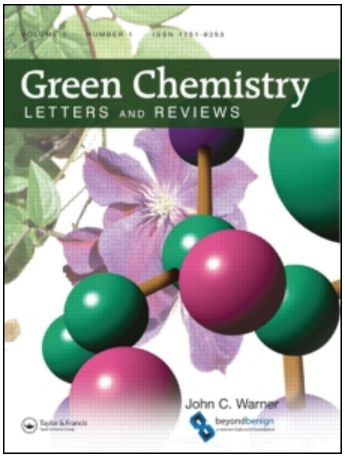

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Boric acid catalyzed bromination of a variety of organic substrates: an eco-friendly and practical protocol

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RESEARCH LETTER

Boric acid catalyzed bromination of a variety of organic substrates: an eco-friendly and practical protocol

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An environmentally benign, easy to operate, and practical protocol for the regioselective bromination of aromatic compounds using boric acid as a recyclable catalyst, KBr as the source of bromide and hydrogen peroxide as the oxidant is described. Peroxoborate generated in solution, from the reaction of boric acid and H_2O_2, very effectively catalyses the bromination of organic substrates at room temperature in a selective manner. The catalyst used is inexpensive, eco-friendly, safe to handle, and recyclable. The methodology is chemoselective for dibenzylidineacetone and regioselective for the other substrates. High yields of the products, mild reaction conditions, high selectivity, use of H_2O or C_2H_5OH as solvent, and redundancy of bromine are some of the major advantages of the synthetic protocol.

Keywords: arenes; aryl ketone; alkenes; bromination; hydrogen peroxide; boric acid

Introduction

Owing to their increasing commercial use, brominated aromatic compounds are very important in synthetic organic chemistry. They are key intermediates in the preparation of many organometallic reagents (*1–4*) and play vital roles in transition metal mediated coupling reactions such as Stille (*5*), Suzuki (*6*), Heck (*7,8*), and Sonogashira reactions (*9,10*). Many pesticides, insecticides, herbicides, pharmaceutically and medicinally active molecules, and fire retardants carry bromo functionality (*11*).

The need for isomerically pure bromoaromatic compounds has led to develop selective brominating agents or bromination protocols (*12*). Most of the processes currently practiced for the bromination of aryl compounds employ toxic, corrosive, and rather expensive molecular bromine, resulting in the formation of large amount of HBr waste, thereby reducing the atom efficiency by 50% (*11*). In large scale operations this causes environmental problems in addition to being expensive. Bromination using HBr with either H_2O_2 (*11,13–15*) or O_2 (*16–18*) as an oxidant was thought to be a possible solution. This, however, met with partial success. In addition, HBr is highly toxic and corrosive, and is as harmful as molecular bromine. These problems enhanced the appeal of bromination protocols based on oxidation of bromide salt by H_2O_2 with better bromide atom economy (*13–16,19,20*). The systems reported so far require metal or other catalysts and volatile organic solvents (*16,19,21–24*). Recently, Adimurthy et al. reported an "eco-friendly and versatile" brominating reagent based on Br^-/BrO_3^- (2:1) and 2MHCl (*25*).

Our endeavor for an eco-benevolent method for bromination of organic substrates has culminated in the development of an easy to operate, practical, and environmentally benign protocol for the regioselective bromination of aromatic compounds involving boric acid as the catalyst, KBr as the source of bromide, and hydrogen peroxide as the oxidant. The solvent is either H_2O or C_2H_5OH.

Results and discussion

Background

Boric acid is easily available, inexpensive, ecologically favorable, safe to handle, and is effective under milder conditions. It can be removed, after reaction, by the aqueous bicarbonate wash. Notably, boron acids (i.e. boric and boronic acids) act as catalyst in a number of transformations, for example, esterification of α-hydroxycarboxylic acids (*26*), aza-Michael (*27*), thia-Michael (*28*) reactions and organic sulfide oxidations (*29*).

The present protocol is based on (i), the role of the catalyst as a Lewis acid in the activation of H_2O_2

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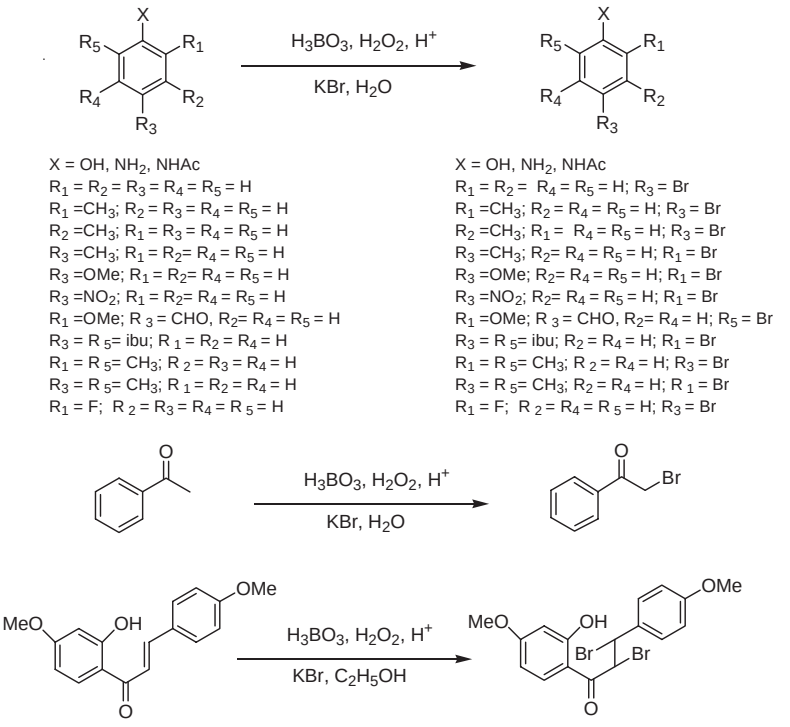


Scheme 1.

forming peroxoborate species, followed by (ii), the oxidation of bromide by peroxoborate intermediate in presence of acid to Br_3^- as the active brominating agent, and finally (iii), site-selective bromination of organic substrates to afford bromoorganic compounds (Scheme 1).

Our earlier work on peroxoborate (*29*) and oxidative bromination of aromatics (*30*) suggested that the peroxoborate intermediate generated *in situ* would enable bromide oxidation in presence of an acid. The fact, that Br_3^- is formed in this process has been ascertained from an independent experiment wherein Br^- was oxidized by the present methodology in the absence of any organic substrate but in the presence of tetrabutylammonium chloride and three equivalents of KBr leading to nearly quantitative isolation of tetrabutylammonium tribromide (TBATB) (98% yield) (Scheme 2).

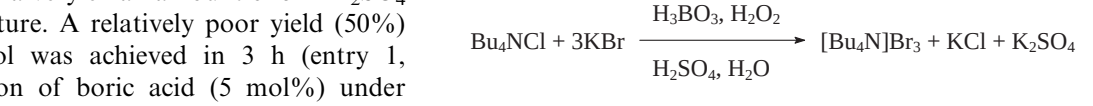
The identity of TBATB has been ascertained by comparing with the authentic product (*31–33*).

Screening of reaction conditions

Initially, we chose phenol as a model substrate and reacted with potassium bromide in water in presence of 30% H_2O_2 and a very small amount of 5M H_2SO_4 at room temperature. A relatively poor yield (50%) of *p*-bromophenol was achieved in 3 h (entry 1, Table 1). Addition of boric acid (5 mol%) under identical conditions, increased the yield to 75% (entry 2, Table 1) within 20 mins. This success encouraged us to conduct the reaction at different temperatures (Table 1).

Although the conversion increased at higher temperature (65°C), the selectivity was relatively lower (71% *p*-bromophenol). Conversely, the reaction was not complete at 5°C even after 8 h (yield 52%, entry 3, Table 1). Thus, room temperature was found to be conducive. Similarly, the experiments on catalyst optimization (Table 1) suggested that the presence of 5 mol% of the catalyst afforded the best result. Bromination of a variety of aromatic compounds was carried out under the standardized experimental conditions in either water (for liquid substrates) or C_2H_5OH (for solid substrates). The details including the isolated yields are shown in Table 2.

Phenols **1–3** and anilines **9** and **10** were found to be the most reactive to give the corresponding *p*-bromophenols **1a–3a** and *p*-bromoanilines **9a** and **10a**, respectively. Regioselective bromination of aromatics is an important protocol in organic synthesis because of their use as synthetic intermediates for a variety of transformations (*22*). Thus, acetanilide **13**



Scheme 2.

Table 1. H_3BO_3-catalysed bromination of phenol with KBr and H_2O_2 in water under different reaction conditions.

Entry	H_3BO_3 (mol%)	Temperature. (°C)	Time (min)	Conversion (%)[a]	Yield (%)[a]		
					Para	Ortho	Di (*o*,*p*)
1	–	25	180	70	50	17	3
2	5	25	20	99	75	20	5
3	5	5	420	75	52	20	3
4	5	65	10	99	71	15	13
5	10	25	10	99	70	17	12
6	7.5	25	15	99	74	20	5
7	2.5	25	40	86	67	17	2

[a]Conversion and selectivity were determined by GC.

gave exclusively the para-derivative in very high yield. Similar results were obtained with the substrates **4**–**8**, **11**, and **12** bearing different functional groups. Notably, with an aromatic ring carrying both meta and *o*,*p*-directing groups, it is the *o*,*p*-directing group that seems to control the substitution as demonstrated for *p*-nitrophenol **6**. Deactivated aniline **12** was smoothly brominated to the corresponding para-bromoaniline **12a** in 2h. β-naphthol **14** selectively afforded 1-bromo β-naphthol in very high yield. This is rather tedious by some other methologies (*34*).

The methodology also works well for bromination of ethylenic and carbonyl functions. For example, vinyl benzene **15** was efficiently brominated to the corresponding dibromo derivative. Quite interesting is the reaction of 4-methoxy-4′-methoxy-2′-hydroxy-chalcone **16**, where the double bond in the chalcone is selectively brominated in the presence of an activated aromatic ring. Product **16a** is an important precursor for flavonoids (cf. vitexin) (*30*). α-bromination of acetophenone **17**, a deactivated aromatic compound, to the corresponding α-bromo acetophenone **17a** in high yield has also been successful. **17a** is an important precursor for heterocycle synthesis (*35*,*36*) and Suzuki coupling reactions (*37*). Also important is the chemoselective bromination of one double bond in a substrate containing two symmetrical double bonds, as demonstrated for dibenzylidine acetone **18**. Imidazole **19**, which is sensitive to usual bromination (*31*), was brominated to 2,4,5-tribromoimidazole **19a** in high yield. This product is believed to be capable of catalytically reactivating phosphorylated acetylcholinesterase (*38*). In yet another interesting reaction, bisphenol-A **20** was brominated to tetrabromobisphenol-A (4,4′-isopropylidene-bis-(2,6-dibromophenol)) **20a** under the conditions used herein. This is otherwise difficult to achieve because of the formation of side products, requirement of high temperature and long-reaction time. Tetrabromobisphenol-A is possibly the largest selling flame retardant used extensively to provide flame retardancy for styrenic thermoplastics and for some thermoset resins (*39*). Our attempt to achieve bromination of benzene was unsuccessful.

Finally, upon completion of the reaction, the catalyst recyclability was examined through a series of reactions involving phenol and the recyclable mother liquor containing boric acid, H_2SO_4 and additional amount of bromide (Table 3).

The reaction continued giving good yields, however, with relatively long reaction times due to leaching of the catalyst. The reaction was performed on a relatively higher scale (5 g) giving good yields (Table 2, entry 1) demonstrating its potential for scaled up applications.

Experimental

Materials and methods

Reagents and solvents were used as purchased. All reactions were monitored by thin layer chromatography (TLC) on silica gel 60 F254 (0.25 mm), visualization was effected with UV and/or by developing in iodine. Purification of the reaction products was carried out by column chromatography using 60–120 mesh silica gel. Organic extracts were dried over Na_2SO_4 (anhydrous). Solvents were removed in rotary evaporator under reduced pressure. Crystalline boric acid and 30% H_2O_2 were used for the reaction. Gas chromatography (GC) analysis was performed on a Thermo Trace GC Ultra using TIPO BP 1 column. The products were characterized by comparing their spectral data recorded on Perkin Elmer Spectrum One FT-IR Spectrometer and Varian-400 FTNMR. Melting points were recorded on BUCHI Melting Point B-540. Gas chromatography mass spectra were recorded on Perkin Elmer Clarus 500 Mass Spectrometer.

General procedure for bromination

To a solution of boric acid (0.05 mmol, 0.0031 g) in 30% H_2O_2 (3 mmol, 0.338 mL), substrate (1 mmol) was added. To this KBr (1.2 mmol, 0.1428 g), 5M H_2SO_4 (0.7 mmol, 0.14 mL) were added and the whole

Table 2. Bromination of organic substrates using KBr and H_3BO_3–H_2O_2 system.

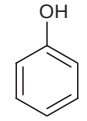
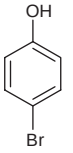
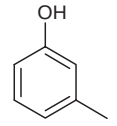
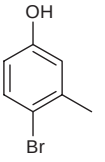
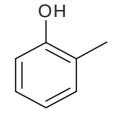
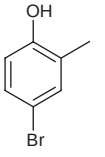
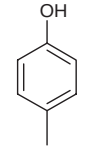
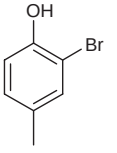
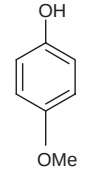
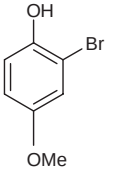
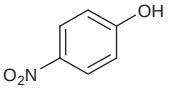
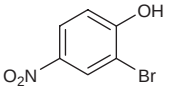
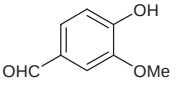
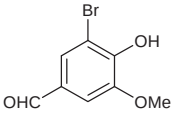
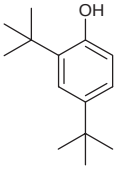
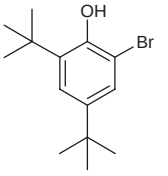
Entry	Substrate[a]	Product (a)	Substrate:KBr	Solvent	Time (min) [h]	Yield[b] (%)	Ortho:Para:Di
1			1:1.2	H_2O	(20)	75[c], 78[d]	20:75:5[e]
2			1:1.2	H_2O	(35)	85	9:85:6[e]
3			1:1.2	H_2O	(35)	80	8:80:16[e]
4			1:1.2	H_2O	(35)	75	75:–:15[f]
5			1:1.2	C_2H_5OH	(45)	76	–
6			1:1.2	C_2H_5OH	[20]	60	60:–:10[f]
7			1:1.2	C_2H_5OH	[2]	77	–
8			1:1.2	C_2H_5OH	(15)	98	–

Table 2. (*Continued*)

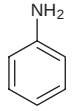
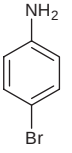
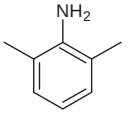
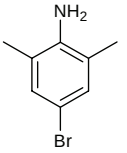
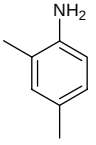
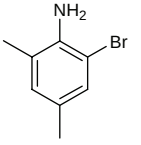
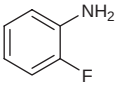
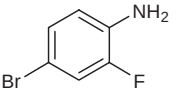
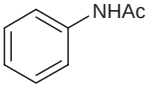
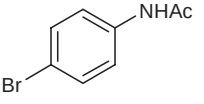
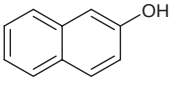
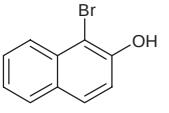
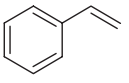
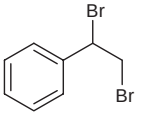
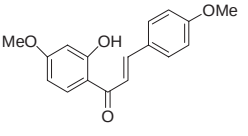
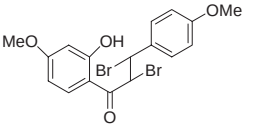
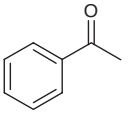
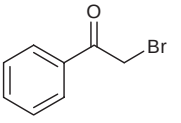
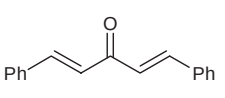
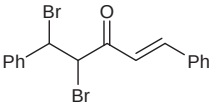
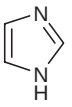
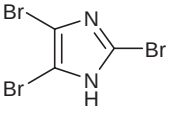
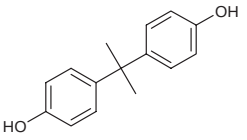
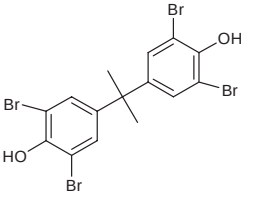
Entry	Substrate[a]	Product (a)	Substrate:KBr	Solvent	Time (min) [h]	Yield[b] (%)	Ortho:Para:Di
9			1:1.2	H_2O	(35)	80	–
10			1:1.2	H_2O	(28)	95	–
11			1:1.2	H_2O	(20)	99	–
12			1:1.2	H_2O	[2]	85	5:80:10[c]
13			1:1.2	C_2H_5OH	[2]	86	–
14			1:1.2	C_2H_5OH	(50)	87	–
15			1:2.2	H_2O	(35)	85	–
16			1:2.2	C_2H_5OH	[2]	70	–
17			1:1.2	H_2O	[24]	76	–

Table 2. (*Continued*)

Entry	Substrate[a]	Product (a)	Substrate:KBr	Solvent	Time (min) [h]	Yield[b] (%)	Ortho:Para:Di
18			1:2.2	C_2H_5OH	[1.5]	90	–
19			1:4	C_2H_5OH	(50)	70	–
20			1:6	C_2H_5OH	40	40	–

[a]Reactions were monitored by TLC.
[b]Isolated yields of the major product.
[c]Yields were determined by GC.
[d]Yield on 5 g scale.
[e]*o,p* selectivity is with respect to OH and NH_2 group.
[f]*o,o*˙ selectivity is with respect to OH group.

was stirred at room temperature. For liquid substrates water (2.5 mL) and for solid substrates C_2H_5OH (2.5 mL) were used as solvents. The progress of the reaction was monitored by TLC. After completion of the reaction, the mixture was extracted with tert-butyl methyl ether. Na_2SO_3 was added to the combined organic extracts (except for anilines) to destroy any excess of H_2O_2, if present, and then filtered and dried over anhydrous Na_2SO_4. However, for anilines, the organic extracts were washed successively with 5% $NaHCO_3$, water and then brine, and Na_2SO_3, followed by drying over anhydrous Na_2SO_4. Evaporation of solvent left the crude product, which was purified by column chromatography on silica gel with ethyl acetate and n-hexane (ratio varied with product) as eluent to afford the pure product. However, solid products were isolated by filtration, dried, and finally purified by column chromatography. The aqueous layer containing boric acid and sulfuric acid was rescued for the next run with an additional amount of bromide.

Table 3. Recycling of the catalyst for the reaction of phenol in water.

Cycle	Yield (%)	Time (h)
1	94	0.75
2	92	3.5
3	91	5

Conclusion

The present results demonstrate the production of bromoorganic compounds with very high selectivity under mild and metal free catalytic conditions. No use of Br_2 and volatile organic solvents in the synthesis, the involvement of cost effective, readily available and non-toxic catalyst, and water or C_2H_5OH as the reaction medium renders this protocol green, attractive, and practically useful.

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Appendix A: Supporting information

Selected spectral data:

4-Bromo-phenol (1a): ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 5.4$ (brs, 1H), 6.72 (d, $J = 8.8$ Hz, 2H), 7.32 (d, $J = 7.6$ Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 112.9$, 117.4, 132.6, 154.8 IR (neat): 3401, 1588, 1489, 1474, 1243, 1070, 1007, 823, 606, 500 cm^{-1}. Mass (EI): 172/174 (M^+).

4-Bromo-3-methyl-phenol (2a): ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 2.3$ (s, 3H), 5.16 (s, 1H), 6.53 (dd, $J_1 = 7.2$ Hz, $J_2 = 8.8$ Hz 1H), 6.71 (d, $J = 3.2$ Hz, 1H), 7.33 (d, $J = 8.8$ Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): $\delta =$ 23.4, 114.6, 115.8, 118.0, 133.2, 139.2, 154.8. IR (neat): 3394, 2981, 2923, 1603, 1578, 1474, 1290, 1240, 1163, 1029, 857, 805, 601 cm^{-1}. MS (EI): 186/188 (M^+).

4-Bromo-2-methyl-phenol (3a): ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 2.21$ (s, 3H), 4.96 (brs, 1H), 6.63 (d, $J = 8.0$ Hz, 1H), 7.16 (dd, $J_1 = 5.6$ Hz, $J_2 = 2.4$Hz, 1H), 7.22 (d, $J =$ 2.4 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 15.8$, 112.7, 116.6, 126.4, 129.8, 133.6, 152.9. IR (KBr): 3407, 2933, 1492, 1407, 1263, 1178, 1118, 814, 630 cm^{-1}.

2-Bromo-4-methyl-phenol (4a): ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 2.26$ (s, 3H), 5.34 (s, 1H), 6.9 (d, $J = 8$ Hz, 1H), 7.01 (d, $J = 8.4$ Hz, 1H), 7.26(d, $J = 6.8$ Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 20.1$, 109.5, 115.8, 118.0, 129.9, 132.2, 132.5, 150.1. IR (neat): 3394, 2981, 2923, 1603, 1578, 1474, 1290, 1240, 1163, 1029, 857, 805, 601 cm^{-1}.

2-Bromo-4-methoxy phenol (5a): ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 3.74$ (s, 3H), 5.32 (brs, 1H), 6.77 (m, 1H), 6.92 (m, 1H), 7.00 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 56.3$, 110.1, 115.5, 116.6, 117.1, 146.6, 153.9. IR (KBr): 3431, 2950, 2842, 1588, 1495, 1208, 1039, 768 cm^{-1}.

3-Bromo-4-hydroxy-5-methoxy-benzaldehyde (7a): ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 3.91$ (s, 3H), 5.31 (s, 1H), 7.37 (s,

$J = 1.4$ Hz 1H), 7.65 (s, $J = 1.4$ Hz 1H), 9.80 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 56.7$, 107.8, 108.1, 130.3, 134.6, 149.0, 158.8, 190. IR (KBr): 3314, 2976, 2945, 2848, 1685, 1588, 1511, 1429, 1358, 1291, 1158, 1055, 682 cm^{-1}.

2-Bromo-4,6-di-*tert*-butyl-phenol (8a): ^1H NMR (400 MHz, $CDCl_3$): $\delta = 1.28$ (s, 9H), 1.40 (s, 9H), 5.64 (s, 1H), 7.24 (s, 1H) 7.31 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 26.8$, 29.5, 29.6, 31.7, 34.6, 35.7, 111.1, 126.4, 136.9, 143.9, 148.2. IR (KBr): 3519, 2955, 2863, 1577, 1485, 1362, 1275, 1178, 870, 840, 742, 712 cm^{-1}. Melting Point observed: 58.2–60.3°C.

4-Bromo-aniline (9a): ^1H NMR (400 MHz, $CDCl_3$): $\delta =$ 3.65 (brs, 2H), 6.56 (d, $J = 8$ Hz, 2H), 7.24 (d, $J = 6.4$ Hz, 2H). ^{13}CNMR (100 MHz, $CDCl_3$): $\delta = 110.3$, 116.8, 132.1, 145.5. IR (KBr): 3375, 3032, 2925, 1629, 1491, 1281, 1178, 1071, 810, 605, 502 cm^{-1}.

4-Bromo-2,6-dimethyl-aniline (10a): ^1H NMR (400 MHz, $CDCl_3$): $\delta = 2.21$ (s, 6H), 7.05 (s, 2H), 8.10 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 17.6$, 18.46, 109.6, 123.8, 130.7, 131.0, 131.4, 131.5, 141.9. IR (KBr): 3394, 1624, 1473, 1265, 1230, 859, 737 cm^{-1}.

2-Bromo-4,6-dimethyl-aniline (11a): ^1H NMR (400 MHz, $CDCl_3$): $\delta = 2.17$ (s, 6H), 5.28 (s, 2H), 6.79 (s, 1H), 7.10 (s, H). ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 18.4$, 20.2, 53.6, 109.6, 123.7, 128.6, 130.4, 130.5, 139.8. IR (KBr): 3387, 2926, 1624, 1483, 1289, 850, 738 cm^{-1}.

4-Bromo-2-fluoro-aniline (12a): ^1H NMR (400 MHz, $CDCl_3$): $\delta = 3.72$ (brs, 2H), 6.64 (m, 1H), 7.02 (m, 1H), 7.12 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 108.9$, 117.8, 118.6, 118.8, 118.9, 124.5, 127.5, 134.0, 150.2, 152.6. IR (KBr): 3391, 3088, 2925, 1711, 1486, 1419, 1209, 1071, 892, 697, 564 cm^{-1}.

4-Bromo-acetanilide (13a): ^1H NMR (400 MHz, $DMSOd_6$): $\delta = 2.02$ (s, 3H), 7.27 (d, $J = 8.4$ Hz, 2H), 7.44 (d, $J = 8.8$ Hz, 2H), 9.56 (s, 1H). ^{13}CNMR (100 MHz, $DMSOd_6$): $\delta =$ 23.5, 114.8, 120.6, 130.7, 137.6, 168.3. IR (KBr): 3293, 3261, 3186, 3052, 1665, 1601, 1524, 1488, 1391, 1325, 1007, 830, 742 cm^{-1}. Melting Point observed: 168°C (Literature 165–169°C)

1-Bromo-2-naphthol (14a): ^1H NMR (400 MHz, $CDCl_3$): $\delta = 5.92$ (brs, 1H), 7.35 (m, 1H), 7.38 (m, 1H), 7.56 (m, 1H), 7.75 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 106.3$, 117.3, 124.3, 125.5, 128.0, 128.4, 129.5, 132.4, 150.7. IR (KBr): 3300, 2920, 2850, 1500, 1450, 1350, 1300, 1230, 980, 930, 810, 750, 650 cm^{-1}.

1,2-(Dibromo-ethyl)-benzene (15a): ^1H NMR (400 MHz, $CDCl_3$): $\delta = 4.04$ (m, 2H), 5.13 (dd, $J_1 = 5.6$ Hz, $J_2 = 5.2$ Hz 1H), 7.36 (m, 5H). ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 35.23$, 51.08, 127.8, 129.1, 129.4, 138.8. IR (KBr): 3064, 3033, 1496, 1455, 1431, 1231, 1198, 1155, 907, 769, 691, 590 cm^{-1}.

4-Methoxy-4′-methoxy-2′-hydroxy-dibromochalcone (16a): ^1H NMR (400 MHz, $CDCl_3$): $\delta = 3.16$ (s, 3H), 3.91 (s, 3H), 4.75 (d, $J = 9.6$ Hz, 1H), 5.04 (d, $J = 10$ Hz, 1H), 5.27(s, 1H), 6.91 (d, $J = 8.4$ Hz, 1H), 7.35 (dd, $J_1 = 4$, $J_2 =$ 8.4 1H), 7.49 (m, 2H), 7.64 (d, $J = 2$ Hz, 1H), 8.0 (d, $J = 7.6$, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 47.4$, 56.4, 57.9, 82.5, 111.56, 129.0, 131.6, 132.7, 134.0, 135.2, 156.3, 193.1. IR (KBr): 3065, 2931, 1688, 1598, 1496, 1459, 1284, 1258, 1096, 1053, 1020, 806, 779, 687, 652, 615 cm^{-1}.

2-Bromo-1-phenyl-ethanone (17a): ^1H NMR (400 MHz, $CDCl_3$): $\delta = 4.46$ (s, 2H), 7.48 (m, 2H), 7.6 (m, 1H), 7.9 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 31.2$, 128.44, 128.71, 133.27, 134.12, 191.42. IR (KBr): 3058, 2935, 1690, 1593, 1450, 1281, 1194, 1020, 764, 687, 615 cm^{-1}.

4,5-Dibromo-1,5-diphenyl-pent-1-en-3-one (18a): ^1H NMR (400 MHz, $CDCl_3$): $\delta = 5.2$ (d, $J = 11.6$ Hz, 1H), 5.47 (d, $J = 11.6$ Hz, 1H), 6.93 (d, $J = 15.6$ Hz, 1H), 7.42 (m, 8H), 7.63 (m, 2H), 7.85 (d, $J = 15.6$ Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 49.6$, 51.7, 122.3, 128.4, 128.9, 129.0, 129.2, 129.4, 131.4, 134.1, 138.3, 146.3, 190.0. IR (KBr): 3057, 3028, 2995, 1690, 1661, 1610, 1575, 1455, 1334, 1202, 1071, 979, 763, 691, 564 cm^{-1}.

2,4,5-Tribromoimidazole (19a): ^1H NMR (400 MHz, $CDCl_3$): $\delta = 1.6$ (brs, 1H), IR (KBr): 3069, 3005, 2924, 2813, 2712, 2618, 1537, 1528, 1394, 1301, 1183, 1004, 980, 837, 661, 515 cm^{-1}. Mass (EI): 304/306 (M^+). Melting Point observed: 219°C (Literature 217–221°C).

4,4′-Isopropylidene-bis-(2,6-dibromophenol (20a): ^1H NMR (400 MHz, $CDCl_3$): $\delta = 1.57$ (s, 6H), 5.8 (s, 2H), 7.25 (s, 4H). ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 30.86$, 42.09, 109.9, 130.5, 144.85, 147.85, IR (KBr): 3476, 2981, 2926, 1557, 1473, 1391, 1326, 1271, 1247, 1175, 1133, 867, 735, 707 cm^{-1}. Melting Point observed: 178°C (Literature 179–181°C).