JOC The Journal of Organic Chemistry

Article

pubs.acs.org/joc

Approach to Vicinal *t*-Boc-amino Dibromides via Catalytic Aminobromination of Nitrostyrenes without Using Chromatography and Recrystallization

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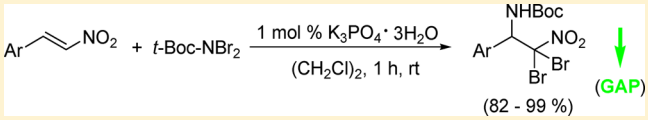
Supporting Information

ABSTRACT: A 1.0 mol % amount of $K_3PO_4 \cdot 3H_2O$ was found to catalyze aminohalogenation reaction of nitrostyrenes with *N*,*N*-dibromo-*tert*-butylcarbamate (*t*-Boc-NBr_2) in a dichloroethane system. Good to excellent yields and complete regioselectivity have been achieved by taking advantage of the GAP workup without using traditional purification techniques such as column chromatography and recrystallization. A new mechanism is proposed involving radical and ionic catalytic cycles and an intramolecular migration.



INTRODUCTION

The aminohalogenation reaction has become an important tool for the synthesis of vicinal haloamine compounds that are versatile building blocks in organic and medicinal chemistry.[1−6] For example, they can be readily converted into many other synthetic precursors, such as aziridines and enamines. In the past one decade, many efforts have been devoted to this reaction under a series of metal-catalyzed and organocatalytic conditions. Functionalized substrates, such as *α*,*β*-unsaturated carboxylic esters,[4,5] *α*,*β*-unsaturated nitriles,[7] *α*,*β*-unsaturated ketones,[8] *β*-nitrostyrenes,[9] and other substrates,[5,10] have been proven to be suitable for the aminohalogenation reaction. In the meantime, several nitrogen/halogen sources including *N*,*N*-dichlorotoluenesulfonamide ($TsNCl_2$),[4,5] $NsNCl_2$/NsNHNa,[4] *N*-bromoacetamide,[11] chloramine-T,[11] *p*-$TsNH_2$/NBS,[12] $NsNCl_2$/$NsNH_2$,[13] and *tert*-butyl-*N*,*N*-dibromo- and dichlorocarbamates[14] have been found to be efficient for aminohalogenation reaction with very well controlled regio- and stereoselectivity. The reaction is believed to go through the formation of aziridinium intermediates, halonium (bromonium or chloronium) intermediates, or radicals. An aziridinium intermediate-based mechanism has been confirmed by the direct formation of imidazoline products that serve as a new protocol for the synthesis of diamino compounds.[1b,14]

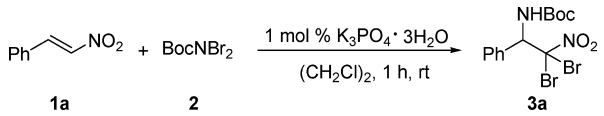
Very recently, we established a new concept called the GAP chemistry (group-assistant-purification chemistry). This chemistry can avoid the use of traditional purification methods such as chromatography or recrystallization, and the pure products can be obtained simply by washing the solid crude products with organic solvents.[15−17] This new concept is attributed to the discovery of achiral/chiral *N*-phosphonyl and chiral *N*-phosphinylimine reagents and their reactions. The characteristics of GAP chemistry require that the functional groups of starting materials should enable the resulting products to have adequate solubility; i.e., the products must be dissolved some solvents (e.g., THF, DCM, etc.) for further transformations but should not be readily dissolved in others (e.g., hexane, petroleum ether, their mixtures with EtOAc, etc.); the functional groups should enable their attached substrates to have efficient chemical reactivity toward various species; For asymmetric reactions, the functional groups should be able to show efficient asymmetric induction and control; the functional groups should have great flexibility for structural modifications so that both physical (e.g., solubility) and chemical properties (tolerable to further transformations) of resulting products can be readily adjusted; the functional group-attached auxiliaries can be cleavable under various conditions and recycled for reuse. So far, controlling solubility of organic products via designing auxiliaries has been very challenging in chemical synthesis. The *N*-phosphonyl and *N*-phosphinyl functional group-based GAP chemistry has been proven to meet this purpose due to the special polarity of P═O bonds in which adequate amount of negative charge and positive charge localized on oxygen and phosphorus, respectively. We are pleased to find that this concept can be extended to other reactions such as aminohalognation of olefins as shown in this paper.

RESULTS AND DISCUSSION

The present aminobromination reaction is based on the use of *β*-nitrostyrenes as the substrates due to their high flexibility for further transformations. The reaction was performed in 1,2-dichloroethane at room temperature without using inert gas protection (Scheme 1). The loading of 1.0 mol % of $K_3PO_4 \cdot 3H_2O$ was able to efficiently catalyze the reaction to

Received: December 16, 2012
Published: January 11, 2013

Scheme 1



completion within 1 h, affording vicinal bromoamine products in good to excellent yields (up to 99%). Since several polar functional groups, nitro, *t*-Boc, and two bromo moieties, exist in the structures of resulting products, they can lower the solubility of product in organic solvents and enable GAP purification to be performed. Small amounts of impurities are either dissolved in alcohol or washed away simply by washing with some organic solvents.

At the beginning of our study, we performed the reaction according to the literature procedure.[13] As anticipated, since nitrostyrene is a difficult aminobromination substrate, it did not result in any products when it was subjected to reaction with *tert*-butyl *N*,*N*-dibromocarbamate for up to 16 h in dichloromethane at room temperature. Screening of a series of organic bases, inorganic bases, and salts was carried out, including several organic bases: DMAP, DIPEA, triethylamine, and triphenylphosphine. We found that these common organic bases afforded no or trace amounts of products as monitored by TLC. Inorganic salts such as sodium fluoride, NaOAc, $KHCO_3$, $NaHCO_3$, and K_2HPO_4 were also proven to be ineffective, giving no product either. Na_2CO_3, K_2CO_3, anhydrous Na_3PO_4,[13] and $Ca(OH)_2$ (10 mol %) resulted in less than 49% of vicinal aminobromides within 1 h as monitored by TLC determination. Two stronger bases, sodium and potassium hydroxide, gave good yields of 86% and 81%, respectively. Pleasantly, when anhydrous K_3PO_4[18] and $K_3PO_4{\cdot}3H_2O$ were employed as the catalyst, more than 90% chemical yield was achieved under the same conditions; similar results were obtained by decreasing the catalyst loading to 5.0 and 2.5 mol %, respectively. The above reaction was performed by reacting 1.0 mmol of nitrostyrene with 1.2 mmol of *tert*-butyl *N*,*N*-dibromocarbamate in 2.5 mL of dichloromethane at room temperature. However, when the catalyst loading was decreased to 1.0 mol %, no product was observed. However, then the volume of solvent was changed from 2.5 to 1.0 mL, > 90% of chemical yield was obtained.

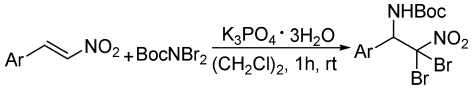
To explore further improvements, we next examined a series of solvents. Three solvents, ethyl acetate, acetonitrile, and acetone, gave very poor yields (5−37%); three other solvents, THF, DMF, and ethanol, did not show any products. However, 1,2-dichloroethane was found to be even more effective and resulted in an almost quantitative yield when the reaction was performed by using 1.2 equiv of *tert*-butyl *N*,*N*-dibromocarbamate in the presence 1.0 mol % of $K_3PO_4{\cdot}3H_2O$ in 1.0 mL of solvent within 1 h. The actual loading of K_3PO_4 is lower than 1.0 mol % if water is excluded from the above stoichiometric calculation.

Since $K_3PO_4{\cdot}3H_2O$ was used in a tiny amount (1.0 mol %), after it was added into reaction mixture containing *tert*-butyl *N*,*N*-dibromocarbamate and nitrostyrene in 1,2-dichloroethane, it could be easily dissolved. At the beginning, the color of reaction mixture was yellow; it gradually became light greenish as the reaction proceeded for 20−30 min.

The preparation of *tert*-butyl *N*,*N*-dibromocarbamate was performed by following the literature procedure.[13] In its synthesis, a modification was made by replacing potassium carbonate with KOH to give a quantitative yield. Essentially, there is no need for further purification of the crude *tert*-butyl *N*,*N*-dibromocarbamate after workup was performed; it was directly subjected to the aminobromination reaction with nitrostyrene. It should be pointed out that as compared with the known procedure by Zwierzak and co-workers in which crude product was contaminated with about 9% of *tert*-butyl *N* bromocarbamate, the present modification would provide an alternative and more efficient approach to *tert*-butyl-*N*,*N*-dibromocarbamate on a large scale. In addition, this synthesis belongs to our GAP chemistry in which the products were purified without using chromatography and recrystallization.

After the catalytic system was established, we investigated the substrate scope of this aminobromination reaction by using a variety of nitrostyrene derivatives with substituents on their aromatic rings. As shown in Table 1, this reaction showed a great substrate scope in which 20 substrates were proven to be suitable for this system. There is no particular trend for these substrates. Most electron withdrawing group (EWG) attached substrates gave nearly quantitatively chemical yields (entries 2, 4, 7, 13, and 15, Table 1); only 4-CF_3 and two dichloro-substituted substrates (entries 6, 11, and 12, Table 1) gave slightly lower yields of 91%, 92%, and 88%, respectively. Interestingly, strong electron donating group (EDG) attached substrates usually give lower chemical yields as compared with those with neutral and EWG-attached substrates, but in this catalytic system, 2-MeO-Ph and 3,4-$(MeO)_2$-Ph cases also afforded the vicinal aminobromide products in quantitatively yields (entries 18 and 19, Table 1). Two other EDG cases, 4-MeO-Ph and 2-BnO-Ph, also showed excellent yields of 94%

Table 1. $K_3PO_4{\cdot}3H_2O$-Catalyzed Aminobromination of Nitrostyrenes[a]



entry	Ar	product	yield[b] (%)
1	Ph	**3a**	98
2	4-ClC_6H_4	**3b**	98
3	4-$MeOC_6H_4$	**3c**	94
4	2-ClC_6H_4	**3d**	99
5	4-MeC_6H_4	**3e**	95
6	4-$CF_3C_6H_4$	**3f**	91
7	4-CNC_6H_4	**3g**	97
8	2-naphthyl	**3h**	91
9	1-naphthyl	**3i**	82
10	2-$BnOC_6H_4$	**3j**	95
11	2, 6-$Cl_2C_6H_3$	**3k**	92
12	3, 4-$Cl_2C_6H_3$	**3l**	88
13	4-FC_6H_4	**3m**	99
14	4-BrC_6H_4	**3n**	96
15	3-FC_6H_4	**3o**	98
16	3-BrC_6H_4	**3p**	86
17	3-Br-4-$MeOC_6H_3$	**3q**	88
18	2-$MeOC_6H_4$	**3r**	98
19	3, 4-$(CH_3O)_2C_6H_3$	**3s**	98
20	4-butyl-C_6H_4	**3t**	83

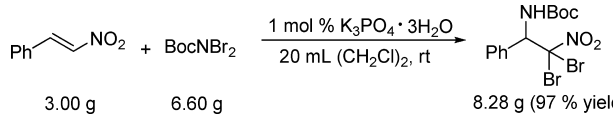
[a]Conditions: **1a** (1.0 mmol), $BocNBr_2$ (1.2 mmol), with $K_3PO_4{\cdot}3H_2O$ (0.01 mmol) in $(CH_2Cl)_2$ (1 mL) at room temperature for 60 min. [b]Isolated yields.

dx.doi.org/10.1021/jo302727v | J. Org. Chem. 2013, 78, 1171−1175

and 95%, respectively (entries 3 and10, Table 1). There are no side products generated from bromination on phenyl rings observed as at all. It is not clear why two neutral cases, 1-naphthyl and 4-butyl-Ph (entries 9 and 20, Table 1), resulted in lowest chemical yields of 82% and 83%, respectively.

As mentioned that this reaction resulted in vicinal aminobromide products which can be purified via GAP process without the use of traditional column chromatography and recrystallization, i.e., after workup is done, the pure product can be readily obtained simply by washing the crude product with organic solvents (in this case, hexane). We also conducted the reaction of nitrostyrene on a scale of 3.0 g (20 mmol) and obtained product **1b** in almost quantitative yield (Scheme 2), which indicates that the present reaction is promising for large-scale production.

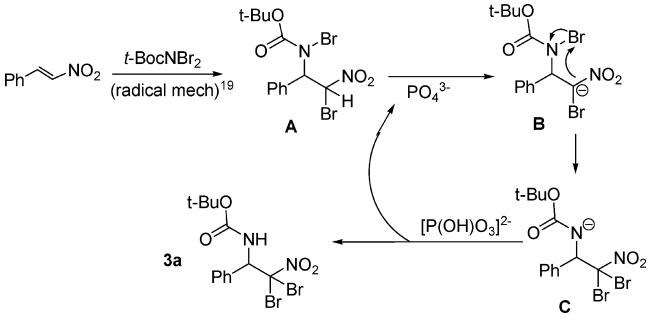
Scheme 2



The vicinal aminobromide products have been fully determined by NMR spectroscopic, HR-MS analysis, etc., and the product of **3a** has been unambiguously analyzed by X-ray diffractional analysis with the ORTEP diagram presented in Figure 1 (see the Supporting Information).

This reaction is suggested to proceed through the free-radical chain stage and ionic catalytic cycle (Scheme 3). The first stage

Scheme 3



of the radical mechanism has been proposed for the reaction of *t*-Boc-NBr_2 with styrene in the literature.[13] This catalytic cycle involves the common spontaneous initiation, propagation, and radical termination to generate the monobromide intermediate (**A**). The deprotonation of **A** by PO_4^{3-} leads to the formation of intermediate **B** and $P(OH)O_3^{2-}$. The intramolecular migration of bromine from amide nitrogen onto carboanion to give intermediate **C** in which the negative charge can be shifted onto the oxygen of the *t*-Boc group. Two contributing structures exist for this negative charge shifting. The protonation of **C** by $P(OH)O_3^-$ affords the final product **3a** and concurrently gives the catalytic species, PO_4^{3-}, back for continuing cycles of stage 2. This mechanistic hypothesis can account for the following observations: (1) several common bases, such as KOH, NaOH, $Ca(OH)_2$, K_2CO_3, etc., can also serve as the catalysts for this reaction, although they are not as efficient as K_3PO_4; (2) only 1.2 equv of *t*-Boc-NBr_2 (no need for 2.0 equiv) is needed for the complete consumption of the starting material of nitrostyrene.

It should be noted that the present work represents the first GAP chemistry example of nonimine-based reactions in our laboratories. It can encourage synthetic chemists to find more GAP preparations so as to reduce the consumption of organic solvents and silica gels for column chromatography. Therefore, the use of nature's energy resources and manpower can be minimized due to the fast synthesis GAP chemistry. If GAP is employed for pharmaceutical and industrial productions on large scales, the environmentally contaminations can also be reduced substantially.

In conclusion, we have demonstrated a concise and efficient aminobromination of *β*-nitrostyrene derivatives with *N,N*-dibromocarbamate as nitrogen/bromine sources in the presence of 1.0 mol % of $K_3PO_4 \cdot 3H_2O$ as catalyst. This reaction proceeded smoothly and environmentally friendly to give the *β,β*-dibromo Boc-protected amines in complete regioselectivity and good to excellent yields (82−99%). By using 1.2 equiv of nitrogen/bromine sources, the reaction can occur to completion within 1 h at room temperature without using protection of inert gases. The GAP chemistry was found to be suitable for simple purifying the products without using traditional purification techniques of column chromatography and recrystallization. A mechanism involving spontaneously initiated free-radical chain and ionic catalytic cycles was proposed to account for experimental observations. Finally, this reaction showed promising result for practical scale up synthesis.

EXPERIMENTAL SECTION

General Methods. Commercial chemicals and solvents were used without any further purification. Melting points were uncorrected. IR spectra were collected in KBr pellets. ^1H NMR, ^{13}C NMR (TMS used as internal standard) spectra were collected in $CDCl_3$. High-resolution mass spectra for all the new compounds were collected on a Q-TOF instrument (Supporting Information).

Procedure for Preparation of BocNBr$_2$. To a stirred solution of $BocNH_2$ (5.86 g, 50 mmol) and NaOH (4.0 g, 0.1 mol) in water (50 mL) was added bromine Br_2 (19 g, 0.12 mol) dropwise at room temperature and the solution stirred for another 2 h. When the reaction was complete, a large amount of orange solid was formed, which was filtered to get the crude product. The residue was dissolved in CH_2Cl_2, washed with brine, dried with anhydrous Na_2SO_4, and concentrated to obtain the pure product (13.7g, quant). Mp = 93−94 °C (lit.[13a] mp 93−95 °C). ^1H NMR (300 MHz, $CDCl_3$): δ 1.49 (s, 9H).

Typical Procedure for the Aminobromination Reaction. Into a vial were added **1a** (149 mg, 1 mmol), $BocNBr_2$ (330 mg, 1.2 mol), $K_3PO_4 \cdot 3H_2O$ (2.7 mg, 1 mol %), and $(CH_2Cl)_2$ (1.0 mL) and the misture stirred for 60 min at room temperature. The reaction completion was indicated by TLC and the color change, which turned from yellow to light green. The reaction mixture was washed with brine and the aqueous phase extracted with DCM. The organic layer was dried with anhydrous Na_2SO_4 and concentrated to near-dryness to give a solid/oil mixture. A tiny amount of oil was washed away by hexane; if more oil stuck on solid product appeared, 10 mL of hexane was added into the above mixture which was heated to give a solution mixture containing white solids. After being cooled to room temperature, the solution was filtrated off to afford pure product **3a**.

*1-(tert-Butoxyformamido)-2,2-dibromo-1-phenyl-2-nitroethane (**3a**):* white solid (415 mg, 98%). Mp = 122−124 °C. ^1H NMR (300 MHz, $CDCl_3$): δ 7.45−7.35 (m, 5H), 5.97 (d, J = 10.20 Hz, 1H), 5.60 (d, J = 9.60 Hz, 1H), 1.44 (s, 9H) ppm. ^{13}C NMR (75.45 MHz, $CDCl_3$): δ 153.8, 133.5, 129.4, 129.0 (2), 128.4 (2), 94.5, 81.1, 64.4, 28.0 (3) ppm. IR (KBr): ν = 3313, 2976, 1693, 1572, 1520, 1456, 1367, 1319, 1248, 1167, 837, 700 cm^{-1}. MS (ESMS/$[M + Na]^+$): calcd for $C_{13}H_{16}Br_2N_2O_4Na$ 446.9349, found 446.9331.

dx.doi.org/10.1021/jo302727v | J. Org. Chem. 2013, 78, 1171−1175

*1-(tert-Butoxyformamido)-2,2-dibromo-1-(4-chlorophenyl)-2-nitroethane (**3b**).* White solid (449 mg, 98%). Mp = 121−123 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.39 (d, J = 9.00 Hz, 2H), 7.35 (d, J = 8.70 Hz, 2H), 5.95 (d, J = 9.30 Hz, 1H), 5.55 (d, J = 9.90 Hz, 1H), 1.43 (s, 9H) ppm. ^{13}C NMR (75.45 MHz, $CDCl_3$): δ 153.7, 135.6, 132.1, 130.4 (2), 128.6 (2), 93.8, 81.3, 63.9, 28.0 (3) ppm. MS (ESMS/[M + Na]$^+$): calcd for $C_{13}H_{15}Br_2ClN_2O_4Na$ 480.8958, found 480.8944. IR (KBr): ν = 3278, 2978, 1687, 1577, 1514, 1369, 1323, 1250, 1163, 831 cm^{-1}.

*1-(tert-Butoxyformamido)-2,2-dibromo-1-(4-methoxyphenyl)-2-nitroethane (**3c**).* White solid (427 mg, 94%). Mp = 129−131 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.34 (d, J = 9.00 Hz, 2H), 6.89 (d, J = 9.00 Hz, 2H), 5.91 (d, J = 10.20 Hz, 1H), 5.54 (d, J = 9.60 Hz, 1H), 3.81 (s, 3H), 1.44 (s, 9H) ppm. ^{13}C NMR (75.45 MHz, $CDCl_3$): δ 160.2, 153.9, 130.2 (2), 125.4, 113.7 (2), 95.0, 81.0, 64.0, 55.1, 28.0 (3) ppm. MS (ESMS/[M + Na]$^+$): calcd for $C_{14}H_{18}Br_2N_2O_5Na$ 476.9455, found 476.9453. IR (KBr): ν = 3313, 2976, 1689, 1576, 1508, 1302, 1244, 1169, 1034, 837 cm^{-1}.

*1-(tert-Butoxyformamido)-2,2-dibromo-1-(2-chlorophenyl)-2-nitroethane (**3d**).* White solid (454 mg, 99%). Mp = 164−166 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.60 (br, 1H), 7.49−7.45 (m, 1H), 7.38−7.34 (m, 2H), 6.70 (d, J = 10.20 Hz, 1H), 5.56 (br, 1H), 1.42 (s, 9H) ppm. ^{13}C NMR (75.45 MHz, $CDCl_3$): δ 153.4, 135.6, 133.1, 130.6, 130.1, 128.4, 127.1, 93.1, 81.6, 59.8, 28.1 (3) ppm. MS (ESMS/[M + Na]$^+$): calcd for $C_{13}H_{15}Br_2ClN_2O_4Na$ 480.8958, found 480.8941. IR (KBr): ν = 3357, 2987, 1709, 1577, 1473, 1365, 1155, 1045, 843 cm^{-1}.

*1-(tert-Butoxyformamido)-2,2-dibromo-1-p-tolyl-2-nitroethane (**3e**).* White solid (416 mg, 95%). Mp = 108−110 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.31 (d, J = 8.10 Hz, 2H), 7.18 (d, J = 8.10 Hz, 2H), 5.93 (d, J = 9.30 Hz, 1H), 5.56 (d, J = 9.00 Hz, 1H), 2.35 (s, 3H), 1.44 (s, 9H) ppm. ^{13}C NMR (75.45 MHz, $CDCl_3$): δ 153.8, 139.4, 130.5, 129.0 (2), 128.8 (2), 94.8, 81.0, 64.3, 28.0, 21.0 (3) ppm. MS (ESMS/[M + Na]$^+$): calcd for $C_{14}H_{18}Br_2N_2O_4Na$ 460.9506, found 460.9479. IR (KBr): ν = 3292, 2978, 1687, 1577, 1509, 1323, 1250, 1161, 1022, 845 cm^{-1}.

*1-(tert-Butoxyformamido)-2,2-dibromo-1-(4-(trifluoromethyl)-phenyl)-2-nitroethane (**3f**).* White solid (448 mg, 91%). Mp = 113−115 °C. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.65 (d, J = 8.70 Hz, 2H), 7.59 (d, J = 8.10 Hz, 2H), 6.04 (d, J = 10.20 Hz, 1H), 5.60 (d, J = 10.50 Hz, 1H), 1.43 (s, 9H) ppm. ^{13}C NMR (75.45 MHz, $CDCl_3$) δ 153.8, 137.7, 131.6 (q, J = 32.82 Hz), 129.6 (2), 125.4, 125.3, 121.8, 93.2, 81.6, 64.1, 28.0 (3) ppm. MS (ESMS/[M + Na]$^+$): calcd for $C_{14}H_{15}Br_2F_3N_2O_4Na$ 514.9223, found 514.9231. IR (KBr): ν = 3319, 2981, 1687, 1579, 1510, 1327, 1250, 1132, 1070, 839 cm^{-1}.

*1-(tert-Butoxyformamido)-2,2-dibromo-1-(4-cyanophenyl)-2-nitroethane (**3g**).* White solids (435 mg, 97%). Mp = 146−148 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.69 (d, J = 8.40 Hz, 2H), 7.59 (d, J = 8.40 Hz, 2H), 6.03 (d, J = 10.20 Hz, 1H), 5.58 (d, J = 9.60 Hz, 1H), 1.43 (s, 9H) ppm. ^{13}C NMR (75.45 MHz, $CDCl_3$): δ 153.6, 138.7, 131.9 (2), 129.9 (2), 117.8, 113.2, 92.6, 81.4, 63.9, 27.8 (3) ppm. MS (ESMS/[M + Na]$^+$): calcd for $C_{14}H_{15}Br_2N_3O_4Na$ 471.9302, found 471.9315. IR (KBr): ν = 3315, 2979, 2239, 1730, 1576, 1502, 1327, 1244, 1159, 833 cm^{-1}.

*1-(tert-Butoxyformamido)-2,2-dibromo-1-(naphthalen-2-yl)-2-nitroethane (**3h**).* White solids (431 mg, 91%). Mp = 139−141 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.91−7.84 (m, 4H), 7.55−7.52 (m, 3H), 6.16 (d, J = 9.60 Hz, 1H), 5.72 (d, J = 10.20 Hz, 1H), 1.44 (s, 9H) ppm. ^{13}C NMR (75.45 MHz, $CDCl_3$): δ 153.9, 133.3, 132.5, 130.8, 129.3, 128.2, 128.1, 127.5, 127.0, 126.6, 125.5, 94.4, 81.2, 64.6, 28.0 (3) ppm. MS (ESMS/[M + Na]$^+$): calcd for $C_{17}H_{18}Br_2N_2O_4Na$: 496.9506; found 496.9549. IR (KBr): ν = 3261, 3149, 2983, 1709, 1574, 1506, 1363, 1254, 1159, 1018 cm^{-1}.

*1-(tert-Butoxyformamido)-2,2-dibromo-1-(naphthalen-1-yl)-2-nitroethane (**3i**).* White solids (389 mg, 82%). Mp = 201−203 °C. ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.42 (d, J = 7.50 Hz, 1H), 7.91 (t, J = 8.40 Hz, 2H), 7.78 (d, J = 6.60 Hz, 1H), 7.65 (t, J = 7.20 Hz, 1H), 7.56 (d, J = 8.10 Hz, 1H), 7.51 (d, J = 8.10 Hz, 1H), 7.00 (d, J = 9.00 Hz, 1H), 5.71 (d, J = 8.40 Hz, 1H), 1.40 (s, 9H) ppm. ^{13}C NMR (75.45 MHz, DMSO-d_6) δ 154.8, 133.1, 131.5, 131.4, 129.8, 128.9, 127.3, 126.9, 125.9, 125.0, 123.0, 94.4, 79.7, 57.8, 27.9 (3) ppm. MS (ESMS/[M + Na]$^+$): calcd for $C_{17}H_{18}Br_2N_2O_4Na$ 496.9506, found 496.9505. IR (KBr): ν = 3240, 3134, 2977, 1693, 1577, 1361, 1257, 1159, 1049, 775 cm^{-1}.

*1-(tert-Butoxyformamido)-2,2-dibromo-1-(2-(benzyloxy)phenyl)-2-nitroethane (**13j**).* White solids (504 mg, 95%). Mp = 120−122 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.50−7.32(m, 7H), 6.99 (d, J = 8.10 Hz, 2H), 6.39 (d, J = 9.60 Hz, 1H), 6.15 (d, J = 7.20 Hz, 1H), 5.15(s, 2H) 1.43 (s, 9H) ppm. ^{13}C NMR (75.45 MHz, DMSO-d_6): δ 155.6, 154.4, 136.8, 130.4, 129.8, 128.3 (2), 127.7 (2), 127.2, 123.8, 120.4, 112.4, 95.0, 79.4, 69.6, 56.7, 28.0 (3) ppm. MS (ESMS/[M + Na]$^+$): calcd for $C_{20}H_{22}Br_2N_2O_5Na$ 552.9769, found 552.9737. IR (KBr): ν = 3246, 3141, 2978, 1699, 1574, 1493, 1367, 1252, 1161, 1020, 748 cm^{-1}.

*1-(tert-Butoxyformamido)-2,2-dibromo-1-(2,6-dichlorophenyl)-2-nitroethane (**3k**).* White solids (454 mg, 92%). Mp = 104−106 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.45(d, J = 7.80 Hz, 1H), 7.35−7.24 (m, 2H), 7.12 (d, J = 10.50 Hz, 1H), 6.43 (d, J = 9.30 Hz, 1H), 1.45 (s, 9H) ppm. ^{13}C NMR (75.45 MHz, $CDCl_3$): δ 153.8, 138.6, 134.4, 130.7, 130.6, 130.0, 129.1, 91.6, 81.4, 62.3, 28.0 (3) ppm. MS (ESMS/[M + Na]$^+$): calcd for $C_{13}H_{14}Br_2Cl_2N_2O_4Na$ 514.8567, found 514.8554. IR (KBr): ν = 3323, 2976, 1703, 1577, 1439, 1348, 1254, 1155, 1014, 769 cm^{-1}.

*1-(tert-Butoxyformamido)-2,2-dibromo-1-(3,4-dichlorophenyl)-2-nitroethane (**3l**).* White solids (434 mg, 88%). Mp = 156−158 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.57 (s, 1H), 7.46 (d, J = 8.40 Hz, 1H), 7.29 (d, J = 8.40 Hz, 1H), 5.94 (d, J = 9.60 Hz, 1H), 5.55 (br, 1H), 1.44 (s, 9H) ppm. ^{13}C NMR (75.45 MHz, $CDCl_3$): δ 153.7, 134.0, 133.9, 132.7, 131.0, 130.4, 128.5, 93.0, 81.7, 63.5, 28.1 (3) ppm. MS (ESMS/[M + Na]$^+$): calcd for $C_{13}H_{14}Br_2Cl_2N_2O_4Na$ 514.8567, found 514.8557. IR (KBr): ν = 3353, 3151, 2976, 1705, 1572, 1473, 1369, 1254, 1159, 1022, 777 cm^{-1}.

*1-(tert-Butoxyformamido)-2,2-dibromo-1-(4-fluorophenyl)-2-nitroethane (**3m**).* White solids (438 mg, 99%). Mp = 118−120 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.42 (dd, J_1 = 8.70 Hz, J_2 = 5.10 Hz, 2H), 7.07 (t, J = 8.70 Hz, 2H), 5.96 (d, J = 9.00 Hz, 1H), 5.55 (br, 1H), 1.44 (s, 9H) ppm. ^{13}C NMR (75.45 MHz, $CDCl_3$): δ 163.1 (d, J = 249 Hz), 153.8, 130.9 (d, J = 7.50 Hz), 129.5, 115.4 (d, J = 21.50 Hz), 94.2, 81.3, 63.8, 28.0 (3) ppm. MS (ESMS/[M + Na]$^+$): calcd for $C_{13}H_{15}Br_2FN_2O_4Na$ 464.9255, found 464.9247. IR (KBr): ν = 3398, 2985, 1697, 1577, 1506, 1369, 1321, 1232, 1167, 850 cm^{-1}.

*1-(tert-Butoxyformamido)-2,2-dibromo-1-(4-bromophenyl)-2-nitroethane (**3n**).* White solids (483 mg, 96%). Mp = 129−131 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.52 (d, J = 8.40 Hz, 2H), 7.32 (d, J = 8.40 Hz, 2H), 5.93 (d, J = 10.20 Hz, 1H), 5.54 (d, J = 10.20 Hz, 1H), 1.43 (s, 9H) ppm. ^{13}C NMR (75.45 MHz, $CDCl_3$): δ 153.7, 132.7, 131.5 (2), 130.6 (2), 123.8, 93.7, 81.4, 63.9, 28.0 (3) ppm. MS (ESMS/[M + Na]$^+$): calcd for $C_{13}H_{15}Br_3N_2O_4Na$ 524.8454, found 524.8455. IR (KBr): ν = 3280, 2978, 1687, 1577, 1512, 1369, 1321, 1250, 1163, 837 cm^{-1}.

*1-(tert-Butoxyformamido)-2,2-dibromo-1-(3-fluorophenyl)-2-nitroethane (**3o**).* White solids (433 mg, 98%). Mp = 135−137 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.36 (dd, J_1 = 7.80 Hz, J_2 = 13.80 Hz, 1H), 7.22 (d, J = 8.40 Hz, 1H), 7.13 (d, J = 9.60 Hz, 1H), 7.11 (t, J = 8.10 Hz, 1H), 5.97 (d, J = 9.00 Hz, 1H), 5.56 (d, J = 9.90 Hz, 1H), 1.44 (s, 9H) ppm. ^{13}C NMR (75.45 MHz, $CDCl_3$): δ 162.2 (d, J = 247 Hz), 153.8, 136.0, 129.9 (d, J = 7.50 Hz), 125.0 (d, J = 3.20 Hz), 116.4 (d, J = 28.20 Hz), 116.1 (d, J = 30.20 Hz), 93.6, 81.4, 63.9, 28.0 (3) ppm. MS (ESMS/[M + Na]$^+$): calcd for $C_{13}H_{15}Br_2FN_2O_4Na$ 464.9255, found 464.9253. IR (KBr): ν = 3253, 3141, 2985, 1695, 1576, 1452, 1379, 1232, 1161, 1018, 775 cm^{-1}.

*1-(tert-Butoxyformamido)-2,2-dibromo-1-(3-bromophenyl)-2-nitroethane (**3p**).* White solids (433 mg, 86%). Mp = 155−157 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.61 (s, 1H), 7.54 (d, J = 8.10 Hz, 1H), 7.37 (d, J = 7.80 Hz, 1H), 7.25 (t, J = 7.80 Hz, 1H), 5.94 (d, J = 10.20 Hz, 1H), 5.56 (d, J = 10.20 Hz, 1H), 1.44 (s, 9H) ppm. ^{13}C NMR (75.45 MHz, DMSO-d_6): δ 154.5, 136.8, 132.1(2), 130.0, 129.0, 121.4, 93.8, 79.7, 64.0, 27.9 (3) ppm. MS (ESMS/[M + Na]$^+$): calcd for $C_{13}H_{15}Br_3N_2O_4Na$ 524.8454, found 524.8464. IR (KBr): ν = 3244, 3143, 2985, 1698, 1576, 1477, 1369, 1255, 1155, 1018, 847 cm^{-1}.

*1-(tert-Butoxyformamido)-2,2-dibromo-1-(3-bromo-4-methoxyphenyl)-2-nitroethane (**3q**).* White solids (469 mg, 88%). Mp = 157−

dx.doi.org/10.1021/jo302727v | J. Org. Chem. 2013, 78, 1171−1175

159 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.63 (d, J = 2.10 Hz, 1H), 7.33 (dd, J_1 = 8.80 Hz, J_2 = 2.10 Hz, 1H), 6.87 (d, J = 8.80 Hz, 1H), 5.88 (d, J = 9.90 Hz, 1H), 5.50 (d, J = 9.90 Hz, 1H), 3.90 (s, 3H), 1.44 (s, 9H) ppm. ^{13}C NMR (75.45 MHz, $CDCl_3$): δ 155.9, 154.5, 133.7, 130.7, 127.7, 111.7, 110.3, 94.5, 79.6, 63.6, 56.2, 27.9 (3) ppm. MS (ESMS/[M + Na]$^+$): calcd for $C_{14}H_{17}Br_3N_2O_5Na$ 554.8560, found 554.8564. IR (KBr): ν = 3269, 3153, 2983, 1695, 1576, 1506, 1369, 1271, 1161, 1022, 845 cm^{-1}.

*1-(tert-Butoxyformamido)-2,2-dibromo-1-(2-methoxyphenyl)-2-nitroethane (**3r**).* White solids (445 mg, 98%). Mp = 153−155 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.37 (t, J = 6.90 Hz, 2H), 7.00−6.91 (m, 2H), 6.29 (d, J = 10.20 Hz, 1H), 6.05 (s, 1H), 3.85 (s, 3H), 1.44 (s, 9H) ppm. ^{13}C NMR (75.45 MHz, $CDCl_3$): δ 157.4, 154.1, 133.3, 130.7, 130.3, 120.5, 111.3, 80.8, 94.6, 61.2, 55.3, 28.1 (3) ppm. MS (ESMS/[M + Na]$^+$): calcd for $C_{14}H_{18}Br_2N_2O_5Na$ 476.9455, found 476.9447. IR (KBr): ν = 3251, 3138, 2976, 1693, 1576, 1493, 1361, 1248, 1159, 1022, 754 cm^{-1}.

*1-(tert-Butoxyformamido)-2,2-dibromo-1-(3,4-dimethoxyphenyl)-2-nitroethane (**3s**).* White solids (474 mg, 98%). Mp = 139−141 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 6.98 (dd, J_1 = 8.10 Hz, J_2 = 2.10 Hz, 1H), 6.89 (d, J = 2.10 Hz, 1H), 6.84 (d, J = 8.10 Hz, 1H), 5.89 (d, J = 9.90 Hz, 1H), 5.54 (d, J = 10.20 Hz, 1H), 3.89 (s, 3H), 3.88 (s, 3H), 1.44 (s, 9H) ppm. ^{13}C NMR (75.45 MHz, DMSO-d_6): δ 154.7, 149.4, 148.2, 126.1, 122.6, 113.2, 110.8, 95.4, 79.5, 64.5, 55.7, 55.4, 28.0 (3) ppm. MS (ESMS/[M + Na]$^+$): calcd for $C_{15}H_{20}Br_2N_2O_6Na$ 506.9561, found 506.9587. IR (KBr): ν = 3359, 2972, 1693, 1574, 1502, 1352, 1315, 1246, 1155, 1024, 845 cm^{-1}.

*1-(tert-Butoxyformamido)-2,2-dibromo-1-(4-tert-butylphenyl)-2-nitroethane (**3t**).* White solids (398 mg, 83%). Mp = 123−125 °C. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.39−7.32 (m, 4H), 5.95 (d, J = 8.70 Hz, 1H), 5.58 (d, J = 8.70 Hz, 1H), 1.44 (s, 9H), 1.31 (s, 9H) ppm. ^{13}C NMR (75.45 MHz, $CDCl_3$) δ 153.9, 152.5, 130.5, 128.7 (2), 125.4 (2), 94.7, 81.1, 64.2, 34.6, 31.1 (3), 28.1 (3) ppm. MS (ESMS/[M + Na]$^+$): calcd for $C_{17}H_{24}Br_2N_2O_6Na$ 502.9976, found 502.9997. IR (KBr): ν = 3253, 3145, 2962, 1705, 1577, 1477, 1365, 1257, 1159, 1016, 837, 775 cm^{-1}.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

^{1}H and ^{13}C NMR spectra of all pure products. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

We gratefully acknowledge financial support from the NIH (R21DA031860-01, G.L.), the National Natural Science Foundation of China (No. 21102071, Y.P.), the Robert A. Welch Foundation (D-1361, G.P.), the Fundamental Research Funds for the Key Universities (Nos. 1107020522 and 1082020502, Y.P.), and the Jiangsu 333 program (Y.P.).

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