, 672, 595, 556 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.36 (1H, d, J = 2.1 Hz, ArH), 7.06 (1H, dd, J = 8.3, 2.1 Hz, ArH), 6.81 (1H, d, J = 8.3 Hz, ArH), 3.87 (3H, s, OMe), 2.51 (2H, t, J = 7.4 Hz, CH_2), 1.54–1.64 (2H, m, CH_2), 0.92 (3H, t, J = 7.4 Hz, CH_3); ^{13}C NMR (75 MHz, $CDCl_3$) δ 153.9, 136.4, 133.2, 128.4, 111.9, 111.4, 56.3, 36.8, 24.6, 13.7; GC-MS (m/z) calcd for $C_{10}H_{13}BrO$ $[M]^+$ 228.01, found 227.95; EI-HRMS (m/z) calcd for $C_{10}H_{12}BrO$ $[M\text{-}H]^-$ 227.0072, found 227.0072.

2.4. 1-Methoxy-4-Propyl-2-(4,4,5,5-Tetramethyl-[1,3,2]Dioxaborolan-2-yl)Benzene (**5**). To a mixture of [1,1′-bis(diphenylphosphino)ferrocene]palladium(II) dichloride (47.7 mg, 0.0655 mmol, 5 mol%), bis(pinacolato)diboron (399 mg, 1.57 mmol, 1.2 eq), and potassium acetate (386 mg, 3.93 mmol, 3.0 eq) was added 2-bromo-1-methoxy-4-propylbenzene **4** (300 mg, 1.31 mmol, 1.0 eq) in DMSO (4.5 mL). After stirring for 24 h at 80°C, the reaction mixture was diluted with toluene and quenched with H_2O. The aqueous layer was then extracted with toluene. The combined organic layers were washed with H_2O, dried over Na_2SO_4, and concentrated *in vacuo*. Purification by silica gel column chromatography (hexane/EtOAc = 20 : 1) afforded **5** (110.3 mg, 0.399 mmol, 31%), **6** (17.0 mg, 0.0616 mmol, 5%), and **4** (69.3 mg, 0.303 mmol, 23%). **5** was obtained as a brown oil; R_f 0.4 (hexane/EtOAc = 5 : 1); IR (neat) ν_{max} 3517, 2967, 1736, 1602, 1348, 1148, 1037, 963, 915, 853, 819, 752, 676, 581 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.47 (1H, d, J = 2.2 Hz, ArH), 7.19 (1H, dd, J = 8.3, 2.4 Hz, ArH), 6.78 (1H, d, J = 8.5 Hz, ArH), 3.80 (3H, s, OMe), 2.52 (2H, t, J = 7.4 Hz, CH_2), 1.55–1.64 (2H, m, CH_2), 1.35 (12H, s, Bpin), 0.92 (3H, t, J = 7.4 Hz, CH_3); ^{13}C NMR (75 MHz, $CDCl_3$) δ 162.5, 136.8, 136.7, 132.4, 110.5, 83.5, 56.0, 55.6, 37.1, 24.9, 13.9; GC-MS (m/z) calcd for $C_{16}H_{25}BO_3$ $[M]^+$ 276.18, found 275.95; EI-HRMS (m/z) calcd for $C_{16}H_{25}BO_3$ $[M]^+$ 276.1897, found 276.1895.

2.5. 2,2′-Dimethoxy-5,5′-Dipropyl-Biphenyl (**6**). To a mixture of 2-bromo-1-methoxy-4-propylbenzene **4** (41.3 mg, 0.180 mmol, 1.0 eq), 1-methoxy-4-propyl-2-(4,4,5,5-tetramethyl-[1,3,2]dioxaborolan-2-yl)benzene **5** (49.6 mg, 0.180 mmol, 1.0 eq), and tetrakis(triphenylphosphine) palladium(0) (10.4 mg, 9.00 μmoL, 5 mol%) was added potassium carbonate (74.6 mg, 0.54 mmol, 3.0 eq) in THF (2.0 mL). After stirring for 8 h at reflux, the reaction mixture was concentrated *in vacuo* and extracted with CH_2Cl_2. The combined organic layers were washed with H_2O, dried over Na_2SO_4, and concentrated *in vacuo*. Purification by silica gel column chromatography (hexane/EtOAc = 20 : 1) afforded **6** (7.7 mg, 0.0258 mmol, 14%) as a yellow oil; R_f 0.38 (hexane/EtOAc = 10 : 1); IR (neat) ν_{max} 2955, 2052, 1727, 1605, 1497, 1244, 1175, 1141, 1037, 893, 809, 757, 634, 511 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.11 (2H, dd, J = 8.3, 2.3 Hz, ArH), 7.06 (2H, d, J = 2.3 Hz, ArH), 6.88 (2H, d, J = 8.3 Hz, ArH), 3.74 (6H, s, OMe), 2.55 (4H, t, J =

7.5 Hz, CH_2), 1.57–1.70 (4H, m, CH_2), 0.95 (6H, t, J = 7.1 Hz, CH_3); ^{13}C NMR (75 MHz, $CDCl_3$) δ 155.2, 134.5, 131.7, 128.3, 127.8, 111.1, 56.0, 37.3, 24.8, 14.0; GC-MS (m/z) calcd for $C_{20}H_{26}O_2$ $[M]^+$ 298.19, found 298.20; EI-HRMS (m/z) calcd for $C_{20}H_{26}O_2$ $[M]^+$ 298.1933, found 298.1930.

*2.6. 2-Methoxy-5-Propylphenylboronic Acid (***7**). To a solution of 2-bromo-1-methoxy-4-propylbenzene **4** (200 mg, 0.873 mmol, 1.0 eq) in THF (3.6 mL) was added 1.6 M *n*-BuLi in hexane (0.709 mL, 1.135 mmol, 1.3 eq) at −78°C. After stirring for 5 min, triisopropyl borate (0.586 mL, 2.619 mmol, 3.0 eq) was added at −78°C and the mixture was allowed to warm up to room temperature. After stirring for 13 h at room temperature, the reaction mixture was acidified with 10% HCl aq. and extracted with EtOAc. The combined organic layers were washed with H_2O, dried over Na_2SO_4, and concentrated *in vacuo*. Purification by silica gel column chromatography (hexane/EtOAc = 13 : 1) afforded **7** (114.6 mg, 0.591 mmol, 68%) and **3** (23.6 mg, 0.157 mmol, 18%). **7** was obtained as a colorless powder; R_f 0.33 (hexane/EtOAc = 3 : 1); mp 71°C; IR (KBr) ν_{max} 3801, 3358, 2926, 2355, 1607, 1415, 1338, 1229, 1155, 1097, 1043, 788, 679, 555 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.64 (1H, d, J = 2.3 Hz, ArH), 7.23 (1H, d, J = 2.3 Hz, ArH), 6.84 (1H, d, J = 8.4 Hz, ArH), 3.89 (3H, s, OMe), 2.55 (2H, t, J = 7.1 Hz, CH_2), 1.56–1.68 (2H, m, CH_2), 0.93 (3H, t, J = 7.1 Hz, CH_3); ^{13}C NMR (75 MHz, $CDCl_3$) δ 162.8, 136.8, 135.3, 132.8, 109.9, 77.3, 55.6, 37.1, 24.9, 13.9; EI-HRMS (m/z) calcd for $C_{10}H_{15}BO_3$ $[M]^+$ 194.1114, found 194.1095.

*2.7. 2,2′-Dimethoxy-5,5′-Dipropyl-Biphenyl (***6**). To a mixture of 2-bromo-1-methoxy-4-propylbenzene **4** (50.5 mg, 0.220 mmol, 1.0 eq) and 2-methoxy-5-propylphenylboronic acid **7** (55.4 mg, 0.287 mmol, 1.3 eq) were added palladium(II) acetate (0.01 mg, 0.437 μmoL, 0.2 mol%), potassium carbonate (75.0 mg, 0.546 mmol, 2.5 eq), and tetrabutylammonium bromide (70.0 mg, 0.218 mmol, 1.0 eq) in H_2O (0.23 mL). The reaction mixture was degassed by freeze/pump/thaw techniques. After stirring for 2 h at 70°C, the reaction mixture was cooled to room temperature, diluted with H_2O, and then extracted with EtOAc. The combined organic layers were washed with H_2O, dried over Na_2SO_4, and concentrated *in vacuo*. Purification by silica gel column chromatography (hexane/EtOAc = 80 : 1) afforded **6** (63.7 mg, 0.213 mmol, 98%).

*2.8. 2,2′-Dihydroxy-5,5′-Dipropyl-Biphenyl (***1**). To a solution of 2,2′-dimethoxy-5,5′-dipropyl-biphenyl **6** (24.2 mg, 0.081 mmol, 1.0 eq) in CH_2Cl_2 (1.4 mL) was added 1 M boron tribromide in CH_2Cl_2 (0.406 mL, 0.406 mmol, 5.0 eq) at −78°C, then allowed to warm up to room temperature. After stirring for 1.5 h, the reaction mixture was quenched carefully with 10% HCl aq. at 0°C and extracted with Et_2O. The combined organic layers were washed with H_2O, dried over Na_2SO_4, and concentrated *in vacuo*. Purification by silica gel column chromatography (hexane/EtOAc = 20 : 1) afforded **1** (18.3 mg, 0.068 mmol, 83%) as a colorless powder; R_f 0.43 (hexane/EtOAc = 3 : 1); mp 144°C; IR (KBr) ν_{max} 3206, 2963, 2923, 2855, 1494, 1415, 1226, 1113, 887, 818, 797, 598, 534, 436 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.13 (2H, dd, J = 8.0, 2.3 Hz, ArH), 7.06 (2H, d, J = 2.3 Hz, ArH), 6.95 (2H, d, J = 8.0 Hz, ArH), 2.57 (4H, t, J = 7.5 Hz, CH_2), 1.60–1.67 (4H, m, CH_2), 0.95 (6H, t, J = 7.5 Hz, CH_3); ^{13}C NMR (125 MHz, $CDCl_3$) δ 151.0, 136.0, 131.1, 130.0, 123.4, 116.5, 37.3, 24.9, 14.0; EI-HRMS (m/z) calcd for $C_{18}H_{22}O_2$ $[M]^+$ 270.1620, found 270.1613.

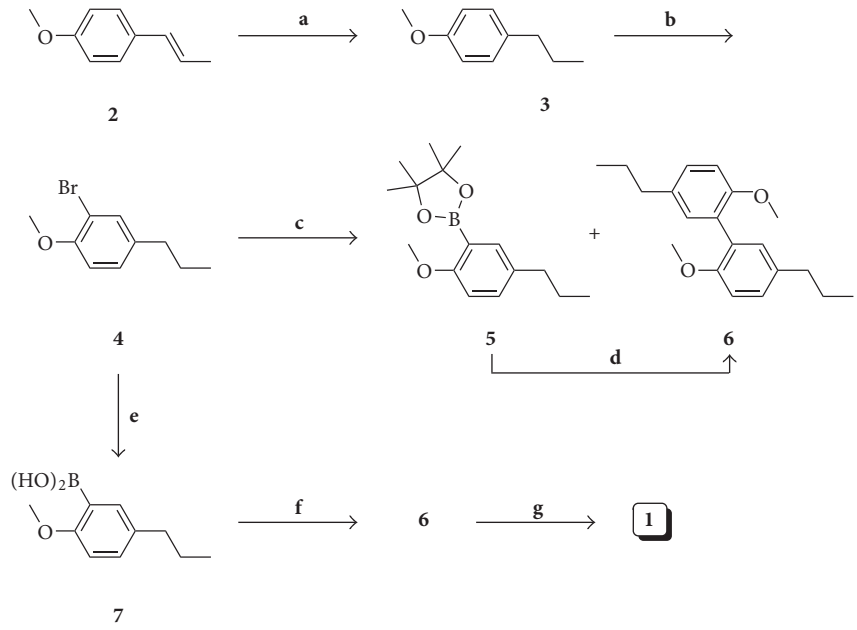
3. Results and Discussion

Starting with commercially available *trans*-anethole (**2**), the synthesis of **1** involved hydrogenation, bromination, boronation, Suzuki-Miyaura reaction, and demethylation, as illustrated in Scheme 1. Initially, direct bromination of **2** using *N*-bromosuccinimide (NBS) was intended as the first step in the synthesis. However, this reaction did not proceed. Therefore, alkene **2** was reduced by H_2 with Pd/C to gave alkane **3** in 94% yield [9]. Obtained **3** was then converted to bromide **4** in good yield (70–80%, data not shown) using NBS and HBF_4/Et_2O in MeCN at −20°C to room temperature [10]. However, the product was a mixture of monobromide **4** and the dibromide compound. It was thought that acidic condition prompted the reactivity of the bromination. Therefore, the reaction was attempted with 1.2 equivalents of NBS without additives in MeCN at room temperature. The desired compound **4** was obtained as a single product in 97% yield [11].

Next, the transformation of bromide **4** into arylboronate ester **5** was pursued. Unfortunately, in a one pot reaction using $(Bpin)_2$ in the presence of 5 mol% $PdCl_2$(dppf) and AcOK in DMSO at 80°C, compound **5** was obtained in only 31% yield along with biaryl compound **6** in 5% yield and recovered starting material **4** in 23% yield [12]. Although the yield for compound **6** could not be improved in this reaction, biaryl product **6** was synthesized in 14% yield through a Suzuki-Miyaura cross-coupling reaction between **4** and **5** in the presence of 5 mol% $Pd(PPh_3)_4$ and K_2CO_3 in THF under reflux condition [13].

As an alternative strategy, arylboronic acid **7** was prepared from bromide **4** as a precursor for the Suzuki-Miyaura reaction (Scheme 1). Bromide **4** was thus converted into **7** with *n*-BuLi and triisopropyl borate in 68% yield, with alkane **3** as a by-product in 18% yield [14]. The Suzuki-Miyaura cross-coupling reaction between **4** and **7** then afforded biaryl product **6** in 98% yield using 0.2 mol% $Pd(OAc)_2$ in H_2O at 70°C in the presence of one equivalent of tetrabutylammonium bromide (TBAB) as a phase transfer catalyst [15]. This reaction was achieved as an eco-friendly system with a high yield. Finally, removal of the methyl group from **6** using BBr_3 in CH_2Cl_2 at −78°C to room temperature gave the desired magnolignan **1** in 83% yield [16]. Synthetic **1** was fully assigned by spectroscopic analysis, including ^{1}H NMR, ^{13}C NMR, IR, and EI-HRMS [3].

In conclusion, the total synthesis of magnolignan **1**, a new skin lightening component for use in cosmetics, was achieved in five steps with overall 50% yield. An aqueous Suzuki-Miyaura reaction was the key step in the synthesis.



Scheme 1: Total synthesis of **1**. Reagents and conditions: (**a**) H_2, 10% (w/w) Pd/C, MeOH, rt, 3 h, 94%; (**b**) NBS, MeCN, rt, 3 h, CCl_4, 97%; (**c**) $PdCl_2$(dppf), $(Bpin)_2$, AcOK, DMSO, 80°C, 24 h, 31% (**5**), 5% (**6**), 23% (**4**); (**d**) **4**, $Pd(PPh_3)_4$, K_2CO_3, THF, reflux, 8 h, 14%; (**e**) *n*-BuLi, $B(OiPr)_3$, THF, −78°C to rt, 13 h, 68% (**7**), 18% (**3**); (**f**) **4**, $Pd(OAc)_2$, K_2CO_3, TBAB, H_2O, 70°C, 2 h, 98%; (**g**) BBr_3, CH_2Cl_2, −78°C to rt, 1.5 h, 83%.

The palladium-catalyzed Suzuki-Miyaura reaction in H_2O was achieved with excellent yield, and can be considered an eco-friendly reaction. Through variation of the Suzuki-Miyaura coupling precursors, this synthetic strategy is well suited for the preparation of a wide range of magnolignan derivatives for use in further SAR studies.

Acknowledgments

The authors are grateful to Ms. Yasuko Shimizu, Sophia University, for measurement of the high-resolution mass spectra, and to Ms. Emiko Okano, Sophia University, for measurement of the NMR spectra (500 MHz).

References

[1] Z.-M. Hu, Q. Zhou, T.-C. Lei, S.-F. Ding, and S.-Z. Xu, "Effects of hydroquinone and its glucoside derivatives on melanogenesis and antioxidation: biosafety as skin whitening agents," *Journal of Dermatological Science*, vol. 55, no. 3, pp. 179–184, 2009.

[2] K. Nakamura, M. Yoshida, H. Uchiwa, Y. Kawa, and M. Mizoguchi, "Down-regulation of melanin synthesis by a biphenyl derivative and its mechanism," *Pigment Cell Research*, vol. 16, no. 5, pp. 494–500, 2003.

[3] Z.-L. Kong, S.-C. Tzeng, and Y.-C. Liu, "Cytotoxic neolignans: an SAR study," *Bioorganic and Medicinal Chemistry Letters*, vol. 15, no. 1, pp. 163–166, 2005.

[4] G. Imokawa, Y. Yada, and M. Okuda, "Allergic contact dermatitis releases soluble factors that stimulate melanogenesis through activation of protein Kinase C-related signal-transduction pathway," *Journal of Investigative Dermatology*, vol. 99, no. 4, pp. 482–488, 1992.

[5] H. P. Seymour, "Separation, purification, and properties of two tyrosinases from hamster melanoma," *The Journal of Biological Chemistry*, vol. 238, pp. 2351–2357, 1963.

[6] H. Ando, Y. Funasaka, M. Oka et al., "Possible involvement of proteolytic degradation of tyrosinase in the regulatory effect of fatty acids on melanogenesis," *Journal of Lipid Research*, vol. 40, no. 7, pp. 1312–1316, 1999.

[7] G. Sartori, R. Maggi, F. Bigi et al., "Oxidative coupling of dichloroaluminium phenolates: highly selective synthesis of hydroxylated bi- and tetraaryls," *Tetrahedron*, vol. 48, no. 43, pp. 9483–9494, 1992.

[8] N. Miyaura and A. Suzuki, "Palladium-catalyzed cross-coupling reactions of organoboron compounds," *Chemical Reviews*, vol. 95, no. 7, pp. 2457–2483, 1995.

[9] U. Bora, K. Yaguchi, A. Kume, T. Maegawa, Y. Monguchi, and H. Sajiki, "Temperature-dependent suppression of palladium on carbon-catalyzed hydrogenations," *Catalysis Communications*, vol. 10, no. 8, pp. 1161–1165, 2009.

[10] T. Oberhauser, "A new bromination method for phenols and anisoles: NBS/HBF_4·Et_2O in CH_3CN," *The Journal of Organic Chemistry*, vol. 62, no. 13, pp. 4504–4506, 1997.

[11] M. C. Carreño, J. L. García Ruano, G. Sanz, M. A. Toledo, and A. Urbano, "*N*-bromosuccinimide in acetonitrile: a mild and regiospecific nuclear brominating reagent for methoxybenzenes and naphthalenes," *The Journal of Organic Chemistry*, vol. 60, no. 16, pp. 5328–5331, 1995.

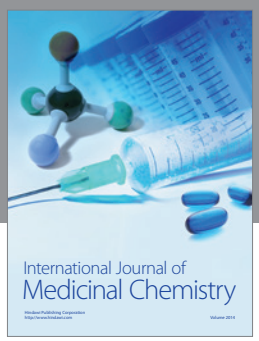
[12] D. C. Gerbino, S. D. Mandolesi, H.-G. Schmalz, and J. C. Podestá, "Introduction of allyl and prenyl side-chains into aromatic systems by Suzuki cross-coupling reactions," *European Journal of Organic Chemistry*, no. 23, pp. 3964–3972, 2009.

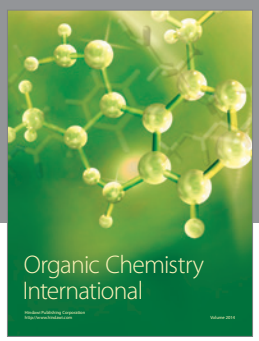
[13] H. Goto, H. Katagiri, Y. Furusho, and E. Yashima, "Oligoresorcinols fold into double helices in water," *Journal of the American Chemical Society*, vol. 128, no. 22, pp. 7176–7178, 2006.

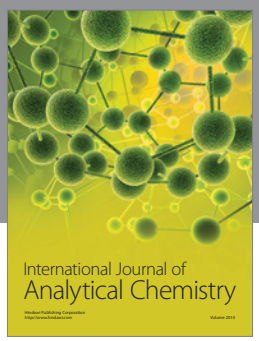
[14] M. C. Redond, M. Veguillas, M. Ribagorda, and M. C. Carreño, "Control of the regio- and stereoselectivity in diels-alder reactions with quinone boronic acids," *Angewandte Chemie International Edition*, vol. 48, no. 2, pp. 370–374, 2009.

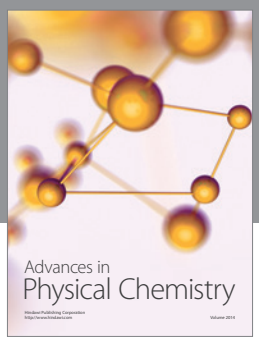
[15] D. Badone, M. Baroni, R. Cardamone, A. Ielmini, and U. Guzzi, "Highly efficient palladium-catalyzed boronic acid coupling reactions in water: scope and limitations," *The Journal of Organic Chemistry*, vol. 62, no. 21, pp. 7170–7173, 1997.

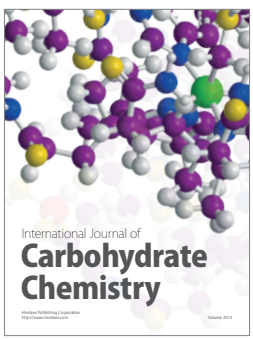
[16] Y.-H. Cho, A. Kina, T. Shimada, and T. Hayashi, "Asymmetric synthesis of axially chiral biaryls by nickel-catalyzed Grignard cross-coupling of dibenzothiophenes," *The Journal of Organic Chemistry*, vol. 69, no. 11, pp. 3811–3823, 2004.

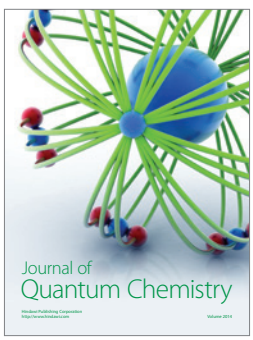


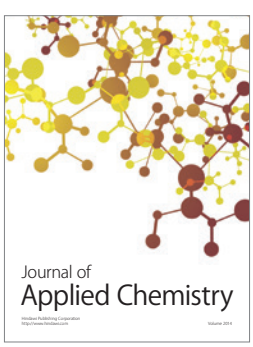


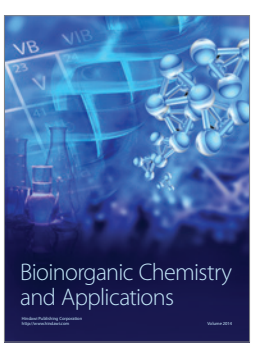


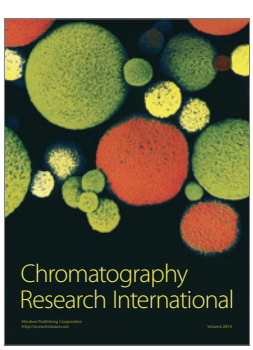


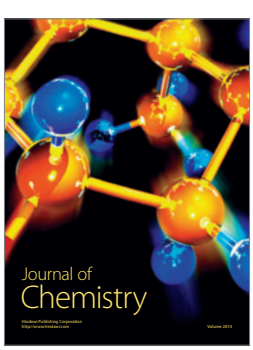












Hindawi

Submit your manuscripts at
http://www.hindawi.com