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Aromatization reactions of 2-cyclohexenones and 1,3-cyclohexadien-1-amines with iodine/sodium alkoxide

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Abstract—2-Cyclohexenones containing an electron withdrawing group in the 4-position and the corresponding *N*-alkyl-1,3-cyclohexadien-1-amines undergo regioselective iodination and aromatization to give 2-iodophenols and *N*-alkyl-2-iodoanilines, respectively, upon reaction with iodine and sodium alkoxide. By contrast, *N*,*N*-dialkyl-1,3-cyclohexadien-1-amine derivatives undergo non-iodinative aromatization to simple *N*,*N*-dialkylanilines under similar conditions. © 2001 Elsevier Science Ltd. All rights reserved.

1. Introduction

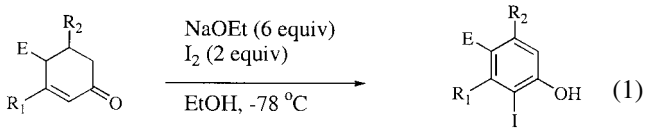
Aromatic iodo compounds are versatile reagents in organic synthesis. In particular, bifunctional reagents such as 2-iodophenols and 2-iodoanilines are useful precursors for the synthesis of a variety of benzoheterocyclic systems. For example, palladium catalyzed annulations and carbonylative cyclizations of these materials with dienes and acetylenes have been widely used in the synthesis of biologically important heterocycles such as benzofurans,[1] dihydrobenzofurans,[2,3] benzopyrans,[3] indolines,[4] indoles,[5] flavones,[6] chromones,[6] quinolines[7] and tetrahydroquinolines.[3] Additional utilities of 2-iodophenols and 2-iodoanilines include transition metal catalyzed coupling reactions with organoboron compounds to provide phenols and anilines with alkyl,[8] aryl[9] and heteroaryl[10] substituents in the *ortho* position. A wide variety of methods are available for the direct iodination of phenols and anilines.[11] Although some simple 2-iodophenols and 2-iodoanilines are readily accessible via this approach, only a limited number of methods are suitable for the regioselective preparation of more highly substituted analogues. For example, direct iodination of substituted phenols with iodine/thallium(I) acetate has been reported to yield 2-iodophenols regioselectively in a few instances.[12] However, the yields of desired products are generally low due to competing diiodination. Iodinations of *N*-alkylanilines and *N*,*N*-dialkylanilines under the same conditions are further complicated by competing oxidative coupling processes.[12] Iodine/copper(II) acetate[13] and iodine/mercury(II) acetate[14] systems have also found limited application in the regioselective *ortho*-iodination of steroidal phenols.

In a recent communication, we reported that the aromatization of a variety of easily accessible 2-cyclohexenones **1a–h** with iodine and sodium alkoxide gives 2-iodophenols **2a–h** in good yields and high regioselectivity (Eq. (1)).[15] Herein we provide full experimental details of this work and further extension of the methodology to the aromatization of the corresponding 1,3-cyclohexadien-1-amines to produce aniline derivatives. In addition, we describe examples of heterocyclic synthesis utilizing some of the 2-iodophenols and 2-iodoanilines prepared in this study.

2. Results and discussion

2.1. Aromatization of 2-cyclohexenones

The 2-cyclohexenones **1a–h** were readily prepared using previously reported procedures.[15–18] Treatment of compounds **1a–h** with 6 equiv. of sodium ethoxide in ethanol followed by slow addition of 2 equiv. of iodine at −78°C gave 50–86% isolated yields of 2-iodophenols **2a–h** as a single regioisomer[19] in each case (Eq. (1), Table 1).



(1)

1a-h **2a-h**

Crude products from these reactions generally contained small amounts of 2,6-diiodophenols (3–5%) and non-iodinated phenols (3–5%) as byproducts which were readily

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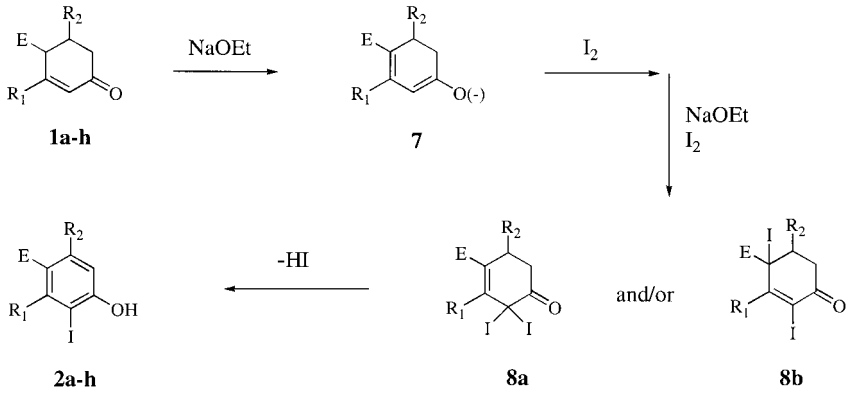
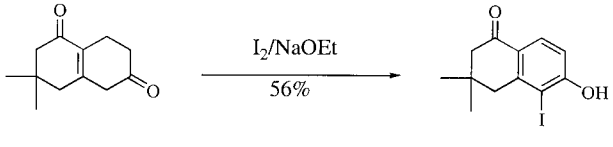
Table 1. Preparation of 2-iodophenols from 2-cyclohexenones

2-Cyclohexenone substrate	E	R_1	R_2	Iodophenol product	Yield (%)
1a	CO_2Me	H	Me	**2a**	66
1b	CO_2Et	H	CF_3	**2b**	86
1c	CO_2Et	H	CO_2Et	**2c**	77
1d	CO_2Et	H	2-Thienyl	**2d**	61
1e	CO_2Me	H	2-Furyl	**2e**	50
1f	CO_2Et	Me	H	**2f**	78
1g	CO_2Et	CF_3	H	**2g**	65
1h	CO_2Et	Ph	H	**2h**	64

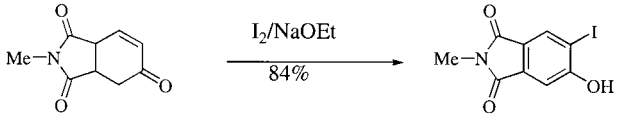


Scheme 1.

removed by preparative HPLC. Low reaction temperature was critical in minimizing the formation of these by-products. For example, iodination at room temperature gave 40–50% of monoiodophenols, 20–25% of diiodophenols and 20–25% of non-iodinated phenols. Carefully controlled stoichiometry of iodine was also important in ensuring high yield of the desired 2-iodophenols. Using greater than 2 equiv. of iodine gave increasing amounts of the diiodophenols whereas less than two equivalents resulted in only partial conversion of the starting material. The reaction appears to be limited to 2-cyclohexenones with an electron withdrawing substituent in the 4-position. For example, bicyclic dione **3** and bicyclic imide **5** gave the expected iodophenols **4** and **6** in 56 and 84% isolated yields, respectively (Eqs. (2) and (3)). However, simple cyclohexenones such as 3-methyl-2-cyclohexenone, 3-phenyl-2-cyclohexenone and 3,4-dimethyl-2-cyclohexenone gave mostly unreacted starting material and small amounts of unidentified non-aromatic products.



(2)



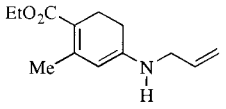
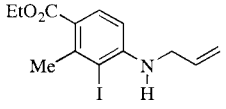
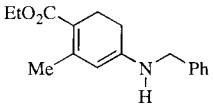
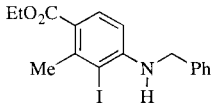
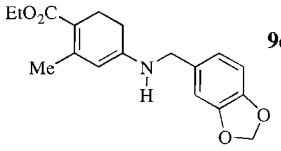
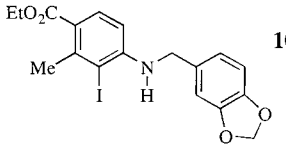
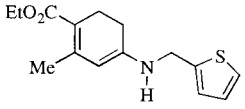
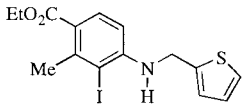
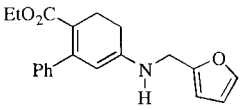
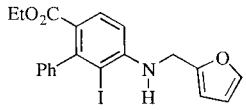
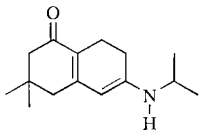
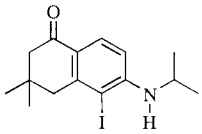
(3)

The reaction most likely proceeds via anionic diiodination of cyclohexenones **1a–h** and subsequent dehydroiodination and aromatization (Scheme 1). The preferential formation of a thermodynamically more stable, linearly conjugated dienolate **7** accounts for the regioselectivity of iodination. Although there are two possible diiodo intermediates **8a** (α,α) and **8b** (α,γ), both of these structures provide the same iodophenol upon dehydroiodination and aromatization. The diiodophenol and non-iodinated phenol byproducts may result from competing mono- and triiodinations of enolate **7** and subsequent dehydroiodination.

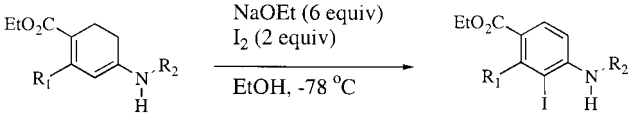
2.2. Aromatization of 1,3-cyclohexadien-1-amines

The results of extending the aromatization methodology to the corresponding 1,3-cyclohexadien-1-amine derivatives **9a–e** and **11a–f** are illustrated in Eqs. (4) and (5).

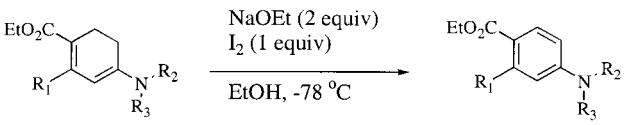
Table 2. Preparation of *N*-alkyl-2-iodoanilines from *N*-alkyl-1,3-cyclohexadien-1-amines

Entry	Dienamine substrate		Iodoaniline product		Yield (%)
1		**9a**		**10a**	47
2		**9b**		**10b**	56
3		**9c**		**10c**	61
4		**9d**		**10d**	42
5		**9e**		**10e**	55
6		**9f**		**10f**	47

Compounds **9a–e** and **11a–f** were readily synthesized by condensing the corresponding cyclohexenones with primary and secondary amines, respectively. Treatment of the secondary enamines **9a–e** with 6 equiv. of sodium ethoxide and 2 equiv. of iodine at −78°C afforded the iodoanilines **10a–e** in 42–61% yield as a single regioisomer in each case (Eq. (4), Table 2, entries 1–5). The bicyclic dienamine **9f** also gave the expected iodoaniline **10f** in 47% yield (Table 2, entry 6). However, the tertiary enamines **11a–f** gave only the non-iodinated aromatic products **12a–f** in 74–89% yield under identical conditions (Eq. (5), Table 3). In this case, complete conversion of the starting material to the product was observed with 2 equiv. of sodium ethoxide and 1 equiv. of iodine. Employing a large excess of iodine (3–4 equiv.) and sodium ethoxide (9–12 equiv.) did not alter the course of the reaction significantly.

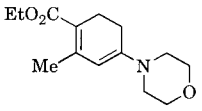
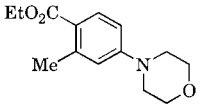
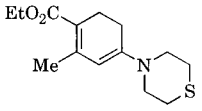
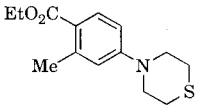
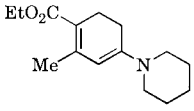
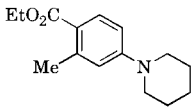
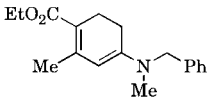
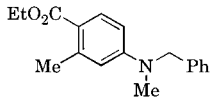
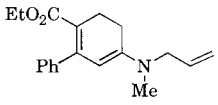
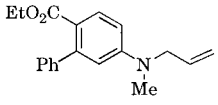
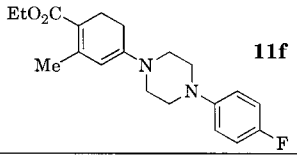
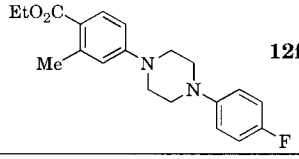


9a-e **10a-e** (4)



11a-f **12a-f** (5)

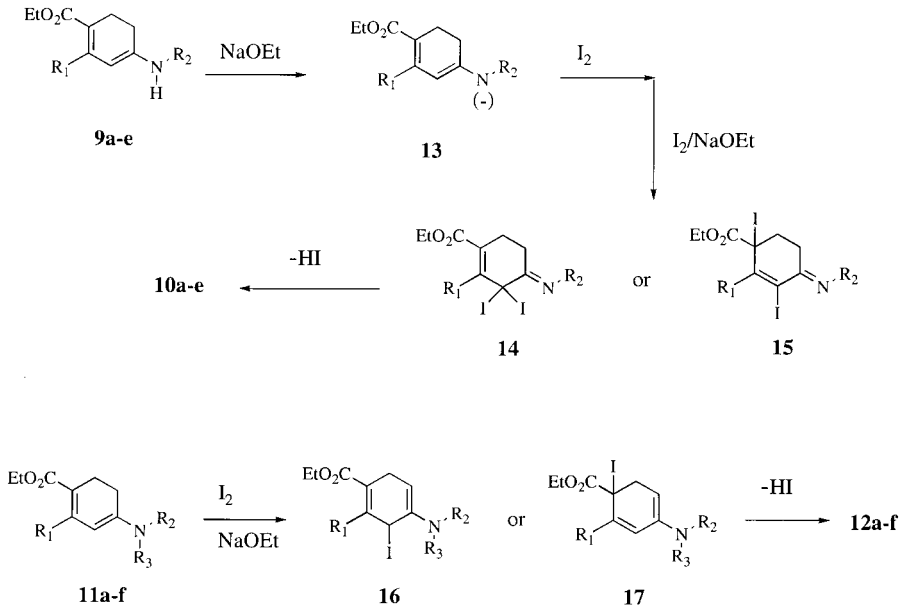
Table 3. *N,N*-Dialkylanilines from *N,N*-dialkyl-1,3-cyclohexadien-1-amines

Entry	Dienamine substrate		*N,N*-dialkylaniline product		Yield (%)
1		**11a**		**12a**	85
2		**11b**		**12b**	88
3		**11c**		**12c**	74
4		**11d**		**12d**	84
5		**11e**		**12e**	89
6		**11f**		**12f**	75

A possible explanation for the divergence in the reactions of secondary and tertiary enamines may lie in the mechanisms and relative rates of iodination (Scheme 2). Secondary enamines **9a–e** have the ability to form the aza-enolate species **13** via deprotonation. Therefore their iodination is most likely assisted by an anion and the reactivity may parallel the cyclohexenones. The aza-enolate species **13** may undergo α,α- or α,γ diiodination to give **14** or **15**. Further dehydroiodination of **14** or **15** leads to the 2-iodoanilines **10**. By contrast, the tertiary enamines **11a–f** are incapable of forming a similar aza-enolate species. In this case the iodination is most likely not assisted by an anion and, consequently, slower than the iodination of secondary enamines. We propose that the iodinations of **11a–f** are sufficiently slow to allow dehydroiodination of the initial mono-iodo species **16** and **17** to successfully compete with the diiodination step and result in non-iodinated *N,N*-dialkylanilines. Consistent with this proposal, compounds **11a–f** may also be aromatized with iodine using milder bases such as aliphatic tertiary amines. For example, treatment of **11a** with 1 equiv. of iodine and 2.5 equiv. of triethylamine or DBU at room temperature gave **12a** in 56 and 63% isolated yields, respectively.

2.3. Synthetic utility of 2-iodophenols and 2-iodoanilines

The 2-iodophenols and 2-iodoanilines described herein are useful precursors for the regioselective synthesis of benzoheterocyclic systems containing multiple substituents. The synthetic utility can be illustrated by the preparation of 2,3-dihydrobenzofurans **19a** and **19b** (Scheme 3) and the indoline derivative **20** (Scheme 4). Thus, iodophenols **2a** and **2f** were alkylated with allyl bromide and the resulting allyl 2-iodophenyl ethers **18a** and **18b** were subjected to tributyltin hydride mediated cyclization reaction[20–23] using catalytic 1,1′-azobiscyclohexylnitrile (ACN) as the free



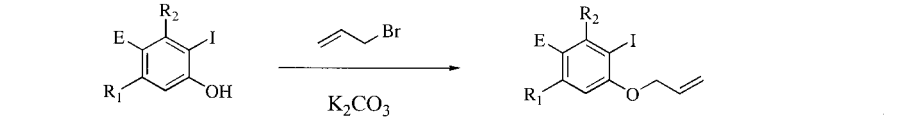
Scheme 2.

radical initiator to produce the regioisomeric 2,3-dihydrobenzofurans **19a** and **19b** in high yield. The indoline derivative **20** was obtained by the cyclization of iodoaniline **10a** under similar conditions.

In conclusion, we have developed an efficient methodology for the regioselective synthesis of 2-iodophenols and 2-iodoanilines with an electron withdrawing group in the 4-position and a variety of alkyl and aryl substituents in 3- or 5-positions. These materials are valuable precursors in the regioselective synthesis of benzoheterocyclic systems with multiple substituents on the benzene ring. In addition, we have provided a useful preparative method for the aromatization of *N*,*N*-dialkyl-1,3-cyclohexadien-1-amine derivatives to the corresponding *N*,*N*-dialkylanilines.

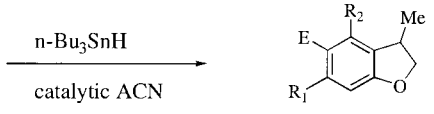
3. Experimental

Melting points were determined with a Mettler Toledo FP62



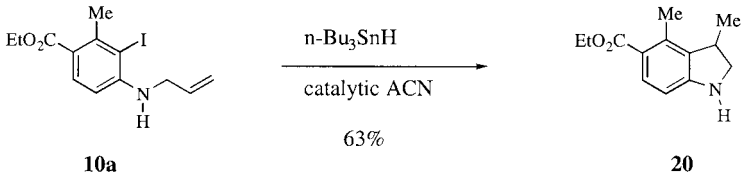
2a, E = CO_2Me, R_1 = Me, R_2 = H
2f, E = CO_2Et, R_1 = H, R_2 = Me

18a, E = CO_2Me, R_1 = Me, R_2 = H, 90% yield
18b, E = CO_2Et, R_1 = H, R_2 = Me, 95% yield



19a, E = CO_2Me, R_1 = Me, R_2 = H, 98% yield
19b, E = CO_2Et, R_1 = H, R_2 = Me, 98% yield

Scheme 3.



10a **20**

Scheme 4.

melting point apparatus and are uncorrected. All ^{1}H, ^{13}C and ^{19}F NMR spectra were recorded on a Bruker AM 360 NMR spectrometer at 360, 90 and 340 MHz, respectively. ^{1}H and ^{13}C chemical shifts (δ) are given in ppm relative to tetramethylsilane as the internal standard. ^{19}F chemical shifts (δ) are expressed in ppm relative to fluorotrichloromethane, with upfield shifts taken as negative. IR spectra were recorded on a Nicolet NEXUS 470 FT-IR instrument. Preparative HPLC was performed on a Waters Prep 500 system with a 25 mm steel column packed with Kieselgel 60 (230–400 mesh). Compound **1f** was purchased from Aldrich Chemical Company. Compounds **1a**,[16] **1b–e**,[15] **1g**,[17] **1h**,[18] **3**[24] and **9f**[24] were prepared according to previously published methods.

3.1. 3a,7a-Dihydro-2-methyl-1*H*-isoindole-1,3,5(2*H*,4*H*)-trione (5)

Compound **5** was prepared by the reaction of 1-methoxy-3-trimethylsilyloxy-1,3-butadiene (Danishefsky's diene) and *N*-methylmaleimide using the general method of cyclohexenone synthesis described in Ref. 16. A solution of 11.36 g (0.066 mol) of 1-methoxy-3-trimethylsilyloxy-1,3-butadiene and 6.59 g (0.059 mol) of *N*-methylmaleimide in 25 mL of toluene was heated at reflux for 24 h. The reaction mixture was then concentrated under reduced pressure to afford a pale yellow oil. To a solution of the above oil in 20 mL of acetone and 130 mL of methylene chloride at −78°C under nitrogen atmosphere was added a mixture of trimethylsilyl triflate (41.7 mL of a 0.06 M solution in methylene chloride, 0.0025 mol) and collidine (16.7 mL of a 0.03 M solution in methylene chloride, 0.0005 mol), resulting in a clear straw-colored solution. After 15 min, the reaction was quenched with an additional 0.5 equiv. of collidine in methylene chloride. The reaction mixture was then diluted with water (100 mL) and extracted with methylene chloride (3×100 mL). The combined extracts were washed with 5% HCl solution, dried ($MgSO_4$) and evaporated. The residue was purified by preparative HPLC using 20% ethyl acetate–hexane as the eluent to give 7.18 g (68%) of compound **5** as a pale yellow solid: mp 99–100°C; ^{1}H NMR ($CDCl_3$) δ 2.59–2.66 (m, 1H), 2.91 (s, 3H), 2.92–2.98 (m, 1H), 3.41–3.46 (m, 1H), 3.72–3.75 (m, 1H), 6.09 (dd, J=2.42, 10.2 Hz, 1H), 6.8 (dd, J=3.76, 10.2 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 25.4, 33.3, 37.5, 41.7, 131.4, 141.9, 174.8, 177.3, 193.7; IR (neat) 1776, 1709, 1686, 1618, 1434, 1301, 1258 cm^{-1}. Anal. calcd for $C_9H_9NO_3$: C, 60.33; H, 5.06; N, 7.82. Found: C, 60.24; H, 5.09; N, 7.76.

3.2. General procedure for the preparation of iodophenols 2a–h, 4 and 6

To a solution of 0.15 mol of sodium ethoxide (prepared by dissolving 3.45 g of sodium in 80 mL of ethanol) at −78°C was added 0.025 mol of the cyclohexenone substrate. After stirring for 15 min, 12.7 g (0.05 mol) of iodine was added in small portions. The reaction mixture was stirred for 3 h at −78°C and allowed to warm to room temperature. After stirring at room temperature overnight, the reaction mixture was neutralized with 5% HCl solution and then concentrated by evaporation of ethanol under reduced pressure. The resulting suspension was extracted with ethyl acetate. The organic layer was washed successively with saturated $NaHSO_3$ solution and brine, dried ($MgSO_4$) and evaporated. The residue was purified by preparative HPLC using 20% ethyl acetate–hexane as the eluent.

3.2.1. Iodophenol 2a. 66% Yield from cyclohexenone **1a**; mp 172–174°C; ^{1}H NMR (DMSO-d_6) δ 2.42 (s, 3H), 3.76 (s, 3H), 6.76 (s, 1H), 8.16 (s, 1H), 11.05 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 21.4, 51.6, 80.7, 117.5, 121.6, 141.4, 142.2, 160.0, 165.4; IR (neat) 3278, 1739, 1672, 1592, 1396, 1267, 1107, 779 cm^{-1}. Anal. calcd for $C_9H_9IO_3$: C, 37.01; H, 3.11; I, 43.45. Found: C, 37.12; H, 3.15; I, 43.30.

3.2.2. Iodophenol 2b. 86% Yield from cyclohexenone **1b**; mp 136–138°C; ^{1}H NMR (DMSO-d_6) δ 1.27 (t, J=7.3 Hz, 3H), 4.26 (q, J=7.1 Hz, 2H), 7.23 (s, 1H), 8.19 (s, 1H), 11.71 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 13.8, 61.4, 88.9, 112.4, 121.9, 123.0 (q, $^{1}J_{C-F}$=273.4 Hz), 129.0 (q, $^{2}J_{C-F}$=31.9 Hz), 141.8, 160.1, 164.0; ^{19}F NMR (DMSO-d_6) δ −55.95; IR (neat) 3358, 1700, 1595, 1398, 1257, 1136, 1063 cm^{-1}. Anal. calcd for $C_{10}H_8F_3IO_3$: C, 33.36; H, 2.24; I, 35.24. Found: C, 33.32; H, 2.22; I, 35.17.

3.2.3. Iodophenol 2c. 77% Yield from cyclohexenone **1c**; mp 83–85°C; ^{1}H NMR (DMSO-d_6) δ 1.25 (t, J=7.1 Hz, 6H), 4.23 (m, 4H), 7.02 (s, 1H), 8.08 (s, 1H), 11.48 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 13.8, 13.9, 61.1, 61.4, 87.0, 113.7, 122.2, 134.9, 140.1, 159.9, 164.7, 166.9; IR (neat) 3232, 1712, 1697, 1585, 1252, 1078 cm^{-1}. Anal. calcd for $C_{12}H_{13}IO_5$: C, 39.58; H, 3.60; I, 34.85. Found: C, 39.65; H, 3.58; I, 34.95.

3.2.4. Iodophenol 2d. 61% Yield from cyclohexenone **1d**; mp 105–107°C; ^{1}H NMR (DMSO-d_6) δ 1.07 (t, J=7.0 Hz, 3H), 4.08 (q, J=7.2 Hz, 2H), 6.93 (s, 1H), 7.03–7.04 (m, 1H), 7.08–7.09 (m, 1H), 7.59–7.60 (m, 1H), 8.03 (s, 1H), 11.21 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 13.7, 60.7, 83.7, 116.6, 123.7, 126.6, 127.5, 135.6, 140.4, 140.7, 159.2, 166.0; IR (neat) 3140, 1654, 1573, 1370, 1305, 1274, 1252, 780 cm^{-1}. Anal. calcd for $C_{13}H_{11}IO_3S$: C, 41.73; H, 2.96; I, 33.91. Found: C, 41.82; H, 2.96; I, 34.00.

3.2.5. Iodophenol 2e. 50% Yield from cyclohexenone **1e**; mp 107–109°C; ^{1}H NMR (DMSO-d_6) δ 3.72 (s, 3H), 6.56–6.57 (m, 1H), 6.66–6.67 (m, 1H), 7.09 (s, 1H), 7.74–7.75 (m, 1H), 7.98 (s, 1H), 11.17 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 52.1, 83.5, 108.9, 111.9, 113.4, 121.9, 131.2, 140.2, 143.6, 150.9, 159.3, 166.8; IR (neat) 3254, 1691, 1672, 1410, 1303, 1270, 751 cm^{-1}. Anal. calcd for $C_{12}H_9IO_4$: C, 41.89; H, 2.64; I, 36.88. Found: C, 41.83; H, 2.67; I, 36.95.

3.2.6. Iodophenol 2f. 59% Yield from cyclohexenone **1f**; mp 111–113°C; ^{1}H NMR ($CDCl_3$) δ 1.37 (t, J=7.3 Hz, 3H), 2.75 (s, 3H), 4.33 (q, J=7.1 Hz, 2H), 6.01 (s, 1H), 6.86 (d, J=8.4 Hz, 1H), 7.77 (d, J=8.4 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 14.4, 27.3, 61.1, 96.9, 111.9, 124.1, 132.4, 144.2, 157.6, 167.0; IR (neat) 3337, 1673, 1554, 1249, 1025, 771 cm^{-1}. Anal. calcd for $C_{10}H_{11}IO_3$: C, 39.24; H, 3.62; I, 41.46. Found: C, 39.37; H, 3.65; I, 41.29.

3.2.7. Iodophenol 2g. 65% Yield from cyclohexenone **1g**; mp 65–66°C; ^{1}H NMR (DMSO-d_6) δ 1.25 (t, J=7.2 Hz, 3H), 4.25 (q, J=7.2 Hz, 2H), 7.15 (d, J=8.4 Hz, 1H), 7.43 (d, J=8.4 Hz, 1H), 11.48 (s, 1H); ^{13}C NMR (DMSO-d_6) δ

13.7, 61.6, 85.5, 117.1, 122.4 (q, $^{1}J_{C-F}$=275.4 Hz), 125.7, 129.62, 130.4 (q, $^{2}J_{C-F}$=29.8 Hz), 159.4, 167.0; ^{19}F NMR (DMSO-d_6) δ −52.47; IR (neat) 3304, 1701, 1318, 1292, 1141 cm^{-1}. Anal. calcd for $C_{10}H_8F_3IO_3$: C, 33.36; H, 2.24; I, 35.24. Found: C, 33.48; H, 2.28; I, 35.09.

3.2.8. Iodophenol 2h. 64% Yield from cyclohexenone **1h**; mp 135–137°C; ^{1}H NMR (DMSO-d_6) δ 0.79 (t, *J*=7.0 Hz, 3H), 3.83 (q, *J*=7.0 Hz, 2H), 6.98 (d, *J*=8.4 Hz, 1H), 7.04 (d, *J*=6.4 Hz, 2H), 7.33–7.39 (m, 3H), 7.69 (d, *J*=8.4 Hz, 1H), 11.19 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 13.4, 60.0, 93.3, 113.2, 123.0, 127.1, 127.6, 128.7, 131.1, 144.3, 148.2, 159.8, 166.2; IR (neat) 3295, 1739, 1669, 1372, 1306, 1230, 699 cm^{-1}. Anal. calcd for $C_{15}H_{13}IO_3$: C, 48.94; H, 3.56; I, 34.47. Found: C, 49.00; H, 3.58; I, 34.58.

3.2.9. Iodophenol 4. 56% Yield from compound **3**; mp 202–203°C; ^{1}H NMR (DMSO-d_6) δ 1.00 (s, 3H), 2.39 (s, 2H), 2.79 (s, 2H), 6.87 (d, *J*=8.6 Hz, 1H), 7.77 (d, *J*=8.6 Hz, 1H), 11.29 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 27.9, 33.1, 49.3, 50.3, 91.7, 113.0, 125.1, 128.2, 147.1, 161.6, 195.7; IR (neat) 3225, 1657, 1632, 1585, 1414, 1301, 1268, 1127, 833 cm^{-1}. Anal. calcd for $C_{12}H_{13}IO_2$: C, 45.59; H, 4.14; I, 40.14. Found: C, 45.86; H, 4.10; I, 40.25.

3.2.10. Iodophenol 6. 84% Yield from compound **5**; mp 236–237°C; ^{1}H NMR (DMSO-d_6) δ 2.93 (s, 3H), 7.11 (s, 1H), 8.03 (s, 1H), 11.77 (br, 1H); ^{13}C NMR (DMSO-d_6) δ 24.2, 91.6, 108.8, 123.8, 134.2, 134.7, 162.6, 167.2, 168.0; IR (neat) 3238, 1760, 1682, 1620, 1598, 1108, 823 cm^{-1}. Anal. calcd for $C_9H_6INO_3$: C, 35.67; H, 2.00; N, 4.62; I, 41.87. Found: C, 35.82; H, 2.03; N, 4.51; I, 41.96.

3.3. General procedure for the preparation of dienamines 9a–e

A solution of 4.9 g (0.027 mol) of the cyclohexenone **1f**, 0.041 mol of a primary amine and 0.1 g of *p*-toluenesulfonic acid in 70 mL of toluene was heated at reflux for 1 h in a Dean–Stark apparatus with azeotropic removal of water. The reaction mixture was then evaporated and the residue was partitioned between ether and water. The organic layer was washed successively with saturated $NaHCO_3$ solution and brine, dried ($MgSO_4$) and evaporated. The residue was purified by preparative HPLC using 20% ethyl acetate–hexane as the eluent. Attempted purification of compound **9a** led to decomposition. Therefore, in this particular case, the crude product was directly used in the aromatization reaction.

3.3.1. Dienamine 9b. 69% Yield from cyclohexenone **1f** and benzylamine; mp 74–75°C; ^{1}H NMR ($CDCl_3$) δ 1.20 (t, *J*=7.1 Hz, 3H), 2.11–2.15 (m, 5H), 2.47 (t, *J*=8.8 Hz, 2H), 4.05 (br, 1H), 4.07 (q, *J*=7.1 Hz, 2H), 4.15 (d, *J*=5.0 Hz, 2H), 4.69 (s, 1H), 7.22–7.29 (m, 5H); ^{13}C NMR ($CDCl_3$) δ 13.9, 21.5, 23.6, 28.9, 46.9, 58.4, 96.0, 108.1, 126.9, 127.1, 128.1, 137.2, 149.1, 150.4, 167.9; IR (neat) 3398, 1736, 1366, 1230, 1217, 773 cm^{-1}. Anal. calcd for $C_{17}H_{21}NO_2$: C, 75.25; H, 7.80; N, 5.16. Found: C, 75.11; H, 7.82; N, 5.16.

3.3.2. Dienamine 9c. 71% Yield from cyclohexenone **1f** and piperonylamine; mp 72–73°C; ^{1}H NMR ($CDCl_3$) δ 1.19 (t, *J*=7.1 Hz, 3H), 2.10 (t, *J*=8.4 Hz, 2H), 2.12 (s, 3H), 2.46 (t, *J*=8.8 Hz, 2H), 3.90 (br, 1H), 4.04 (d, *J*=4.9 Hz, 2H), 4.06 (q, *J*=7.1 Hz, 2H), 4.65 (s, 1H), 5.86 (s, 2H), 6.68 (s, 2H), 6.71 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 13.9, 21.5, 23.6, 28.9, 46.7, 58.4, 96.0, 100.4, 107.6, 107.7, 108.2, 120.4, 131.0, 146.3, 147.3, 149.0, 150.1, 167.8; IR (neat) 3402, 1738, 1366, 1231, 1217, 1037 cm^{-1}. Anal. calcd for $C_{18}H_{21}NO_4$: C, 68.55; H, 6.71; N, 4.44. Found: C, 68.36; H, 6.72; N, 4.39.

3.3.3. Dienamine 9d. 58% Yield from cyclohexenone **1f** and 2-(aminomethyl)thiophene; mp 66–67°C; ^{1}H NMR ($CDCl_3$) δ 1.19 (t, *J*=7.2 Hz, 3H), 2.10 (t, *J*=8.4 Hz, 2H), 2.14 (s, 3H), 2.46 (t, *J*=8.8 Hz, 2H), 3.98 (br, 1H), 4.07 (q, *J*=7.2 Hz, 2H), 4.32 (d, *J*=4.9 Hz, 2H), 4.72 (s, 1H), 6.87–6.92 (m, 2H), 7.12–7.16 (m, 1H); ^{13}C NMR ($CDCl_3$) δ 13.9, 21.5, 23.5, 28.8, 41.6, 58.5, 96.5, 108.6, 124.4, 125.3, 126.2, 140.0, 148.7, 149.6, 167.8; IR (neat) 3390, 1736, 1366, 1230, 1217, 703 cm^{-1}. Anal. calcd for $C_{15}H_{19}NO_2S$: C, 64.95; H, 6.90; N, 5.05. Found: C, 64.80; H, 6.89; N, 5.00.

3.3.4. Dienamine 9e. 61% Yield from cyclohexenone **1f** and furfurylamine; mp 64–65°C; ^{1}H NMR ($CDCl_3$) δ 1.18 (t, *J*=7.1 Hz, 3H), 2.09 (t, *J*=8.3 Hz, 2H), 2.13 (s, 3H), 2.44 (t, *J*=8.9 Hz, 2H), 4.01 (br, 1H), 4.05 (q, *J*=7.2 Hz, 2H), 4.13 (d, *J*=4.9 Hz, 2H), 4.68 (s, 1H), 6.15 (d, *J*=2.9 Hz, 1H), 6.24 (d, *J*=1.8 Hz, 1H), 7.28 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 13.9, 21.5, 23.5, 28.7, 39.7, 58.4, 96.2, 106.9, 108.5, 109.7, 141.5, 148.8, 149.8, 150.4, 167.8; IR (neat) 3384, 1725, 1509, 1259, 1203, 737 cm^{-1}. Anal. calcd for $C_{15}H_{19}NO_3$: C, 68.94; H, 7.33; N, 5.36. Found: C, 68.88; H, 7.30; N, 5.37.

3.4. General procedure for the preparation of iodoanilines 10a–f

To a solution of 0.042 mol of sodium ethoxide (prepared by dissolving 1.01 g of sodium in 30 mL of ethanol) at −78°C was added 0.007 mol of the dienamine substrate. After stirring for 15 min, 3.67 g (0.015 mol) of iodine was added in small portions. The reaction mixture was stirred for 3 h at −78°C and allowed to warm to room temperature. After stirring at room temperature overnight, the reaction mixture was neutralized with 5% HCl solution and ethanol was removed by evaporation under reduced pressure. The resulting suspension was extracted with ethyl acetate. The organic layer was washed successively with saturated $NaHSO_3$ solution and brine, then dried ($MgSO_4$) and evaporated. The residue was purified by preparative HPLC using 10% ethyl acetate–hexane as the eluent.

3.4.1. Iodoaniline 10a. 47% Yield from dienamine **9a**; ^{1}H NMR ($CDCl_3$) δ 1.28 (t, *J*=7.1 Hz, 3H), 2.71 (s, 3H), 3.79–3.81 (m, 2H), 4.22 (q, *J*=7.1 Hz, 2H), 4.94 (br, 1H), 5.12–5.15 (m, 1H), 5.17–5.22 (m, 1H), 5.81–5.91 (m, 1H), 6.29 (d, *J*=8.8 Hz, 1H), 7.71 (d, *J*=8.8 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 13.7, 27.3, 45.7, 59.8, 95.0, 106.5, 116.0, 119.1, 131.4, 133.1, 143.5, 149.0, 166.5; IR (neat) 3388, 1704, 1589, 1365, 1249, 1171, 1080, 772 cm^{-1}. Anal. calcd for $C_{13}H_{16}INO_2$: C, 45.24; H, 4.67; N, 4.06; I, 36.76. Found: C, 45.28; H, 4.68; N, 4.03; I, 36.85.

3.4.2. Iodoaniline 10b. 56% Yield from dienamine **9b**; ^{1}H

NMR ($CDCl_3$) δ 1.35 (t, J=7.1 Hz, 3H), 2.79 (s, 3H), 4.29 (q, J=7.1 Hz, 2H), 4.61 (d, J=5.5 Hz, 2H), 5.32 (br, 1H), 6.37 (d, J=8.8 Hz, 1H), 7.25–7.39 (m, 5H), 7.75 (d, J=8.8 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 14.5, 28.1, 48.3, 60.6, 95.7, 107.4, 120.1, 127.2, 127.6, 128.9, 132.2, 138.0, 144.3, 149.8, 167.3; IR (neat) 3387, 1702, 1590, 1507, 1249, 1170, 1078, 771 cm^{-1}. Anal. calcd for $C_{17}H_{18}INO_2$: C, 51.66; H, 4.59; N, 3.54; I, 32.11. Found: C, 51.72; H, 4.63; N, 3.48; I, 32.04.

3.4.3. Iodoaniline 10c. 61% Yield from dienamine **9c**; mp 84–86°C; ^{1}H NMR ($CDCl_3$) δ 1.27 (t, J=7.2 Hz, 3H), 2.71 (s, 3H), 4.22 (q, J=7.2 Hz, 2H), 4.27 (d, J=5.5 Hz, 2H), 5.17 (br, 1H), 5.87 (s, 2H), 6.28 (d, J=8.6 Hz, 1H), 6.70 (s, 2H), 6.74 (s, 1H), 7.67 (d, J=8.6 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 13.7, 27.3, 47.4, 59.8, 95.0, 100.4, 106.6, 106.9, 107.8, 119.3, 119.7, 131.1, 131.4, 143.5, 146.3, 147.4, 148.9, 166.5; IR (neat) 3398, 1698, 1592, 1488, 1236, 1171, 1037, 770 cm^{-1}. Anal. calcd for $C_{18}H_{18}INO_4$: C, 49.22; H, 4.13; N, 3.19; I, 28.89. Found: C, 49.42; H, 4.17; N, 3.15; I, 28.71.

3.4.4. Iodoaniline 10d. 42% Yield from dienamine **9d**; ^{1}H NMR ($CDCl_3$) δ 1.35 (t, J=7.2 Hz, 3H), 2.79 (s, 3H), 4.29 (q, J=7.2 Hz, 2H), 4.61 (d, J=5.8 Hz, 2H), 5.30 (br, 1H), 6.46 (d, J=8.7 Hz, 1H), 6.96–7.02 (m, 2H), 7.22–7.23 (m, 1H), 7.78 (d, J=8.6 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 14.5, 28.1, 43.6, 60.6, 95.9, 107.4, 120.5, 125.0, 125.4, 127.1, 132.2, 141.4, 144.3, 149.4, 167.2; IR (neat) 3379, 1703, 1588, 1365, 1242, 1172, 1079, 771 cm^{-1}. Anal. calcd for $C_{15}H_{16}INO_2S$: C, 44.90; H, 4.02; N, 3.49; I, 31.63. Found: C, 45.14; H, 4.05; N, 3.46; I, 31.42.

3.4.5. Iodoaniline 10e. 55% Yield from dienamine **9e**; ^{1}H NMR ($CDCl_3$) δ 1.28 (t, J=7.2 Hz, 3H), 2.71 (s, 3H), 4.23 (q, J=7.2 Hz, 2H), 4.34 (d, J=5.5 Hz, 2H), 5.17 (br, 1H), 6.17 (d, J=2.9 Hz, 1H), 6.24–6.26 (m, 1H), 6.39 (d, J=8.6 Hz, 1H), 7.30 (s, 1H), 7.72 (d, J=8.6 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 13.7, 27.3, 40.8, 59.8, 95.1, 106.5, 106.7, 109.8, 119.7, 131.4, 141.6, 143.5, 148.7, 150.7, 166.5; IR (neat) 3388, 1702, 1589, 1245, 1172, 1078, 770 cm^{-1}. Anal. calcd for $C_{15}H_{16}INO_3$: C, 46.77; H, 4.19; N, 3.64; I, 32.94. Found: C, 46.98; H, 4.28; N, 3.57; I, 32.77.

3.4.6. Iodoaniline 10f. 47% Yield from dienamine **9f**; mp 102–103°C; ^{1}H NMR ($CDCl_3$) δ 1.06 (s, 6H), 1.29 (d, J=6.4 Hz, 2H), 2.38 (s, 2H), 2.77 (s, 2H), 3.71–3.79 (m, 1H), 4.84 (d, J=6.9 Hz, 1H), 6.48 (d, J=8.8 Hz, 1H), 7.93 (d, J=8.8 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 22.9, 28.6, 33.4, 44.9, 51.0, 51.2, 91.4, 108.6, 123.2, 129.0, 146.8, 150.6, 196.4; IR (DMSO) 3436, 1661, 1025, 953 cm^{-1}. Anal. calcd for $C_{15}H_{20}INO$: C, 50.43; H, 5.64; N, 3.92; I, 35.52. Found: C, 50.66; H, 5.67; N, 3.79; I, 35.31.

3.5. General procedure for the preparation of dienamines 11a–f

A solution of 0.027 mol of the cyclohexenone substrate, 0.041 mol of a secondary amine and 0.1 g of *p*-toluenesulfonic acid in 70 mL of toluene was heated at reflux for 24 h in a Dean–Stark apparatus with azeotropic removal of water. The reaction mixture was evaporated and the residue was partitioned between ethyl acetate and water. The organic layer was washed successively with saturated $NaHCO_3$ solution and brine, then dried ($MgSO_4$) and evaporated. The residue was purified by preparative HPLC using 20% ethyl acetate–hexane.

3.5.1. Dienamine 11a. 75% Yield from cyclohexenone **1f** and morpholine; mp 82–84°C; ^{1}H NMR ($CDCl_3$) δ 1.24 (t, J=7.1 Hz, 3H), 2.15 (s, 3H), 2.18 (t, J=9.3 Hz, 2H), 2.50 (t, J=9.0 Hz, 2H), 3.03 (t, J=4.9 Hz, 4H), 3.69 (t, J=4.9 Hz, 4H), 4.11 (q, J=7.1 Hz, 2H), 4.82 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 14.6, 21.8, 24.4, 25.4, 46.5, 59.3, 66.4, 102.7, 110.5, 147.8, 153.7, 168.3; IR (neat) 1705, 1603, 1269, 1232, 1113 cm^{-1}. Anal. calcd for $C_{14}H_{21}NO_3$: C, 66.91; H, 8.42; N, 5.57. Found: C, 66.87; H, 8.37; N, 5.54.

3.5.2. Dienamine 11b. 85% Yield from cyclohexenone **1f** and thiomorpholine; ^{1}H NMR ($CDCl_3$) δ 1.27 (t, J=7.2 Hz, 3H), 2.18 (s, 3H), 2.19 (t, J=9.7 Hz, 2H), 2.53 (t, J=8.9 Hz, 2H), 2.59–2.61 (m, 4H), 3.51–3.54 (m, 4H), 4.15 (q, J=7.1 Hz, 2H), 4.83 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 14.6, 22.0, 24.6, 25.8, 26.0, 48.8, 59.3, 102.4, 109.3, 148.2, 152.4, 168.3; IR (neat) 1710, 1366, 1263, 1217, 1050, 1005 cm^{-1}. HRMS (EI) *m/z* calcd for $C_{14}H_{21}NO_2S$: 267.1293. Found: 267.1292.

3.5.3. Dienamine 11c. 75% Yield from cyclohexenone **1f** and piperidine; ^{1}H NMR ($CDCl_3$) δ 1.24 (t, J=7.2 Hz, 3H), 1.55 (br, 6H), 2.17 (s, 3H), 2.19 (t, J=9.2 Hz, 2H), 2.51 (t, J=8.9 Hz, 2H), 3.08 (br, 4H), 4.11 (q, J=7.1 Hz, 2H), 4.81 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 14.6, 22.1, 24.5, 24.6, 25.3, 26.0, 47.1, 59.1, 101.4, 108.2, 149.1, 154.4, 168.4; IR (neat) 1737, 1716, 1602, 1447, 1365, 1265, 1231, 1217, 1051 cm^{-1}. Anal. calcd for $C_{15}H_{23}NO_2$: C, 72.25; H, 9.30; N, 5.62. Found: C, 72.17; H, 9.31; N, 5.53.

3.5.4. Dienamine 11d. 80% Yield from cyclohexenone **1f** and *N*-methylbenzylamine; ^{1}H NMR ($CDCl_3$) δ 1.27 (t, J=7.2 Hz, 3H), 2.24 (s, 3H), 2.34 (t, J=9.6 Hz, 2H), 2.56 (t, J=9.3 Hz, 2H), 2.86 (s, 3H), 4.15 (q, J=7.1 Hz, 2H), 4.41 (s, 2H), 4.78 (s, 1H), 7.12 (d, J=7.1 Hz, 2H), 7.24 (t, J=7.3 Hz, 1H), 7.32 (t, J=7.7 Hz, 2H); ^{13}C NMR ($CDCl_3$) δ 14.7, 22.3, 24.7, 25.9, 37.9, 54.5, 59.1, 99.3, 107.4, 126.6, 127.3, 128.8, 138.0, 149.9, 154.0, 168.5; IR (neat) 1709, 1603, 1453, 1366, 1262, 1216, 1051, 747 cm^{-1}. HRMS (EI) *m/z* calcd for $C_{18}H_{23}NO_2$: 285.1729. Found: 285.1703.

3.5.5. Dienamine 11e. 39% Yield from cyclohexenone **1h** and *N*-methylallylamine; ^{1}H NMR ($CDCl_3$) δ 0.85 (t, J=7.2 Hz, 3H), 2.43 (t, J=9.5 Hz, 2H), 2.70 (t, J=9.3 Hz, 2H), 2.84 (s, 3H), 3.81–3.83 (m, 2H), 4.37 (q, J=7.2 Hz, 2H), 4.75 (s, 1H), 5.09–5.19 (m, 2H), 5.71–5.79 (m, 1H), 7.17–7.32 (m, 5H); ^{13}C NMR ($CDCl_3$) δ 13.8, 25.2, 25.3, 37.7, 53.7, 59.1, 97.9, 108.0, 116.5, 126.6, 127.5, 127.6, 133.1, 144.4, 151.5, 153.5, 168.7; IR (neat) 1728, 1671, 1259, 1178, 1091, 1017, 797 cm^{-1}. HRMS (EI) *m/z* calcd for $C_{19}H_{23}NO_2$: 297.1729. Found: 297.1715.

3.5.6. Dienamine 11f. 75% Yield from cyclohexenone **1f** and 1-(4-fluorophenyl)piperazine; mp 102–103°C; ^{1}H NMR ($CDCl_3$) δ 1.27 (t, J=7.3 Hz, 3H), 2.21 (s, 3H), 2.25 (t, J=9.2 Hz, 2H), 2.56 (t, J=8.8 Hz, 2H), 3.11 (t, J=5.4 Hz, 4H), 3.24 (t, J=5.4 Hz, 4H), 4.15 (q, J=7.1 Hz, 2H), 4.90 (s, 1H), 6.85–6.89 (m, 2H), 6.93–6.97 (m, 2H); ^{13}C NMR

($CDCl_3$) δ 14.6, 22.0, 24.6, 25.8, 46.2, 50.0, 59.3, 102.9, 110.2, 115.7 (d, $^2J_{C-F}$=22.1 Hz), 118.3 (d, $^3J_{C-F}$=7.6 Hz), 147.8, 148.0, 153.4, 157.5 (d, $^1J_{C-F}$=239.4 Hz), 168.4; ^{19}F NMR ($CDCl_3$) δ −125.62; IR (neat) 1682, 1524, 1509, 1229, 1195, 828 cm^{-1}. Anal. calcd for $C_{20}H_{25}FN_2O_2$: C, 69.74; H, 7.32; N, 8.13. Found: C, 69.63; H, 7.35; N, 8.18.

3.6. General procedure for the preparation of *N*,*N*-dialkylanilines 12a–f

To a solution of 0.008 mol of sodium ethoxide (prepared by dissolving 0.18 g of sodium in 20 mL of ethanol) at −78°C was added 0.004 mol of the dienamine substrate. After stirring for 15 min, 1.01 g (0.004 mol) of iodine was added in small portions. The reaction mixture was stirred for 3 h at −78°C and allowed to warm to room temperature. After stirring at room temperature overnight, the reaction mixture was neutralized with 5% HCl solution and ethanol was removed by evaporation under reduced pressure. The resulting suspension was extracted with ethyl acetate. The organic layer was washed successively with saturated $NaHSO_3$ solution and brine, then dried ($MgSO_4$) and evaporated. The residue was purified by preparative HPLC using 10% ethyl acetate–hexane as the eluent.

3.6.1. Aniline 12a. 85% Yield from dienamine **11a**; mp 56–58°C; ^{1}H NMR ($CDCl_3$) δ 1.35 (t, *J*=7.2 Hz, 3H), 2.58 (s, 3H), 3.23 (t, *J*=4.9 Hz, 4H), 3.82 (t, *J*=4.9 Hz, 4H), 4.29 (q, *J*=7.2 Hz, 2H), 6.66–6.69 (m, 2H), 7.89 (d, *J*=8.6 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 14.5, 22.8, 47.9, 60.2, 66.7, 111.4, 116.9, 120.0, 132.7, 142.4, 153.4, 167.3; IR (neat) 1700, 1605, 1234, 1123, 771 cm^{-1}. Anal. calcd for $C_{14}H_{19}NO_3$: C, 67.45; H, 7.68; N, 5.62. Found: C, 67.48; H, 7.70; N, 5.61.

3.6.2. Aniline 12b. 88% Yield from dienamine **11b**; ^{1}H NMR ($CDCl_3$) δ 1.35 (t, *J*=7.2 Hz, 3H), 2.57 (s, 3H), 2.65–2.68 (m, 4H), 3.68–3.71 (m, 4H), 4.29 (q, *J*=7.1 Hz, 2H), 6.61–6.65 (m, 2H), 7.88 (d, *J*=8.5 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 14.5, 22.9, 26.0, 50.6, 60.1, 111.8, 117.4, 119.0, 132.9, 142.7, 152.3, 167.2; IR (neat) 1702, 1602, 1261, 1224, 1156, 1080, 773 cm^{-1}. Anal. calcd for $C_{14}H_{19}NO_2S$: C, 63.37; H, 7.22; N, 5.28. Found: C, 63.44; H, 7.27; N, 5.33.

3.6.3. Aniline 12c. 74% Yield from dienamine **11c**; ^{1}H NMR ($CDCl_3$) δ 1.36 (t, *J*=7.2 Hz, 3H), 1.61–1.67 (m, 6H), 2.59 (s, 3H), 3.28 (t, *J*=5.7 Hz, 4H), 4.29 (q, *J*=7.1 Hz, 2H), 6.67–6.69 (m, 2H), 7.88 (d, *J*=8.6 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 14.5, 22.9, 22.5, 25.5, 48.9, 59.6, 111.5, 117.1, 118.3, 132.7, 142.4, 153.8, 167.4; IR (neat) 1703, 1602, 1233, 1126, 774 cm^{-1}. Anal. calcd for $C_{15}H_{21}NO_2$: C, 72.84; H, 8.56; N, 5.66. Found: C, 72.60; H, 8.60; N, 5.60.

3.6.4. Aniline 12d. 84% Yield from dienamine **11d**; ^{1}H NMR ($CDCl_3$) δ 1.38 (t, *J*=7.4 Hz, 3H), 2.62 (s, 3H), 3.09 (s, 3H), 4.32 (q, *J*=7.4 Hz, 2H), 4.61 (s, 2H), 6.56–6.58 (m, 2H), 7.20 (d, *J*=7.2 Hz, 2H), 7.27 (t, *J*=7.1 Hz, 1H), 7.34 (t, *J*=7.7 Hz, 2H), 7.92 (d, *J*=8.4 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 14.6, 23.1, 38.5, 55.9, 59.9, 108.9, 114.2, 117.0, 126.6, 127.2, 128.8, 133.0, 138.1, 142.8, 152.1, 167.5; IR (neat) 1699, 1602, 1253, 1158, 1076, 772 cm^{-1}. Anal. calcd for $C_{18}H_{21}NO_2$: C, 76.30; H, 7.47; N, 4.94. Found: C, 76.18; H, 7.48; N, 4.91.

3.6.5. Aniline 12e. 89% Yield from dienamine **11e**; ^{1}H NMR ($CDCl_3$) δ 1.00 (t, *J*=7.2 Hz, 3H), 3.03 (s, 3H), 3.99–4.01 (m, 2H), 4.05 (q, *J*=7.2 Hz, 2H), 5.13–5.20 (m, 2H), 5.78–5.88 (m, 1H), 6.56 (d, *J*=2.7 Hz, 1H), 6.68 (dd, *J*=2.7, 6.1 Hz, 1H), 7.31–7.41 (m, 5H), 7.90 (d, *J*=8.8 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 13.9, 38.1, 54.7, 60.0, 110.1, 113.9, 116.5, 117.4, 126.8, 127.7, 128.5, 132.6, 132.7, 143.4, 145.4, 151.3, 168.0; IR (neat) 1698, 1597, 1279, 1147, 1097, 700 cm^{-1}. Anal. calcd for $C_{19}H_{21}NO_2$: C, 77.26; H, 7.17; N, 4.74. Found: C, 77.13; H, 7.20; N, 4.70.

3.6.6. Aniline 12f. 75% Yield from dienamine **11f**; mp 88–90°C; ^{1}H NMR ($CDCl_3$) δ 1.37 (t, *J*=7.2 Hz, 3H), 2.63 (s, 3H), 3.22 (t, *J*=5.2 Hz, 4H), 3.44 (t, *J*=5.3 Hz, 4H), 4.32 (q, *J*=7.0 Hz, 2H), 6.74–6.77 (m, 2H), 6.89–6.93 (m, 2H), 6.97–7.02 (m, 2H), 7.93 (d, *J*=8.5 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 14.5, 22.9, 47.9, 50.3, 60.2, 111.8, 115.7 (d, $^2J_{C-F}$=22.2 Hz), 117.4, 118.29 (d, $^3J_{C-F}$=7.6 Hz), 119.8, 132.7, 142.9, 147.8, 153.2, 157.5 (d, $^1J_{C-F}$=239.5 Hz), 167.3; ^{19}F NMR ($CDCl_3$) δ −125.79; IR (neat) 1681, 1600, 1508, 1292, 1227, 1154, 827, 777 cm^{-1}. Anal. calcd for $C_{20}H_{23}FN_2O_2$: C, 70.16; H, 6.77; N, 8.18. Found: C, 70.16; H, 6.80; N, 8.21.

3.6.7. Methyl 5-iodo-2-methyl-4-(2-propenyloxy)benzoate (18a). To a solution of 4.0 g (0.014 mol) of iodophenol **2a** and 2.42 g (0.02 mol) of allyl bromide in 50 mL of acetone was added 2.84 g (0.02 mol) of potassium carbonate and the resulting slurry was heated at reflux for 1 h. After cooling to room temperature, the mixture was filtered and the filtrate was evaporated under reduced pressure. The residue was diluted with water (100 mL) and extracted with ethyl acetate (3×100 mL). The combined organic layers were washed with water, dried ($MgSO_4$) and evaporated. Purification of the residue by preparative HPLC using 2% ethyl acetate–hexane as the eluent gave 4.10 g (90%) of compound **18a** as a pale yellow solid: mp 110–111°C; ^{1}H NMR ($CDCl_3$) δ 2.48 (s, 3H), 3.77(s, 3H), 4.53–4.55 (m, 2H), 5.23–5.26 (m, 1H), 5.41–5.46 (m, 1H), 5.91–5.99 (m, 1H), 6.52 (s, 1H), 8.28 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 21.6, 51.1, 68.9, 81.4, 114.0, 117.3, 122.8, 131.2, 141.3, 142.7, 158.9, 165.4; IR (neat) 1702, 1368, 1248, 1096, 981, 776 cm^{-1}. Anal. calcd for $C_{12}H_{13}IO_3$: C, 43.40; H, 3.95; I, 38.21. Found: C, 43.39; H, 3.96; I, 38.18.

3.6.8. Ethyl 3-iodo-2-methyl-4-(2-propenyloxy)benzoate (18b). Treatment of 4.0 g (0.014 mol) of iodophenol **2f** with 2.42 g (0.02 mol) of allyl bromide and 2.84 g (0.02 mol) of potassium carbonate as above gave 4.28 g (95%) of compound **18b** as a pale yellow solid: mp 46–48°C; ^{1}H NMR ($CDCl_3$) δ 1.29 (t, *J*=7.2 Hz, 3H), 2.69 (s, 3H), 4.25 (q, *J*=7.2 Hz, 2H), 4.55–4.56 (m, 2H), 5.23–5.26 (m, 1H), 5.44–5.49 (m, 1H), 5.92–6.02 (m, 1H), 6.55 (d, *J*=8.6 Hz, 1H), 7.72 (d, *J*=8.6 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 13.6, 26.5, 60.2, 69.1, 96.4, 107.9, 117.2, 123.9, 131.1, 131.4, 144.0, 158.7, 166.4; IR (neat) 1701, 1276, 1247, 1211, 1183, 1090, 1061, 771 cm^{-1}. Anal. calcd for $C_{13}H_{15}IO_3$: C, 45.11; H, 4.37; I, 36.66. Found: C, 44.98; H, 4.35; I, 36.53.

3.6.9. Methyl 3,6-dimethyl-2,3-dihydrobenzofuran-5-carboxylate (19a). A solution of 2.0 g (0.004 mol) of **18a**, 3.5 g (0.012 mol) of tributyltin hydride and 50 mg of 1,1′-azobis(cyclohexanecarbonitrile) in 250 mL of toluene was heated at reflux for 1 h. After cooling to room temperature, the mixture was evaporated under reduced pressure and the residue was purified by preparative HPLC using 2% ethyl acetate–hexane as the eluent to give 1.22 g (98%) of **19a** as a pale yellow oil: ^{1}H NMR ($CDCl_3$) δ 1.25 (d, J=6.9 Hz, 3H), 2.49 (s, 3H), 3.39–3.48 (m, 1H), 3.77 (s, 3H), 4.02–4.06 (m, 1H), 4.64 (t, J=8.9 Hz, 2H), 6.55 (s, 1H), 7.69 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 18.8, 21.8, 35.1, 50.8, 78.8, 111.7, 120.9, 126.1, 129.3, 142.0, 162.3, 167.0; IR (neat) 1715, 1255, 1134, 1116, 962, 783 cm^{-1}. Anal. calcd for $C_{12}H_{14}O_3$: C, 69.89; H, 6.84. Found: C, 69.89; H, 6.86.

3.6.10. Ethyl 3,4-dimethyl-2,3-dihydrobenzofuran-5-carboxylate (19b). Treatment of 2.0 g (0.006 mol) of **18b** with 3.5 g (0.012 mol) of tributyltin hydride and 50 mg of 1,1′-azobis(cyclohexanecarbonitrile) as above gave 1.25 g (98%) of **19b** as a pale yellow oil: ^{1}H NMR ($CDCl_3$) δ 1.19 (d, J=6.9 Hz, 3H), 1.28 (t, J=7.1 Hz, 3H), 2.46 (s, 3H), 3.36–3.44 (m, 1H), 4.17–4.25 (m, 3H), 4.52 (t, J=8.5 Hz, 2H), 6.56 (d, J=8.4 Hz, 1H), 7.75 (d, J=8.4 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 13.7, 16.8, 19.3, 35.1, 59.6, 78.5, 106.1, 121.8, 131.8, 131.9, 137.0, 161.4, 166.7; IR (neat) 1708, 1252, 1160, 1123, 1050, 780 cm^{-1}. Anal. calcd for $C_{13}H_{16}O_3$: C, 70.89; H, 7.32. Found: C, 70.83; H, 7.32.

3.6.11. Ethyl 3,4-dimethyl-2,3-dihydroindole-5-carboxylate (20). Treatment of 2.0 g (0.006 mol) of **10a** with 3.5 g (0.012 mol) of tributyltin hydride and 50 mg of 1,1′-azobis(cyclohexanecarbonitrile) as above gave 0.8 g (63%) of **20** as a white solid: mp 90–92°C; ^{1}H NMR ($CDCl_3$) δ 1.13 (d, J=6.9 Hz, 3H), 1.27 (t, J=7.1 Hz, 3H), 2.44 (s, 3H), 3.15–3.18 (m, 1H), 3.25–3.33 (m, 1H), 3.63 (t, J=8.5 Hz, 1H), 4.01 (br, 1H), 4.18–4.23 (m, 2H) 6.32 (d, J=8.3 Hz, 1H), 7.68 (d, J=8.3 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 13.8, 16.6, 18.9, 34.5, 54.1, 59.2, 104.7, 118.6, 131.7, 132.9, 136.3, 153.1, 167.1; IR (neat) 3359, 1686, 1598, 1587, 1255, 1241, 1143, 1050 cm^{-1}. Anal. calcd for $C_{13}H_{17}NO_2$: C, 71.21; H, 7.81; N, 6.39. Found: C, 71.06; H, 7.77; N, 6.38.

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