ISSN 1070-4280, Russian Journal of Organic Chemistry, 2012, Vol. 48, No. 7, pp. 908–913. © Pleiades Publishing, Ltd., 2012.
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Stereoselective Synthesis of Natural (2*E*,4*E*)-Dienamides and Their Synthetic Analogs

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Received December 10, 2011

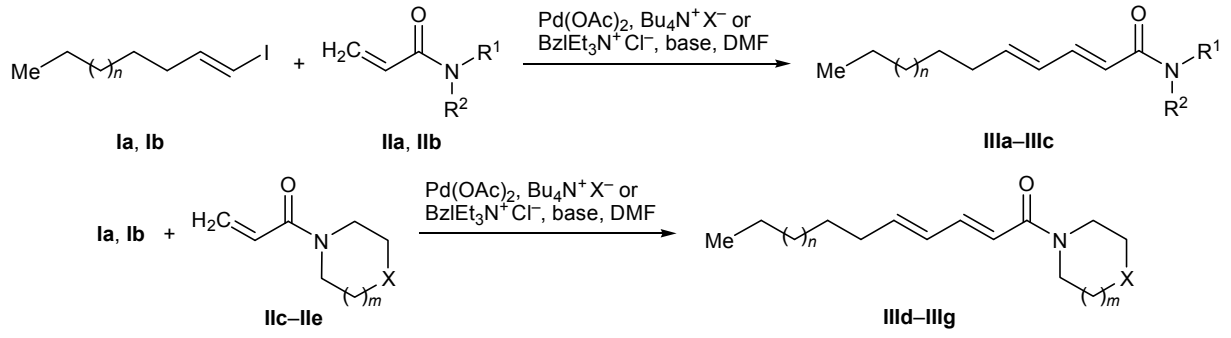
Abstract—A procedure has been developed for stereoselective synthesis of a number of naturally occurring (2*E*,4*E*)-dienamides and their analogs via palladium-catalyzed reaction of (1*E*)-1-iodoalk-1-enes with acrylamides.

DOI: 10.1134/S1070428012070032

A strategic line in the development of world pharmacy is stereoselective synthesis and functionalization of natural compounds or their synthetic analogs [1–3]. In recent time natural (2*E*,4*E*)-dienamides from different plants of the *Piperaceae* and *Echinacea* families have attracted increased interest due to broad spectrum of their medicinal properties [4–13]. For example, piperine and piperchabamide E exhibit hepatoprotective activity [4, 5], retrofractamide A and piperlonguminine were reported to control adipogenesis [6], piplartine showed anxiolytic and antidepressant activity [7], and sinthetic analogs of piperine stimulated melanocyte proliferation in human skin [8]. Pellitorine, guineensine, and dehydropipernonaline were considered to be anti-inflammatory agents of new generation, which revealed a strong potential in the treatment of rheumatoid arthritis, cerebral stroke, psoriasis, allergy, and atherosclerosis [9]. Rukachaisirikul et al. [10] reported on antitubercular effect of sarmentine, pellitorine, and guineensine isolated from *Piper sarmentosum*. Many (2*E*,4*E*)-dienamides, such as pellitorine, pergumidiene, 1-[(2*E*,4*E*)-1-oxodeca-2,4-dien-1-yl]-piperidine, and (2*E*,4*E*,8*Z*)-*N*-isobutylicosa-2,4,8-trienamide, showed antibacterial and antifungal activity [11–13].

The main problem in the synthesis of the above alkaloids is stereoselective construction of a conjugated (2*E*,4*E*)-diene system linked to carboxamide functionality. In early studies, Knoevenagel condensation [14, 15], Wittig reaction [16], various elimination processes [17, 18], and thermolysis of *cis*-2,5-disubstituted 2,5-dihydrothiophene 1,1-dioxides [19] were used for this purpose. However, these methods were characterized by poor overall yields and unsatisfactory stereochemical purity of targeted (2*E*,4*E*)-dienamides. Later procedures based on isomerization of alkynes [20–22], Stille [23, 24], Suzuki [25], and Horner–Wadsworth–Emmons [26] reactions, homologation of

Scheme 1.



I, $n = 1$ (**a**), 3 (**b**); **II**, $R^1 = R^2 = Me$ (**a**); $R^1 = i$-Bu, $R^2 = H$ (**b**); $m = 0$, X = CH_2 (**c**); $m = 1$, X = CH_2 (**d**), O (**e**); **III**, $R^1 = R^2 = Me$, $n = 1$ (**a**), 3 (**b**); $n = 1$, $R^1 = i$-Bu, $R^2 = H$ (**c**); X = CH_2: $n = 1$, $m = 0$ (**d**); $n = m = 1$ (**e**); $n = 3$, $m = 1$ (**f**); $n = 1$, $m = 1$, X = O (**g**).

Reaction of (1*E*)-1-iodohept-1-ene (**Ia**) with *N*,*N*-dimethylacrylamide (**IIa**)[a]

Run no.	Quaternary salt	Base	Solvent	Yield of **IIIa**,[b] %
1	Bu_4NCl	K_2CO_3	DMF	93
2	Bu_4NBr	K_2CO_3	DMF	82
3	Bu_4NI	K_2CO_3	DMF	8
4	$BzlEt_3NCl$	K_2CO_3	DMF	92
5	Bu_4NHSO_4	K_2CO_3	DMF	33
6	–	K_2CO_3	DMF	22
7	Bu_4NCl	Cs_2CO_3	DMF	94
8	Bu_4NCl	Bu_3N	DMF	30
9	Bu_4NCl	Et(*i*-Pr)$_2$N	DMF	42
10	Bu_4NCl	Na_2CO_3	DMF	28
11	Bu_4NCl	Na_3PO_4	DMF	41
12	Bu_4NCl	NaOAc	DMF	76
13	Bu_4NCl	K_2CO_3	Acetonitrile	70
14	Bu_4NCl	K_2CO_3	DMA	90
15	Bu_4NCl	K_2CO_3	HMPA	91
16	Bu_4NCl	K_2CO_3	*N*-Methylpyrrolidin-2-one	95
17	Bu_4NCl	K_2CO_3	DMSO	91
18	Bu_4NCl	K_2CO_3	Dioxane	92
19	Bu_4NCl	K_2CO_3	Water	59
20	Bu_4NCl	K_2CO_3	DMF–H_2O, 9:1	94
21	Bu_4NCl	K_2CO_3	DMF	70[c]
22	Bu_4NCl	K_2CO_3	DMF–H_2O, 9:1	77[c]

[a] Amounts of the reactants: 1 mmol of (1*E*)-1-iodohept-1-ene (**Ia**), 2 mmol of *N*,*N*-dimethylacrylamide (**IIa**), 1 mmol of quaternary ammonium salt, 2.5 mmol of base, 0.02 mmol of $Pd(OAc)_2$, 0.4 ml of solvent; 70°C, 6 h.

[b] GLC data.

[c] Reaction time 3 h.

(2*E*)-penta-2,4-dien-1-ylcarbonyl structures [27, 28], and cross metathesis [29] required expensive starting materials and difficultly accessible reagents.

Thus development of efficient stereoselective procedures for the synthesis of such compounds from accessible initial substances is an important problem. In the present work we tried to synthesize (2*E*,4*E*)-dienamides with high stereochemical purity via palladium-catalyzed reaction of (1*E*)-1-iodoalk-1-enes (prepared according to optimized procedure [30]) with acrylamides (Jeffery modification of the Mizoroki–Heck reactions) [31–35]. (1*E*)-1-Iodoalk-1-enes **Ia** and **Ib** reacted with acrylamides **IIa**–**IIe** in the presence of $Pd(OAc)_2$ quaternary ammonium salt, and base in aprotic solvents to produce the corresponding (2*E*,4*E*)-dienamides **IIIa**–**IIIg** in 80–91% yield (Scheme 1). The structure and stereochemical purity of the products were confirmed by their ^{1}H and ^{13}C NMR spectra, GC–MS data, and capillary column GLC. The coupling constant for the vinylic proton on C^2 in the ^{1}H NMR spectra of **IIIa**–**IIIg** was 14.7–15.0 Hz, indicating *trans*-configuration of the C^2=C^3 double bond.

With a view to optimize the reaction conditions, we examined the effects of the quaternary ammonium salt, base (organic and inorganic), and solvent on the yield and stereochemical purity of (2*E*,4*E*)-*N*,*N*-dimethyldeca-2,4-dienamide (**IIIa**) from (1*E*)-1-iodohept-1-ene (**Ia**) and *N*,*N*-dimethylacrylamide (**IIa**) (see table). In the absence of quaternary ammonium salt the yield was poor (run no. 6). Tetrabutylammonium iodide inhibited the reaction of (1*E*)-1-iodohept-1-ene (**Ia**) with *N*,*N*-dimethylacrylamide (**IIa**) (run no. 3). Compound **IIIa** was formed in more than 92% yield when the

reaction was carried out in the presence of chlorine-containing quaternary ammonium salts, Bu_4NCl and $BzlEt_3NCl$ (run nos. 1, 4).

The nature of the base was also an essential factor. Such tertiary amines as tributylamine and ethyl(diisopropyl)amine ensured poor yield of (2*E*,4*E*)-*N*,*N*-dimethyldeca-2,4-dienamide (**IIIa**) (run nos. 8, 9). In the presence of inorganic bases (Na_2CO_3, Na_3PO_4) compound **IIIa** was formed in 28–41% yield (run nos. 10, 11). Almost quantitative yield of dienamide **IIIa** was achieved with the use of stronger bases (K_2CO_3, Cs_2CO_3; run nos. 1, 7).

The yield of (2*E*,4*E*)-*N*,*N*-dimethyldeca-2,4-dienamide (**IIIa**) also depended on the solvent nature. The yield of **IIIa** in water was 59% (run no. 19), while highly polar aprotic solvents (DMF, DMA, HMPA, *N*-methylpyrrolidin-2-one, DMSO, dioxane) ensured almost quantitative formation of compound **IIIa** (run nos. 1, 14–18). The presence of water in the solvent (DMF–H_2O, 9:1) accelerated the reaction (run nos. 20–22). The best result (95% of **IIIa**) was obtained in *N*-methylpyrrolidin-2-one (run no. 16).

The above factors (quaternary ammonium salt, base, and solvent) almost did not affect the stereochemical purity of (2*E*,4*E*)-*N*,*N*-dimethyldeca-2,4-dienamide (**IIIa**); in all cases, the fraction of isomeric by-products did not exceed 5%.

Thus the optimal reaction system with account taken of its accessibility is $Pd(OAc)_2$–Bu_4NCl–K_2CO_3 in DMF–H_2O (9:1) (run no. 20). Using that system we synthesized with high yield and stereoselectivity some natural (2*E*,4*E*)-dienamides, (2*E*,4*E*)-*N*-isobutyldeca-2,4-dienamide (**IIIc**, pellitorine), 1-[(2*E*,4*E*)-1-oxodeca-2,4-dien-1-yl]pyrrolidine (**IIId**, sarmentine), 1-[(2*E*,4*E*)-1-oxo-deca-2,4-dien-1-yl]piperidine (**IIIe**), and 1-[(2*E*,4*E*)-1-oxododeca-2,4-dien-1-yl]piperidine (**IIIf**) and their analogs, (2*E*,4*E*)-*N*,*N*-dimethyldeca-2,4-dienamide (**IIIa**), (2*E*,4*E*)-*N*,*N*-dimethyldodeca-2,4-dienamide (**IIIb**), and 4-[(2*E*,4*E*)-1-oxodeca-2,4-dien-1-yl]morpholine (**IIIg**). Cyclic dienamides **IIId**–**IIIg** were formed with higher stereoselectivity: the fraction of the (*E*,*E*)-isomer was 98% and more.

EXPERIMENTAL

The IR spectra were recorded from thin films or KBr pellets on a Shimadzu IR Prestige-21 spectrometer with Fourier transform. The ^1H and ^{13}C NMR spectra were measured from solutions in $CDCl_3$ on a Bruker AM-300 spectrometer at 300 and 75.47 MHz, respectively, using tetramethylsilane as internal reference. Gas chromatographic–mass spectrometric analysis was performed on a Shimadzu GCMS-QP2010S instrument (electron impact, 70 eV, amu range 33–500 Da; HP-1MS capillary column, 30 m×0.25 mm, film thickness 0.25 μm; injector temperature 280°C, ion source temperature 200°C, oven temperature programming from 50 to 280°C at a rate of 10 deg/min; carrier gas helium, flow rate 1.1 ml/min).

(*E*)-1-Iodoalk-1-enes Ia and Ib (*general procedure***).** The corresponding terminal alkyne, 0.01 mol, was dissolved in 10 ml of anhydrous hexane, 15 ml of a 1 M solution of diisobutylaluminum hydride in hexane was added, and the mixture was stirred for 6 h at 55°C under argon. The mixture was cooled to –50°C, a solution of 2.79 g (0.011 mol) of iodine in 15 ml of anhydrous THF was added over a period of 30 min, and the mixture was allowed to warm up to room temperature over a period of 1 h, stirred for 12 h at that temperature, and treated with 25 ml of 10% sulfuric acid on cooling with ice. The organic layer was separated, the aqueous layer was extracted with hexane (3×15 ml), the extracts were combined with the organic phase, washed with a saturated solution of sodium chloride, dried over Na_2SO_4, and concentrated, and the residue was subjected to column chromatography on silica gel using hexane–chloroform (6:1 to 2:1) as eluent.

(*E*)-1-Iodohept-1-ene (Ia). Yield 1.98 g (88%), oily substance. IR spectrum, ν, cm^{-1}: 2955, 2924, 2855, 1605, 1458, 1209, 1173, 939. ^1H NMR spectrum, δ, ppm: 0.88 t (3H, CH_3, J = 6.9 Hz), 1.21–1.44 m (6H, CH_2), 2.05 q.d (2H, 3-H, ^3J = 7, ^4J = 1.5 Hz), 5.97 d.t (1H, 1-H, $^3J_{trans}$ = 14.4, ^4J = 1.5 Hz), 6.51 d.t (1H, 2-H, $^3J_{trans}$ = 14.4, ^3J = 7 Hz). ^{13}C NMR spectrum, δ_C, ppm: 13.93 (C^7), 22.35 (C^6), 27.99 (C^4), 31.04 (C^5), 35.95 (C^3), 74.27 (C^1), 146.69 (C^2). Mass spectrum, *m*/*z* (I_{rel}, %): 224 (34) $[M]^+$, 167 (24), 154 (55), 97 (22), 69 (13), 55 (100), 41 (23), 39 (13).

(*E*)-1-Iodonon-1-ene (Ib). Yield 2.25 g (89%), oily substance. IR spectrum, ν, cm^{-1}: 2955, 2926, 2855, 1607, 1456, 1211, 1198, 945. ^1H NMR spectrum, δ, ppm: 0.88 t (3H, CH_3, J = 7 Hz), 1.21–1.43 m (10H, CH_2), 2.04 q.d (2H, 3-H, ^3J = 7, ^4J = 1.5 Hz), 5.97 d.t (1H, 1-H, $^3J_{trans}$ = 14.3, ^4J = 1.5 Hz), 6.50 d.t (1H, 2-H, $^3J_{trans}$ = 14.3, ^3J = 7 Hz). ^{13}C NMR spectrum, δ_C, ppm: 14.00 (C^9), 22.58 (C^8), 28.30 (C^4), 28.82 (CH_2), 28.96 (CH_2), 31.68 (C^7), 35.98 (C^3), 74.23 (C^1), 146.59 (C^2). Mass spectrum, *m*/*z* (I_{rel}, %): 252 (35) $[M]^+$, 168 (11), 167 (45), 154 (38), 83 (73), 70 (16), 69 (100), 57 (12), 56 (11), 55 (40), 43 (27), 41 (25), 39 (11).

Acrylamides IIb–IIe (*general procedure*). A solution of 0.04 mol of the corresponding amine in 20 ml of anhydrous methylene chloride was slowly added at 0–5°C to 0.02 mol of acryloyl chloride in 20 ml of anhydrous methylene chloride. The mixture was stirred for 3 h at room temperature in an inert atmosphere, and the precipitate was filtered off and washed with methylene chloride (2 × 10 ml). The organic layer was washed in succession with 5 ml of water and 5 ml of a saturated solution of $NaHCO_3$ and dried over Na_2SO_4, the solvent was removed under reduced pressure, and the residue was purified by column chromatography on silica gel using hexane–ethyl acetate (5 : 1 to 1 : 1) as eluent.

***N*-(2-Methylpropyl)prop-2-enamide (IIb).** Yield 1.98 g (78%). IR spectrum, ν, cm^{-1}: 3287, 2961, 2928, 1656, 1626, 1555, 1244, 988, 955. ^1H NMR spectrum, δ, ppm: 0.92 d (6H, CH_3, J = 6.7 Hz), 1.76–1.89 m [1H, C**H**$(CH_3)_2$], 3.13 t (2H, CH_2N, J = 6.4 Hz), 5.59 d.d (1H, 3-H_{cis}, ^3J = 8.8, ^2J = 3 Hz), 6.21–6.36 m (2H, 3-H_{trans}, 2-H), 7.25 br.s (1H, NH). ^{13}C NMR spectrum, δ_C, ppm: 19.90 (CH_3), 28.20 [**C**H$(CH_3)_2$], 46.77 (CH_2N), 125.39 (C^3), 131.11 (C^2), 165.92 (C^1). Mass spectrum, *m*/*z* (I_{rel}, %): 127 (17) $[M]^+$, 112 (36), 85 (11), 84 (87), 72 (25), 55 (100), 43 (14), 41 (21), 39 (12).

1-(Prop-2-enoyl)pyrrolidine (IIc). Yield 1.38 g (55%). IR spectrum, ν, cm^{-1}: 2972, 2872, 1647, 1609, 1436, 1375, 982, 797. ^1H NMR spectrum, δ, ppm: 1.65–1.85 m (4H, 3′-H, 4′-H), 3.31–3.40 m (4H, CH_2N), 5.48 d.d (1H, 3-H_{cis}, ^3J = 10.1, ^2J = 2.6 Hz), 6.16 d.d (1H, 3-H_{trans}, ^3J = 16.8, ^2J = 2.6 Hz), 6.29 d.d (1H, 2-H, J = 16.8, 10.1 Hz). ^{13}C NMR spectrum, δ_C, ppm: 23.67 and 25.53 ($C^{3'}$, $C^{4'}$), 45.24 and 45.96 (CH_2N), 126.46 (C^3), 128.38 (C^2), 163.76 (C^1). Mass spectrum, *m*/*z* (I_{rel}, %): 125 (75) $[M]^+$, 124 (36), 97 (14), 96 (24), 70 (39), 69 (32), 68 (18), 56 (13), 55 (100), 43 (12), 42 (19), 41 (22), 39 (14).

1-(Prop-2-enoyl)piperidine (IId). Yield 1.90 g (68%). IR spectrum, ν, cm^{-1}: 2938, 2857, 1794, 1724, 1643, 1609, 1591, 144 5, 1252, 1227, 1016, 984. ^1H NMR spectrum, δ, ppm: 1.51–1.72 m (6H, CH_2), 3.50 s and 3.61 s (2H each, CH_2N), 5.65 d.d (1H, 3-H_{cis}, ^3J = 10.7, ^2J = 1.9 Hz), 6.24 d.d (1H, 3-H_{trans}, ^3J = 16.7, ^2J = 1.9 Hz), 6.60 d.d (1H, 2-H, J = 16.7, 10.7 Hz). ^{13}C NMR spectrum, δ_C, ppm: 24.28 ($C^{4'}$), 25.26 and 26.36 ($C^{3'}$, $C^{5'}$), 42.82 and 46.69 (CH_2N), 126.84 (C^3), 127.82 (C^2), 165.14 (C^1). Mass spectrum, *m*/*z* (I_{rel}, %): 139 (60) $[M]^+$, 138 (100), 122 (10), 97 (12), 96 (15), 84 (26), 55 (22).

4-(Prop-2-enoyl)morpholine (IIe). Yield 1.78 g (63%). IR spectrum, ν, cm^{-1}: 2857, 1647, 1612, 1439, 1263, 1238, 1115, 1038, 953. ^1H NMR spectrum, δ, ppm: 3.51–3.73 m (8H, NCH_2CH_2O), 5.72 d.d (1H, 3-H_{cis}, ^3J = 10.6, ^2J = 1.9 Hz), 6.29 d.d (1H, 3-H_{trans}, ^3J = 16.7, ^2J = 1.9 Hz), 6.57 d.d (1H, 2-H, J = 16.7, 10.6 Hz). ^{13}C NMR spectrum, δ_C, ppm: 41.74 and 45.66 (CH_2N), 66.22 (CH_2O), 126.64 (C^2), 127.69 (C^3), 164.92 (C^1). Mass spectrum, *m*/*z* (I_{rel}, %): 141 (36) $[M]^+$, 140 (12), 126 (58), 112 (22), 111 (15), 110 (15), 109 (12), 98 (10), 96 (26), 86 (72), 83 (13), 70 (14), 68 (14), 57 (17), 56 (86), 55 (100), 42 (23).

(2*E*,4*E*)-Alkadienamides IIIa–IIIg (*general procedure*). A solution of 4.5 mg (0.02 mmol) of $Pd(OAc)_2$ in 0.1 ml of DMF–H_2O (9 : 1) was added to a suspension of 0.346 g (2.5 mmol) of K_2CO_3, 0.278 g (1 mmol) of Bu_4NCl, 1 mmol of iodoalkene **Ia** or **Ib**, and 2 mmol of acrylamide **IIa**–**IIe** in 0.7 ml of DMF–H_2O (9 : 1). The mixture was purged with argon and heated at 70°C under stirring until complete consumption of the initial iodoalkene (6–15 h, GLC). The mixture was treated with 3 ml of water and 5 ml of diethyl ether, the organic phase was separated, the aqueous phase was extracted with diethyl ether (2 × 5 ml), and the extracts were combined with the organic phase, washed with a saturated solution of NaCl (5 ml), dried over Na_2SO_4, and concentrated. The crude product was purified by column chromatography on silica gel using hexane–ethyl acetate (9 : 1 to 1 : 1) as eluent.

(2*E*,4*E*)-*N*,*N*-Dimethyldeca-2,4-dienamide (IIIa) was synthesized from **Ia** and **IIa**. Yield 0.164 g (84%), oily substance. IR spectrum, ν, cm^{-1}: 2955, 2928, 2859, 1717, 1651, 1624, 1458, 1398, 1134, 1001. ^1H NMR spectrum, δ, ppm: 0.88 t (3H, CH_3, J = 7 Hz), 1.21–1.46 m (6H, CH_2), 2.14 q (2H, 6-H, J = 6.9 Hz), 3.00 s and 3.06 s (3H each, CH_3N), 6.06 d.t (1H, 5-H, J = 15.1, 6.9 Hz), 6.18 d.d (1H, 4-H, J = 15.1, 10.7 Hz), 6.24 d (1H, 2-H, J = 14.9 Hz), 7.23 d.d (1H, 3-H, J = 14.9, 10.7 Hz). ^{13}C NMR spectrum, δ_C, ppm: 13.78 (C^{10}), 22.23 (C^9), 28.26 (C^7), 31.13 (C^8), 32.69 (C^6), 35.54 and 37.06 (CH_3N), 118.07 (C^2), 128.56 (C^4), 142.73 and 142.82 (C^3, C^5), 166.94 (C^1). Mass spectrum, *m*/*z* (I_{rel}, %): 195 (25) $[M]^+$, 152 (18), 151 (31), 124 (100), 95 (22), 81 (82), 79 (21), 77 (14), 72 (37), 69 (22), 67 (25), 66 (27), 55 (15), 53 (23), 43 (13), 42 (20), 41 (35), 39 (16).

(2*E*,4*E*)-*N*,*N*-Dimethyldodeca-2,4-dienamide (IIIb) was synthesized from **Ib** and **IIa**. Yield 0.183 g (82%), oily substance. IR spectrum, ν, cm^{-1}: 2953, 2925, 2855, 1719, 1647, 1611, 1458, 1400, 1144,

1061. ^{1}H NMR spectrum, δ, ppm: 0.88 t (3H, CH_3, J = 7 Hz), 1.21–1.46 m (10H, CH_2), 2.15 q (2H, 6-H, J = 6.9 Hz), 3.00 s and 3.07 s (3H each, CH_3N), 6.06 d.t (1H, 5-H, J = 15.3, 6.9 Hz), 6.19 d.d (1H, 4-H, J = 15.3, 10.6 Hz), 6.25 d (1H, 2-H, J = 15 Hz), 7.25 d.d (1H, 3-H, J = 15, 10.6 Hz). ^{13}C NMR spectrum, δ_C, ppm: 13.82 (C^{12}), 22.36 (C^{11}), 28.56 (C^7), 28.86 (CH_2), 31.52 (C^{10}), 32.69 (C^6), 35.42 and 36.98 (CH_3N), 118.10 (C^2), 128.53 (C^4), 142.58 and 142.64 (C^3, C^5), 166.78 (C^1). Mass spectrum, m/z (I_{rel}, %): 223 (16) $[M]^+$, 179 (15), 125 (10), 124 (100), 95 (19), 91 (10), 87 (17), 81 (55), 79 (14), 72 (29), 67 (11), 55 (15), 44 (16), 43 (10), 41 (13).

(2*E*,4*E*)-*N*-(2-Methylpropyl)deca-2,4-dienamide (IIIc, pellitorine) was synthesized from **Ia** and **IIb**. Yield 0.190 g (85%), mp 88–89°C. IR spectrum, ν, cm^{-1}: 3296, 2955, 2926, 2868, 1655, 1628, 1551, 1466, 1256, 995. ^{1}H NMR spectrum, δ, ppm: 0.86–0.95 m (9H, CH_3), 1.22–1.46 m (6H, CH_2), 1.74–1.87 m [1H, C**H**$(CH_3)_2$], 2.13 q (2H, 6-H, J = 7 Hz), 3.14 t (2H, CH_2N, J = 6.4 Hz), 5.93 d (1H, 3-H, J = 15 Hz), 5.99–6.17 m (2H, 4-H, 5-H), 6.64 br.s (1H, NH), 7.17 d.d (1H, 3-H, J = 15, 10.3 Hz). ^{13}C NMR spectrum, δ_C, ppm: 13.82 (C^{10}), 20.02 [CH(**C**$H_3)_2$], 22.30 (C^9), 28.35 (C^7), 28.44 [**C**H$(CH_3)_2$], 31.20 (C^8), 32.72 (C^6), 46.86 (CH_2N), 122.15 (C^2), 128.26 (C^4), 140.69 (C^3), 142.55 (C^5), 166.63 (C^1). Mass spectrum, m/z (I_{rel}, %): 223 (19) $[M]^+$, 152 (36), 151 (100), 113 (24), 110 (21), 96 (87), 95 (31), 81 (86), 79 (20), 69 (32), 67 (33), 66 (22), 57 (21), 55 (25), 53 (27), 44 (27), 41 (40).

(2*E*,4*E*)-1-(Pyrrolidin-1-yl)deca-2,4-dien-1-one (IIId, sarmentine) was synthesized from **Ia** and **IIc**. Yield 0.201 g (91%), oily substance. IR spectrum, ν, cm^{-1}: 2955, 2926, 2870, 1653, 1624, 1600, 1425, 999. ^{1}H NMR spectrum, δ, ppm: 0.89 t (3H, CH_3, J = 6.9 Hz), 1.26–1.47 m (6H, CH_2), 1.81–2.03 m (4H, 3′-H, 4′-H), 2.14 q (2H, 6-H, J = 7 Hz), 3.46–3.58 m (4H, CH_2N), 6.02–6.23 m (2H, 4-H, 5-H), 6.10 d (inside multiplet, 1H, 2-H, J = 14.7 Hz), 7.26 d.d (1H, 3-H, J = 14.7, 10.6 Hz). ^{13}C NMR spectrum, δ_C, ppm: 13.76 (C^{10}), 22.24 (C^9), 24.10 and 25.86 ($C^{3'}$, $C^{4'}$), 28.23 (C^7), 31.11 (C^8), 32.69 (C^6), 45.57 and 46.17 (CH_2N), 119.66 (C^2), 128.50 (C^4), 141.86 and 142.79 (C^3, C^5), 164.89 (C^1). Mass spectrum, m/z (I_{rel}, %): 221 (22) $[M]^+$, 178 (13), 164 (15), 151 (29), 150 (100), 113 (17), 98 (27), 95 (26), 81 (76), 79 (17), 70 (46), 69 (30), 67 (27), 66 (18), 55 (36), 53 (23), 41 (28).

(2*E*,4*E*)-1-(Piperidin-1-yl)deca-2,4-dien-1-one (IIIe) was synthesized from **Ia** and **IId**. Yield 0.198 g (84%), oily substance. IR spectrum, ν, cm^{-1}: 2930, 2857, 1719, 1649, 1624, 1603, 1439, 1254, 1138, 1018, 999. ^{1}H NMR spectrum, δ, ppm: 0.88 t (3H, CH_3, J = 6.9 Hz), 1.20–1.46 m (6H, CH_2), 1.50–1.69 m (6H, CH_2), 2.14 q (2H, 6-H, J = 6.9 Hz), 3.49 br.s and 3.59 br.s (2H each, CH_2N), 6.04 d.t (1H, 5-H, J = 15.1, 6.9 Hz), 6.18 d.d (1H, 4-H, J = 15.1, 10.7 Hz), 6.26 d (1H, 2-H, J = 14.9 Hz), 7.23 d.d (1H, 3-H, J = 14.9, 10.7 Hz). ^{13}C NMR spectrum, δ_C, ppm: 13.81 (C^{10}), 22.29 (C^9), 24.48 ($C^{4'}$), 25.35 and 26.58 ($C^{3'}$, $C^{5'}$), 28.34 (C^7), 31.19 (C^8), 32.72 (C^6), 42.96 and 46.68 (CH_2N), 118.41 (C^2), 128.71 (C^4), 142.28 and 142.61 (C^3, C^5), 165.50 (C^1). Mass spectrum, m/z (I_{rel}, %): 235 (29) $[M]^+$, 192 (100), 178 (29), 176 (20), 164 (51), 151 (25), 138 (34), 84 (42), 83 (28), 81 (33), 78 (21), 69 (28), 41 (29).

(2*E*,4*E*)-1-(Piperidin-1-yl)dodeca-2,4-dien-1-one (IIIf) was synthesized from **Ib** and **IId**. Yield 0.214 g (81%), oily substance. IR spectrum, ν, cm^{-1}: 2924, 2855, 1718, 1651, 1618, 1603, 1439, 1254, 1136, 1018, 999. ^{1}H NMR spectrum, δ, ppm: 0.88 t (3H, CH_3, J = 6.9 Hz), 1.21–1.46 m (10H, CH_2), 1.51–1.69 m (6H, CH_2), 2.14 q (2H, 6-H, J = 6.9 Hz), 3.49 br.s and 3.60 br.s (2H each, CH_2N), 6.05 d.t (1H, 5-H, J = 15.1, 6.9 Hz), 6.18 d.d (1H, 4-H, J = 15.1, 10.6 Hz), 6.26 d (1H, 2-H, J = 14.8 Hz), 7.23 d.d (1H, 3-H, J = 14.8, 10.6 Hz). ^{13}C NMR spectrum, δ_C, ppm: 13.96 (C^{12}), 22.51 (C^{11}), 24.54 ($C^{4'}$), 25.46 and 26.59 ($C^{3'}$, $C^{5'}$), 28.70 (C^7), 28.99 (CH_2), 31.64 (C^{10}), 32.80 (C^6), 43.05 (CH_2N), 46.75 (CH_2N), 118.40 (C^2), 128.71 (C^4), 142.44 and 142.70 (C^3, C^5), 165.58 (C^1). Mass spectrum, m/z (I_{rel}, %): 263 (19) $[M]^+$, 192 (59), 178 (25), 164 (57), 138 (48), 95 (22), 84 (100), 81 (59), 69 (21), 67 (23), 55 (38), 53 (20), 43 (20), 41 (34).

(2*E*,4*E*)-1-(Morpholin-4-yl)deca-2,4-dien-1-one (IIIg) was synthesized from **Ia** and **IIe**. Yield 0.189 g (80%), oily substance. IR spectrum, ν, cm^{-1}: 2957, 2926, 2853, 1653, 1624, 1601, 1431, 1267, 1244, 1117, 1042, 999. ^{1}H NMR spectrum, δ, ppm: 0.89 t (3H, CH_3, J = 7 Hz), 1.20–1.48 m (6H, CH_2), 2.15 q (2H, 6-H, J = 6.9 Hz), 3.50–3.72 m (8H, NCH_2CH_2O), 6.04–6.16 m (2H, 4-H, 5-H), 6.20 d (1H, 2-H, J = 14.8 Hz), 7.28 d.d (1H, 3-H, J = 14.8, 10 Hz). ^{13}C NMR spectrum, δ_C, ppm: 13.79 (C^{10}), 22.27 (C^9), 28.23 (C^7), 31.14 (C^8), 32.72 (C^6), 42.40 and 45.87 (CH_2N), 66.63 (CH_2O), 117.17 (C^2), 128.44 (C^4), 143.33 and 143.57 (C^3, C^5), 165.73 (C^1). Mass spectrum, m/z (I_{rel}, %): 237 (35) $[M]^+$, 194 (23), 166 (100), 151 (77), 95 (35), 86 (30), 81 (93), 79 (23), 69 (24), 67 (30), 66 (40), 56 (32), 55 (22), 53 (23), 41 (51).

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