JOC The Journal of Organic Chemistry

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Methyl-α-D-2-selenonyl Pent-2-enofuranoside: A Reactive Selenosugar for the Diversity Oriented Synthesis of Enantiomerically Pure Heterocycles, Carbocycles, and Isonucleosides

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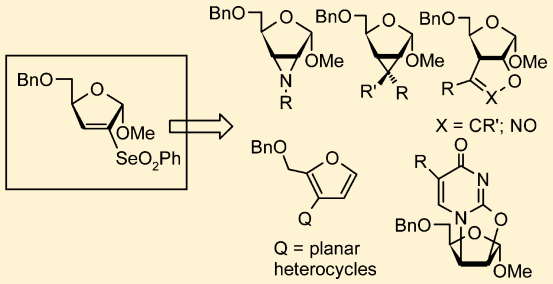
Supporting Information

ABSTRACT: The construction of vinyl selenone on a furanoside led to a highly reactive synthetic intermediate methyl-α-D-2-selenonyl pent-2-enofuranoside composed of a masked aldehyde, an electron-deficient double bond along with an excellent leaving group. This new Michael acceptor on reactions with different nucleophiles afforded bicyclic azasugars, cyclopropanated carbohydrate, dihydrofuran- and dihydroisoxazole- substituted furanosides, and isonucleosides in moderate to good yields. Hydrolysis of the hemiacetal linkage of some of these modified carbohydrates afforded enantiopure aziridines, nitrocyclopropane, and dihydrofuran.

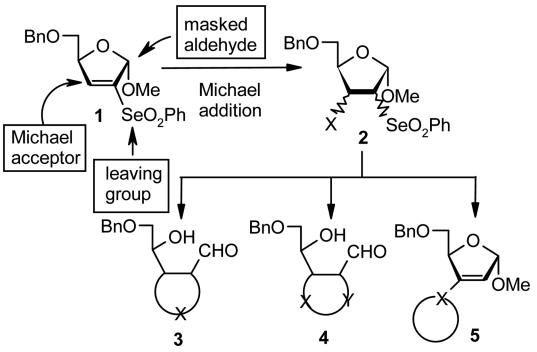


Vinyl sulfones have been used as Michael acceptors and 2π partners in organic synthesis.[1] We have extensively employed vinyl sulfone-modified carbohydrates for accessing a wide range of modified carbohydrates as well as enantiopure carbocycles and heterocycles.[1b,2] In most of the cases, it is necessary to remove the sulfone group after the synthetic transformation. In general, several methodologies are available for the desulfonylation, although Na−Hg- and Mg/MeOH-mediated reductions are the most widely used methods for the desulfonylation of organic molecules.[3] Attempted desulfonylation of furanosides using many of these reagents led to the extensive degradation of starting materials.[4,5] We reintroduced the Mg-$NiBr_2$-MeOH[3] reagent systems for the synthesis of various 2,3-dideoxy-2-alkylamino furanosides via desulfonylation. However, none of these reagents were efficient enough to desulfonylate modified carbohydrates[3] including nucleosides.[6]

Since desulfonylation of vinyl sulfone-modified carbohydrates remains an unsolved problem to date, we looked for alternative Michael acceptors (and a 2π partner) derived from carbohydrates. Vinyl selenones have been used in simple systems in the past to fulfill both the requirements.[7] Although vinyl selenone functionality has been effectively used in more complex nucleoside chemistry for accessing a plethora of modified nucleosides,[8] vinyl selenones derived from carbohydrates have rarely been utilized partly because the stability of carbohydrate selenones or selenoxides is notoriously unpredictable.[2e,9] Nevertheless, we have designed strategies for the synthesis of stable vinyl selenone-modified furanosides and showed their applications as 2π partners by synthesizing a wide range of triazoles.[2e]

It should be noted that in recent time, we have utilized the vinyl sulfone-modified carbohydrates as efficient Michael acceptors in diversity oriented synthesis (DOS) to generate complex molecular scaffolds.[2b,c] We presumed that vinyl selenone-modified carbohydrates would be excellent synthetic intermediates for generating skeletal complexity along with stereochemical diversity. In order to initiate a study with this class of hitherto unknown Michael acceptors, we selected methyl-α-D-2-selenonyl pent-2-enofuranoside **1** (Scheme 1),

Scheme 1. Reaction Patterns of Methyl-α-D-2-selenonyl Pent-2-enofuranoside



which was easily synthesized in relatively large scale from D-xylose.[2e] We presumed that a single starting material like **1** composed of a masked aldehyde, an electron-deficient double bond along with the excellent leaving ability of the selenone group would easily generate enantiomerically pure cyclic structures depicted in Scheme 1.

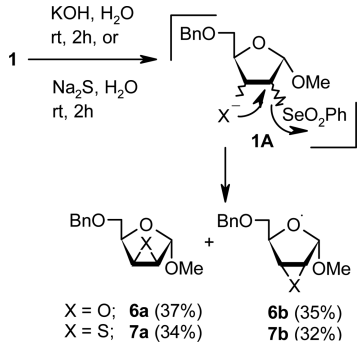
Initial studies indicated that vinyl selenone **1** on reaction with potassium hydroxide or sodium sulfide in water at room temperature afforded a diastereomeric mixture of oxiranes

Received: May 27, 2015
Published: October 28, 2015

DOI: 10.1021/acs.joc.5b01192
J. Org. Chem. 2015, 80, 11057−11064

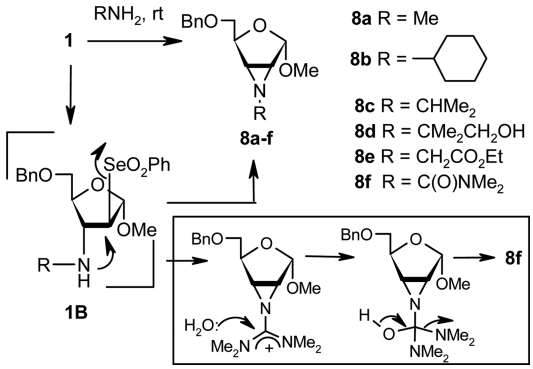
6a[10]/**6b**[11] (1:1) and thiiranes **7a**/**7b** (1:1), respectively (Scheme 2). Although the expected products were obtained

Scheme 2. Synthesis of Oxirane and Thiirane Derivatives from Selenosugar 1



as mixtures, these reactions established the expected reaction pattern of **1**, which prompted us to utilize this molecule as a synthetic intermediate for the diversity oriented synthesis of a wide range of molecules. Thus, compound **1** on treatment with aqueous methylamine in DMF at room temperature afforded a single diastereomeric aziridine **8a** (Scheme 3) Cyclohexyl-

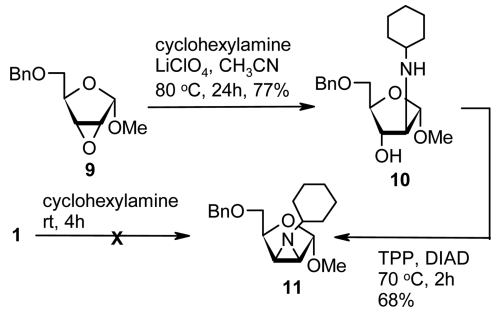
Scheme 3. Synthesis of Aziridinated Carbohydrates from Selenosugar 1[a]



[a]Reagents and conditions: **8a**: 40% methylamine, DMF (2 h, 78%); **8b**: neat cyclohexylamine (2 h, 81%); **8c**: neat isopropylamine (2 h, 85%) ; **8d**: neat 2-amino-2-methyl-1-propanol (4 h, 80%); **8e**: glycine ethylester hydrochloride, DMSO, Et3N (3 h, 85%); **8f**: TMG, DMF, (10 h, 65%).

amine, isopropylamine, and 2-amino-2-methyl-1-propanol on reaction with **1** at room temperature afforded single diastereomeric aziridine derivatives **8b**–**d**, respectively. Glycine ethyl esterhydrochloride reacted with **1** in the presence of Et_3N/DMSO at room temperature to afford the aziridine derivative **8e**.[12] The powerful Michael acceptor **1** even reacts with an organic base tetramethylguanidine (TMG) to afford an urea derivative **8f** (Scheme 3). The structure of the aziridines was established by synthesizing the diastereomer of **8b** in an alternative pathway. Thus, the known *ribo*-epoxide **9** was opened by cyclohexylamine at C-2 position following the known pattern[2e] to produce aminoalcohol **10**, which was converted to the corresponding *N*-alkylaziridin **11** under Mitsunobu conditions (Scheme 4). The *lyxo*-aziridin **11** was not identical to **8b** obtained from vinyl selenone **1** (Scheme 3), which indicated the D-*ribo* configuration of **8b**. It is also logical

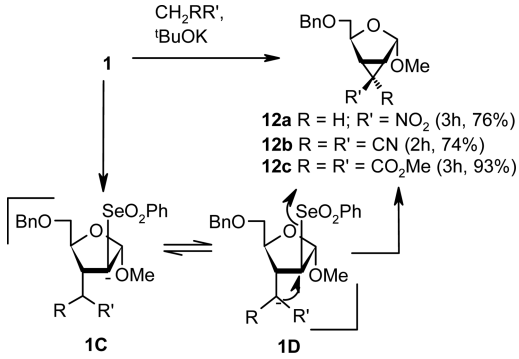
Scheme 4. Synthesis of Isomeric Aziridinated Carbohydrate



to presume that the C-3 position of **1** was attacked from the α-face of **1** because of the least stereoelectronic hindrance (Scheme 3). This assumption is supported by the fact that smaller nucleophiles in Scheme 2 did not differentiate between the two faces and produced diastereomeric mixtures.

Vinyl selenone **1** also efficiently reacted with nitromethane, malononitrile, and dimethyl malonate in the presence of ^{t}BuOK in THF at room temperature to afford single diastereomeric cyclopropanated sugar derivatives **12a**–**c**, respectively, in good yields (Scheme 5).[13] The stereochemistry at C-2 and C-3

Scheme 5. Synthesis of Cyclopropanated Carbohydrates from Selenosugar 1



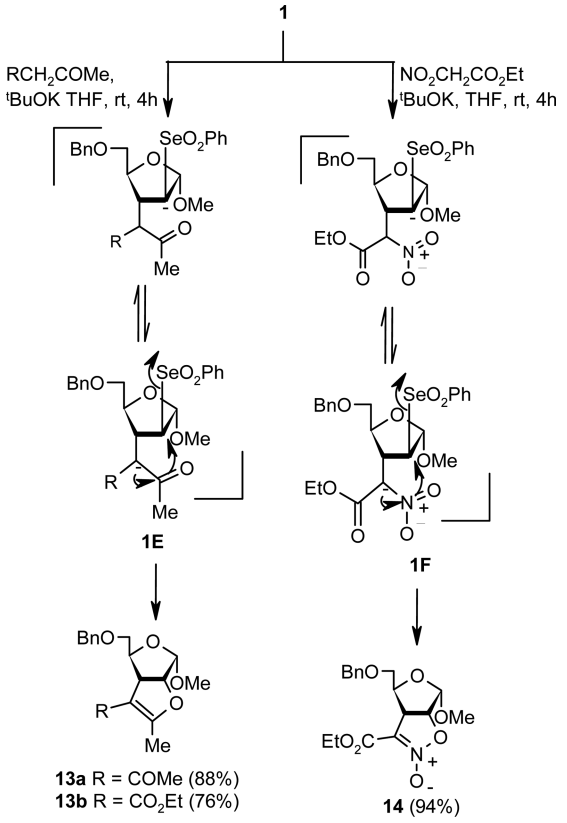
centers of **12a**–**c** have been determined by 1D ^{1}H NOE difference spectroscopic technique (Figures S1 and S2, see SI). Structural features of these compounds are comparable to those of aziridines **8a**–**e**. Ambident nucleophiles such as acetyl acetone and ethyl acetoacetate on reactions with **1** in the presence of ^{t}BuOK in THF at room temperature afforded single diastereomeric dihydrofuran derivatives **13a**–**b**, respectively.[14] Similarly, ethyl nitroacetate on treatment with **1** in the presence of ^{t}BuOK in THF produced single diastereomeric dihydroisoxazole derivative **14** in excellent yield (Scheme 6).[15] The structure of compound **14** has been unambiguously secured by X-ray diffraction of its single crystal (Figure S3, see SI).

The smaller nucleophiles like KO^- or NaS^- attack C-3 of **1** from the α- as well as β-faces generating the intermediate **1A** (Scheme 2), which afforded the mixtures of epoxides/thiiranes **6** and **7** after instantaneous elimination. The stereoelectronic repulsion of CH_2OBn attached to C-4 of **1** is not sufficient to block the attack of small nucleophiles like KO^- or NaS^- at C-3 of **1** from the β-face.

This was also observed in case of 5′-monomethoxytritylated vinylselenone-modified uridine, which afforded a mixture *ribo*- and *lyxo*-thioepoxides.[8] Even a larger group like C-5′

DOI: 10.1021/acs.joc.5b01192
J. Org. Chem. 2015, 80, 11057–11064

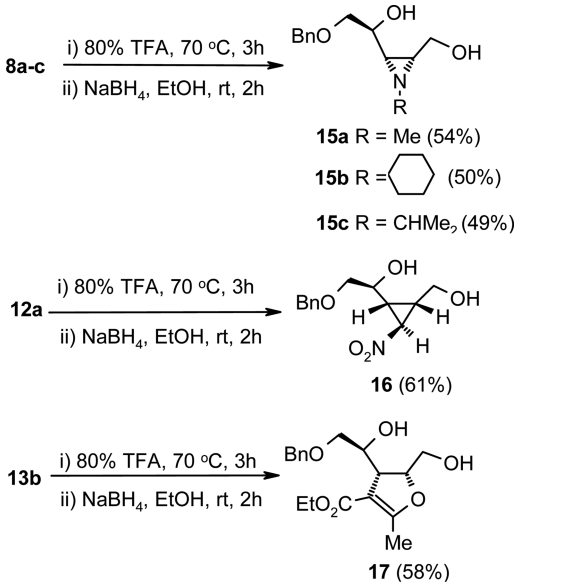
Scheme 6. Synthesis of Dihydrofurans and Dihydroisoxazole from Selenosugar 1



CH_2OMMTr could not block the nucleophilic addition of NaS^- to the vinyl selenone bond from the β-face. However, the stereoelectronic repulsion imposed by CH_2OBn moiety was sufficient to force nucleophiles attached to a small methyl (in case of $MeNH_2$; Scheme 3) or nitro (in case of $MeNO_2$; Scheme 5) group to attack the C-3 position exclusively from the α-face of **1**. Thus, all alkyl amines, including TMG, afforded the final products **8** via the intermediate **1B** (Scheme 3). Although the formation of **8f** from **1** was unexpected, the product formation may be explained by the nucleophilic attack of TMG's =NH group at the C-3 position followed by the addition of a molecule of water and elimination of one of the $-NMe_2$ groups (Scheme 3). The adducts of active methylene compounds **1C**, however, required the 1,3-shift of the residual acidic hydrogen to afford **1D**; the carbanion, thus generated, attacked the C-2 position to displace the selenonyl group to afford cyclopropanated carbohydrates **12** (Scheme 5). Similar shift of negative charge generated the intermediates **1E** and **1F** from the adducts of **1** and acetylacetone and ethylnitroacetate, respectively; dispersion of negative charge generated the more stable oxygen nucleophiles in both cases and the intramolecular attack at C-2 afforded compounds **13** and **14** (Scheme 6).

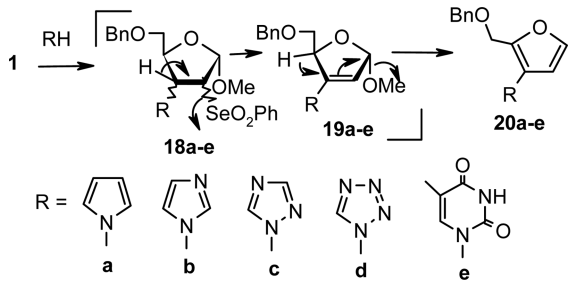
To establish the strategy for the synthesis of enantiopure and densely functionalized aziridine,[16] cyclopropane,[17] and dihydrofuran[18] articulated in Scheme 1, compounds **8a–c** were treated with 80% aqueous TFA at 70 °C followed by $NaBH_4$ reduction; and the products were isolated as alcohols **15a–c**, respectively. Using the same methodology, cyclopropane **16** and densely substituted dihydrofuran **17** were synthesized from **12a** and **13b**, respectively (Scheme 7).

Scheme 7. Synthesis of Densely Functionalized Enantiopure Aziridines, Nitrocyclopropane, and Dihydrofuran



Since vinyl selenone **1** was capable of affording C-3-substituted isonucleosides,[19] different planar heterocycles, such as pyrrole, imidazole, 1,2,4-triazole, 1-*H*-tetrazole, and the nucleobase thymine, were reacted with the Michael acceptor, but the reaction conditions caused exhaustive elimination to afford furan-linked heterocycles **20a–e**, respectively (Scheme 8).[20] It is probable that planar hetero-

Scheme 8. Synthesis of Furan-Linked Heterocycles from Selenosugar 1[a]

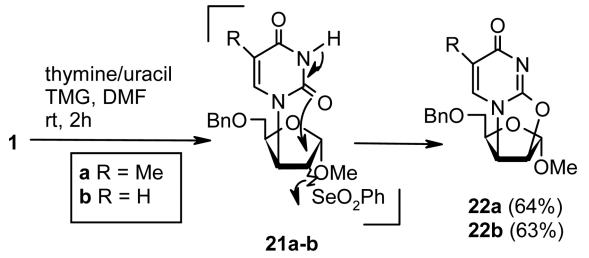


[a]Reagents and conditions: **20a**: pyrrole, ^{t}BuOK, THF, rt (1 h, 73%); **20b**: imidazole, H_2O, 80 °C (6 h, 86%); **20c**: 1,2,4-triazole, K_2CO_3, THF, rt (2 h, 80%); **20d**: 1-*H*-tetrazole, K_2CO_3, THF, 70 °C (10 h, 76%); **20e**: RH = thymine, ^{t}BuOK, THF, rt (10 h, 64%).

cycles first reacted with **1** to produce intermediates **18a–e** followed by elimination of phenyl seleninic acid ($PhSeO_2H$) to produce intermediates **19a–e**. Concomitant elimination of methanol from **19a–e** afforded isonucleosides **20a–e**, respectively (Scheme 8). In order to avoid the double elimination we opted for an organic base TMG. For pyrrole, imidazole, 1,2,4-triazole, and 1-*H*-tetrazole the base reacted directly with **1** to afford **8f**. However, instead of reacting with **1**, the same base TMG efficiently deprotonated thymine and uracil, respectively, to afford the *O*-anhydroisonucleosides **22a–b**, respectively, in good yields (Scheme 9). Due to the electronic repulsion between nucleobase and anomeric methoxy group, nucleobases first attacked from the β-face of C-3 centers of **1** to form intermediates **21a–b** which

DOI: 10.1021/acs.joc.5b01192
J. Org. Chem. 2015, 80, 11057–11064

Scheme 9. *O*-Anhydro Isonucleosides from Selenosugar 1



underwent intramolecular nucleophilic displacement of PhO_2Se group by the attack of C-2 oxygen of nucleobases to form **22a–b**. The anhydroisonucleoside **22a** was shown to be a key intermediate for the synthesis of the corresponding 3-deoxy-3-isonucleoside by regio- and stereospecific ring-opening of the tricyclic system.[19] Structures of **20e** and **22a** have been established by X-ray diffraction of their single crystals (Figures S4 and S5, see SI). A plausible mechanism for the formation of **22a–b** is delineated in Scheme 9.

In summary, we have introduced a densely functionalized Michael acceptor, namely vinyl selenone-modified carbohydrate **1** composed of a masked aldehyde, an electron-deficient double bond attached to selenone, and an excellent leaving group. Using the DOS strategy, this synthetic intermediate was reacted with a wide range of nucleophiles to afford a variety of products. Most of the compounds are reported for the first time. The strategy opens up a new avenue for the synthesis of different classes of enantiopure products starting from a single intermediate.

EXPERIMENTAL SECTION

General methods: Carbohydrates and other fine chemicals were obtained from commercial suppliers and used without purification. Solvents were dried and distilled following the standard procedures. TLC was carried out on precoated plates (Merck silica gel 60, f_{254}), and the spots were visualized with UV light or by charring the plates dipped in 5% H_2SO_4-MeOH solution. Column chromatography was performed on silica gel (230–400 mesh). ^1H and ^{13}C NMR for compounds were recorded at 400 MHz instrument and 50.3 MHz instrument, respectively, using either $CDCl_3$ as the solvent unless stated otherwise. DEPT experiments were carried out to identify the methylene carbons. High-resolution mass spectra were recorded using QTOF mass analyzer. Optical rotations were recorded at 589 nm.

Compounds 6a[10] and 6b.[11] Potassium hydroxide (0.082 g, 1.47 mmol) was added to a well-stirred mixture of vinyl selenone **1** (0.2 g, 0.49 mmol) in water (4 mL) at room temperature for 2 h. The mixture was partitioned between EtOAc (3 × 15 mL) and satd. aq. NH_4Cl solution (50 mL). Organic layers were pooled together, dried over anhyd. Na_2SO_4, and filtered, and the filtrate was evaporated to dryness to get a residue. The residue thus obtained was purified over silica gel column to afford compounds **6a** (0.043 g, 37%) and **6b** (0.041 g, 35%). **Compound 6a**: [Eluent: EtOAc:pet ether (1:5)] Colorless gum: ^1H NMR (400 MHz, $CDCl_3$): δ 3.42 (s, 3H), 3.65–3.67 (m, 3H), 3.77 (d, 1H, J = 2.8 Hz), 4.21 (t, 1H, J = 6.2 Hz), 4.60 (q, 2H, J = 12.0 Hz), 4.95 (s, 1H), 7.26–7.36 (m, 5H). **Compound 6b**: [Eluent: EtOAc: pet ether (1:2)] Yellowish gum: ^1H NMR (400 MHz, $CDCl_3$): δ 3.52 (s, 3H), 3.58–3.60 (m, 2H), 3.70 (d, 1H, J = 2.8 Hz), 3.76 (d, 1H, J = 2.8 Hz), 4.39 (t, 1H, J = 3.6 Hz), 4.55 (q, 2H, J = 12.0 Hz), 5.19 (s, 1H), 7.30–7.38 (m, 5H).

Compounds 7a and 7b. Sodium sulfide (0.076 g, 0.98 mmol) was added to a well-stirred mixture of vinyl selenone **1** (0.2 g, 0.49 mmol) in water (4 mL) at room temperature for 2 h. The mixture was partitioned between EtOAc (3 × 15 mL) and satd. aq. NH_4Cl solution (50 mL). Organic layers were pooled together, dried over anhyd. Na_2SO_4, and filtered, and the filtrate was evaporated to dryness to get a residue. The residue thus obtained was purified over silica gel column to afford compounds **7a** (0.042 g, 34%) and **7b** (0.04 g, 32%). **Compound 7a**: [Eluent: EtOAc:pet ether (1:4)] Yellowish gum: $[\alpha]_D^{26}$ +42.2 (c 0.90 in $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 3.35 (d, 1H, J = 4.8 Hz), 3.43 (s, 3H), 3.56 (dd, 1H, J = 2.2, 4.6 Hz), 3.58–3.65 (m, 2H), 4.48–4.51 (m, 1H), 4.59 (q, 2H, J = 12.0 Hz), 4.99 (s, 1H), 7.30–7.36 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 38.8, 39.8, 55.8, 71.8 (CH_2), 73.8 (CH_2), 76.0, 105.1, 128.0, 128.7, 138.1; HRMS [ES^+, $(M + Na)^+$] for $C_{13}H_{16}O_3SNa$ found 275.0723, calcd 275.0718. **Compound 7b**: [Eluent: EtOAc:pet ether (1:2)] Yellowish gum: $[\alpha]_D^{26}$ +36.2 (c 1.00 in $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 3.38 (dd, 1H, J = 0.8, 5.2 Hz), 3.54–3.65 (m, 6H), 4.39 (t, 1H, J = 3.0 Hz), 4.57 (q, 2H, J = 12.0 Hz), 5.43 (s, 1H), 7.31–7.39 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 39.0, 40.4, 57.9, 72.5(CH_2), 73.6(CH_2), 79.1, 104.4, 127.6, 128.0, 128.7, 138.0; HRMS [ES^+, $(M + Na)^+$] for $C_{13}H_{16}O_3SNa$ found 275.0711, calcd 275.0718.

General Procedure for Synthesis of *N*-alkyl Aziridines 8b–d from Vinyl Selenone 1. A mixture of vinyl selenone **1**(1 equiv) and appropriate amine (5 equiv) was stirred at room temperature. After completion of reaction (TLC), the mixture was partitioned between EtOAc and satd. aq. NH_4Cl solution. Organic layers were pooled together, dried over anhyd. Na_2SO_4, and filtered, and the filtrate was concentrated under reduced pressure to get a residue. The residue was purified by column chromatography over silica gel to give the corresponding product.

Compound 8a. To a well-stirred solution of vinyl selenone **1** (0.15 g, 0.36 mmol) in DMF (10 mL) 40% methylamine (2 mL) was added, and the mixture was stirred at room temperature for 2 h. After completion of reaction (TLC), the mixture was partitioned between EtOAc (3 × 15 mL) and satd. aq. NH_4Cl solution (50 mL). Organic layers were pooled together, dried over anhyd. Na_2SO_4, and filtered, and the filtrate was concentrated under reduced pressure to get a residue. The residue was purified by column chromatography to give **8a** (0.072 g, 78%). [Eluent: EtOAc:pet ether (1:1)] Yellowish gum; $[\alpha]_D^{26}$ +15.6 (c 1.03 in $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 2.24 (d, 1H, J = 4.8 Hz), 2.31–2.34 (m, 4H), 3.40–3.49 (m, 5H), 4.28 (t, 1H, J = 4.6 Hz), 4.52 (d, 2H, J = 2.8 Hz), 5.05 (s, 1H), 7.29–7.35 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 44.6, 46.2, 46.5, 57.2, 71.4 (CH_2), 73.5 (CH_2), 78.6, 104.1, 127.6, 127.7, 128.4, 138.1; HRMS [ES^+, $(M + H)^+$] for $C_{14}H_{20}NO_3$ found 250.1428, calcd 250.1443.

Compound 8b. Following the general procedure, cyclohexylamine (0.2 mL, 1.8 mmol) was reacted with **1** (0.15 g, 0.36 mmol) for 2 h to afford **8b** (0.099 g, 81%). [Eluent: EtOAc:pet ether (1:2)] Yellowish gum; $[\alpha]_D^{26}$ +25.0 (c 1.14 in $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 1.07–1.77 (m, 11H), 2.31 (d, 1H, J = 5.2 Hz), 2.36 (dd, 1H, J = 1.6, 4.8 Hz), 3.41–3.50 (m, 5H), 4.23–4.25 (m, 1H), 4.52 (q, 2H, J = 12.0 Hz), 5.04 (d, 1H, J = 1.6 Hz), 7.24–7.34 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 25.0 (2 × CH_2), 26.0 (CH_2), 32.4 (CH_2), 43.6, 44.2, 57.2, 66.0, 71.6 (CH_2), 73.5 (CH_2), 78.7, 104.3, 127.5, 127.7, 128.4, 138.2; HRMS [ES^+, $(M + H)^+$] for $C_{19}H_{28}NO_3$ found 318.2049, calcd 318.2069.

Compound 8c. Following the general procedure, isopropylamine (0.15 mL, 1.8 mmol) was reacted with **1** (0.15 g, 0.36 mmol) for 2 h to afford **8c** (0.087 g, 85%). [Eluent: EtOAc:pet ether (1:2)] Yellowish gum; $[\alpha]_D^{26}$ +35.9 (c 0.62 in $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 1.12 (d, 6H, J = 6.4 Hz), 1.49–1.54 (m, 1H), 2.29 (d, 1H, J = 5.2 Hz), 2.34–2.36 (m, 1H), 3.41–3.50 (m, 5H), 4.23–4.25 (m, 1H), 4.52 (q, 2H, J = 12.0 Hz), 5.04 (s, 1H), 7.24–7.34 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 21.9, 44.3, 45.0, 57.3, 58.0, 71.6 (CH_2), 73.5 (CH_2), 78.7, 104.3, 127.6, 127.7, 128.5, 138.2; HRMS [ES^+, $(M + H)^+$] for $C_{16}H_{24}NO_3$ found 278.1781, calcd 278.1756.

Compound 8d. Following the general procedure 2-amino-2-methyl-1-propanol (0.17 mL, 1.8 mmol) was reacted with **1** (0.15 g, 0.36 mmol) for 4h to afford **8d** (0.09 g, 80%). [Eluent: EtOAc:pet ether (1:1)] Yellowish gum; $[\alpha]_D^{26}$ +22.7 (c 1.08 in $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 0.72 (s, 3H), 1.03 (s, 3H), 2.53 (d, 1H, J = 4.8 Hz), 2.75 (dd, 1H, J = 1.8, 5.0 Hz), 3.12 (bs, 1H), 3.29 (d, 1H, J = 11.2 Hz), 3.42–3.54 (m, 6H), 4.20–4.22 (m, 1H), 4.53 (q, 2H, J = 12.2 Hz), 5.05 (d, 1H, J = 1.2 Hz), 7.27–7.35 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 17.5, 23.8, 37.3, 39.7, 55.4, 57.5, 71.5 (CH_2), 72.0

DOI: 10.1021/acs.joc.5b01192
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(CH_2), 73.5 (CH_2), 79.8, 104.6, 127.6, 127.7, 128.5, 138.1; HRMS [ES$^+$, (M + H)$^+$] for $C_{17}H_{26}NO_4$ found 308.1875, calcd 308.1862.

Compound 8e. To the glycine ethyl ester hydrochloride (0.1 g, 0.72 mmol) in dry DMSO was added triethylamine (0.15 mL, 1.08 mmol) at room temperature. After 10 min vinyl selenone **1** (0.15 g, 0.36 mmol) was added to the solution, and stirring was continued for 3 h. The mixture was partitioned between EtOAc (3 × 10 mL) and satd. aq. $NaHCO_3$ solution (50 mL). Organic layers were pooled together, dried over anhyd. Na_2SO_4, and filtered, and the filtrate was evaporated to get a residue. The residue was purified over silica gel column to afford **8e** (0.1 g, 85%). [Eluent: EtOAc:pet ether (1:1)] Yellowish gum; $[\alpha]_D^{26}$ +33.6 (*c* 1.18 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.19−1.23 (m, 3H), 2.44 (d, 1H, *J* = 4.8 Hz), 2.53 (d, 1H, *J* = 3.6 Hz), 2.93 (d, 1H, *J* = 16.0 Hz), 3.22 (d, 1H, *J* = 16.0 Hz), 3.45−3.51 (m, 5H), 4.12 (q, 2H, *J* = 7.2 Hz), 4.35 (t, 1H, *J* = 4.0 Hz), 4.50 (q, 2H, *J* = 12.2 Hz), 5.10 (s, 1H), 7.22−7.32 (m, 5H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 14.0, 45.2, 45.3, 57.1, 58.0 (CH_2), 60.7 (CH_2), 71.3 (CH_2), 73.3 (CH_2), 78.6, 104.0, 127.4, 127.6, 128.3, 137.9, 169.5; HRMS [ES$^+$, (M + H)$^+$] for $C_{17}H_{24}NO_5$ found 322.1650, calcd 322.1654.

Compound 8f. To the solution of vinyl selenone **1** (0.1 g, 0.24 mmol), TMG (0.048 g, 0.38 mmol) was added, and the mixture was stirred at room temperature for 10 h. The mixture was partitioned between EtOAc(3 × 15 mL) and satd. aq. NH_4Cl solution (60 mL). The organic layers were pooled together, dried over anhyd. Na_2SO_4, and filtered, and the filtrate was evaporated to get a residue. The residue was purified by column chromatography over silica gel to afford **8f** (0.049 g, 65%). [Eluent: EtOAc:pet ether (1:1)] Yellowish gum; $[\alpha]_D^{26}$ −35.7 (*c* 1.0 in $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$): δ 2.91 (s, 3H), 3.16 (s, 3H), 3.26 (dd, 1H, *J* = 1.6, 5.2 Hz), 3.37 (d, 1H, *J* = 5.0 Hz), 3.50 (s, 3H), 3.56 (d, 2H, *J* = 3.8 Hz), 4.38 (t, 1H, *J* = 3.8 Hz), 4.53 (d, 2H, *J* = 4.0 Hz), 5.19 (d, 1H, *J* = 1.4 Hz), 7.27−7.34 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 36.6, 37.0, 43.5, 45.1, 57.7, 71.4 (CH_2), 73.6 (CH_2), 78.6, 104.2, 127.6, 127.9, 128.6, 138.1, 163.2; HRMS [ES$^+$, (M + H)$^+$] for $C_{16}H_{23}N_2O_4$ found 307.1638, calcd 307.1658.

Compound 10. To a solution of the oxirane **9** (0.15 g, 0.64 mmol) and $LiClO_4$ (0.136 g, 1.28 mmol) in MeCN (10 mL), cyclohexylamine (0.146 mL, 1.28 mmol) was added. Then the mixture was heated under stirring at 80 °C for 24 h. Volatile matters were evaporated under vacuum, and the residue was partitioned between EtOAc (3 × 15 mL) and satd. aq. NH_4Cl solution (50 mL). Organic layers were pooled together, dried over anhyd. Na_2SO_4, and filtered, and the filtrate was evaporated to dryness under reduced pressure. The residue was purified by silica column chromatography to afford **10** (0.163 g, 77%). [Eluent: EtOAc:pet ether (3:2)] Yellowish gum; $[\alpha]_D^{26}$ +11.2 (*c* 1.00 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.96−1.82 (m, 11H), 2.83−2.89 (m, 1H), 3.20−3.24 (m, 1H), 3.45 (s, 3H), 3.69 (s, 1H), 3.79−3.88 (m, 2H), 4.33 (d, 1H, *J* = 2.0 Hz), 4.41 (s, 1H), 4.57 (s, 2H), 5.25 (s, 1H), 7.32−7.42 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 24.3 (CH_2), 24.6 (CH_2), 29.3 (CH_2), 29.4 (CH_2), 30.7 (CH_2), 55.7, 56.9, 65.1, 69.8 (CH_2), 74.0, 74.6 (CH_2), 85.2, 104.8, 128.9, 129.2, 136.2; HRMS [ES$^+$, (M + H)$^+$] for $C_{19}H_{30}NO_4$ found 336.2158, calcd 336.2175.

Compound 11. To a chilled solution of compound **10** (0.15 g, 0.45 mmol) and TPP (0.236 g, 0.9 mmol) in dry THF (15 mL), DIAD (0.177 mL, 0.9 mmol) was added dropwise with stirring. The solution was heated at 70 °C for 2 h, cooled, and then evaporated under reduced pressure to give a thick residue. The residue was purified by column chromatography over silica gel to afford **11** (0.102 g, 68%). [Eluent: EtOAc:pet ether (1:3)] Yellowish gum; $[\alpha]_D^{26}$ −31.5 (*c* 1.00 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.12−1.76 (m, 11H), 2.36 (d, 1H, *J* = 5.2 Hz), 2.41 (dd, 1H, *J* = 1.8, 5.0 Hz), 3.37 (s, 3H), 3.63 (d, 2H, *J* = 6.4 Hz), 4.13−4.17 (m, 1H), 4.57 (q, 2H, *J* = 11.8 Hz), 4.82 (s, 1H), 7.28−7.35 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 24.8 (CH_2), 26.2 (CH_2), 32.5 (CH_2), 32.7 (CH_2), 42.1, 44.8, 55.2, 64.9, 69.9 (CH_2), 73.9 (CH_2), 76.0, 104.1, 127.9, 128.2, 128.6, 138.3; HRMS [ES$^+$, (M + H)$^+$] for $C_{19}H_{28}NO_3$ found 318.2055, calcd 318.2069.

General Procedure for Synthesis of Cyclopropanes 12a−c, Dihydrofurans 13a−b, and Dihydrooxazole 14 from Vinyl Selenone 1. Active methylene compound (1.6 equiv) was added to a suspension of ^{t}BuOK (1.2 equiv) in dry THF (20 mL/mmol vinyl selenone) at ambient temperature, and the resulting solution was stirred for 0.5 h at this temperature under nitrogen. A solution of vinyl selenone **1** (1 equiv) in dry THF was added dropwise to the reaction mixture, and the resulting solution was stirred at appropriate temperature. After completion of the reaction (TLC), volatile matters were evaporated under vacuum, and the residue was partitioned between EtOAc and satd. aq. NH_4Cl solution. Organic layers were pooled together, dried over anhyd. Na_2SO_4, and filtered, and the filtrate was evaporated to dryness under reduced pressure to get a residue. The residue was purified by column chromatography over silica gel to give the corresponding product.

Compound 12a. Following the general procedure, nitromethane (0.031 mL, 0.57 mmol) was treated with **1** (0.15 g, 0.36 mmol) in the presence of ^{t}BuOK (0.049 g, 0.44 mmol) at room temperature for 3 h to afford **12a** (0.078 g, 76%). [Eluent: EtOAc:pet ether (1:5)] Colorless gum: $[\alpha]_D^{26}$ +30.9 (*c* 1.10 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.69 (dd, 1 H, *J* = 1.4, 7.8 Hz), 2.92 (d,1 H, *J* = 7.6 Hz), 3.44 (s, 3 H), 3.52 (d, 2 H, *J* = 4.0 Hz), 4.38 (t, 1 H, *J* = 4.0 Hz), 4.44 (s, 1 H), 4.57 (q, 2 H, *J* = 12.0 Hz), 5.36 (d, 1 H, *J* = 2.8 Hz), 7.32−7.40 (m, 5 H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 31.9, 33.6, 57.3, 59.3, 72.2 (CH_2), 73.7 (CH_2), 79.7, 105.6, 127.7, 128.1, 128.7, 137.9; HRMS [ES$^+$, (M + H)$^+$] for $C_{14}H_{18}NO_5$ found 280.1178, calcd 280.1185.

Compound 12b. Following the general procedure, malononitrile (0.037 g, 0.57 mmol) was treated with **1** (0.15 g, 0.36 mmol) in the presence of ^{t}BuOK (0.049 g, 0.44 mmol) at room temperature for 2 h to afford **12b** (0.077 g, 74%). [Eluent: EtOAc:pet ether (1:3)] Yellowish gum: $[\alpha]_D^{26}$ +5.2 (*c* 1.10 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.72 (d, 1 H, *J* = 6.8 Hz), 2.90 (dd,1 H, *J* = 2.4, 6.8 Hz), 3.51 (s, 3 H), 3.59 (excess malononitrile) 3.61−3.69 (m, 2 H), 4.50−4.62 (m, 3 H), 5.54 (d, 1 H, *J* = 2.8 Hz), 7.28−7.40 (m, 5 H);^{13}C NMR (50 MHz, $CDCl_3$): δ 8.8 (excess malononitrile) 6.5, 35.8, 37.6, 57.9, 71.6 (CH_2), 73.6 (CH_2), 77.9, 104.9, 109.3 (excess malononitrile), 111.7, 114.2, 127.7, 128.2, 128.7, 137.5; HRMS [ES$^+$, (M + H)$^+$] for $C_{16}H_{17}N_2O_3$ found 285.1236, calcd 285.1239.

Compound 12c. Following the general procedure, dimethyl malonate (0.065 mL, 0.57 mmol) was treated with **1** (0.15 g, 0.36 mmol) in the presence of ^{t}BuOK (0.049 g, 0.44 mmol) at room temperature for 3 h to afford **12c** (0.12 g, 93%). [Eluent: EtOAc:pet ether (1:3)] Yellowish gum: $[\alpha]_D^{26}$ +5.2 (*c* 1.10 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.24 (d, 1 H, *J* = 7.2 Hz), 2.66 (dd, 1 H, *J* = 2.8, 7.2 Hz), 3.42 (s, 3 H), 3.52−3.61 (m, 2 H), 3.70 (s, 3 H), 3.77 (s, 3 H), 4.55 (q, 2 H, *J* = 12.0 Hz), 4.71 (t, 1 H, *J* = 4.0 Hz), 5.43 (d, 1 H, *J* = 2.8 Hz), 7.26−7.37 (m, 5 H);^{13}C NMR (50 MHz, $CDCl_3$): δ 33.0, 33.9, 34.7, 52.1, 52.7, 57.4, 72.1 (CH_2), 73.1 (CH_2), 76.4, 105.5, 127.3, 127.5, 127.7, 128.2, 137.8, 166.3, 169.2; HRMS [ES$^+$, (M + Na)$^+$] for $C_{18}H_{22}O_7Na$ found 373.1257, calcd 373.1263.

Compound 13a. Following the general procedure, acetylacetone (0.058 mL, 0.57 mmol) was treated with **1** (0.15 g, 0.36 mmol) in the presence of ^{t}BuOK (0.049 g, 0.44 mmol) at room temperature for 4 h to afford **13a** (0.103 g, 88%). [Eluent: EtOAc:pet ether (1:3)] Yellowish gum: $[\alpha]_D^{26}$ +8.7 (*c* 1.00 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.27−2.33 (m, 6 H), 3.42 (s, 3 H), 3.72−3.78 (m, 2 H), 3.93 (dd, 1 H, *J* = 1.8, 10.4 Hz), 4.14−4.16 (m, 1 H), 4.61 (q, 2 H, *J* = 12.2 Hz), 4.98 (dd, 1 H, *J* = 4.6, 10.6 Hz), 5.15 (d, 1 H, *J* = 4.8 Hz), 7.26−7.35 (m, 5 H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 15.4, 29.2, 48.1, 55.6, 71.8 (CH_2), 73.5 (CH_2), 83.5, 84.4, 103.7, 116.7, 127.6, 128.3, 138.3, 168.3, 193.5; HRMS [ES$^+$, (M + H)$^+$] for $C_{18}H_{23}O_5$ found 319.1554, calcd 319.1545.

Compound 13b. Following the general procedure, ethyl acetoacetate (0.072 mL, 0.57 mmol) was treated with **1** (0.15 g, 0.36 mmol) in the presence of ^{t}BuOK (0.049 g, 0.44 mmol) at room temperature for 4 h to afford **13b** (0.097 g, 76%). [Eluent: EtOAc:pet ether (1:9)] Yellowish gum: $[\alpha]_D^{26}$ +33.9 (*c* 0.62 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.15 (t, 3 H, *J* = 7.2 Hz), 2.33 (s, 3 H), 3.40 (s, 3 H), 3.61−3.68 (m, 2 H), 3.87 (d, 1 H; *J* = 10.4 Hz), 4.02−4.10 (m, 2

DOI: 10.1021/acs.joc.5b01192
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H), 4.18−4.21 (m, 1 H), 4.60 (s, 2 H), 5.00 (dd, 1 H, J = 4.4, 10.8 Hz), 5.13 (d, 1 H, J = 5.2 Hz), 7.26−7.34 (m, 5 H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 14.1, 14.3, 47.2, 55.4, 59.5 (CH_2), 71.3 (CH_2), 73.5 (CH_2), 83.5, 84.8, 103.5, 104.1, 127.7, 128.3, 138.2, 165.6, 170.0; HRMS [ES$^+$, (M + H)$^+$] for $C_{19}H_{25}O_6$ found 349.1644, calcd 349.1651.

Compound 14. Following the general procedure, ethyl nitroacetate (0.063 mL, 0.57 mmol) was treated with **1** (0.15 g, 0.36 mmol) in the presence of ^{t}BuOK (0.049 g, 0.44 mmol) at room temperature for 4 h to afford **14** (0.12 g, 94%). [Eluent: EtOAc:pet ether (1:3)] White solid: mp 103 °C; $[\alpha]_D^{26}$ +62.4 (c 1.33 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.25 (t, 3 H, J = 7.0 Hz), 3.44 (s, 3 H), 3.73 (dd, 1 H, J = 3.6, 10.8 Hz), 3.85 (dd, 1 H, J = 1.8, 10.6 Hz), 4.17−4.27 (m, 3 H), 4.39 (s, 1 H), 4.62 (q, 2 H, J = 12.0 Hz), 4.93 (dd, 1 H, J = 4.2, 11.0 Hz), 5.16 (d, 1 H, J = 4.0 Hz), 7.30−7.36 (m, 5 H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 14.0, 46.7, 55.3, 61.9 (CH_2), 69.8 (CH_2), 73.7 (CH_2), 76.5, 81.3, 103.1, 108.8, 127.7, 127.8, 128.4, 137.8, 158.8; HRMS [ES$^+$, (M + Na)$^+$] for $C_{17}H_{21}NO_7Na$ found 374.1218, calcd 374.1216.

General Procedure for Opening of Sugar Ring. TFA (80%, 2 mL) was added to the compound (1 mmol), and the mixture was stirred at 70 °C. After completion of reaction (3 h), the mixture was partitioned between EtOAc and satd. aq. $NaHCO_3$ solution. The organic layers were pooled together, dried over anhyd. Na_2SO_4, and filtered, and the filtrate was evaporated to dryness to get a residue. To the solution of residue in ethanol (10 mL/mmol compound), $NaBH_4$ (2 mmol) was added, and the mixture was stirred at room temperature for 2 h. The volatile matters were evaporated under vacuum, and the residue was partitioned between EtOAc and satd. aq. NH_4Cl solution. Organic layers were pooled together, dried over anhyd. Na_2SO_4, and filtered, and the filtrate was evaporated to dryness. The residue thus obtained was purified over silica gel column to afford corresponding products.

Compound 15a. Following the general procedure, compound **8a** (0.1 g, 0.4 mmol) was converted to **15a** (0.051 g, 54% in two steps). [Eluent: EtOAc:pet ether (1:1)] Colorless gum; $[\alpha]_D^{26}$ −12.7 (c 1.00 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.87 (bs, 1H), 1.25 (s, 1H), 1.56 (t,1H,J = 7.2 Hz), 1.78−1.83 (m, 1H), 2.33 (s, 3H), 3.48−3.72 (m, 4H), 3.89−3.93 (m, 1H), 4.59 (q, 2H, J = 12.0 Hz), 7.30−7.34 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 45.3, 45.5, 47.2, 61.6 (CH_2), 70.1, 73.1 (CH_2), 73.7 (CH_2), 128.0, 128.1, 128.7, 137.9; HRMS [ES$^+$, (M + H)$^+$] for $C_{13}H_{20}NO_3$ found 238.1470, calcd 238.1443.

Compound 15b. Following the general procedure, compound **8b** (0.1 g, 0.31 mmol) was converted to **15b** (0.048 g, 50% in two steps). [Eluent: EtOAc:pet ether (2:3)] Yellowish gum; $[\alpha]_D^{26}$ −3.2 (c 0.66 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.13−1.33 (m, 6H), 1.58−1.77 (m, 8H), 1.85−1.90 (m, 1H), 3.53−3.63 (m, 3H), 3.73 (dd, 1H, J = 2.4, 8.8 Hz), 3.84−3.88 (m, 1H), 4.58 (q, 2H, J = 11.6 Hz), 7.30−7.38 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 24.9 (CH_2), 26.1 (CH_2), 32.6 (CH_2), 32.8 (CH_2), 43.0, 43.2, 61.8 (CH_2), 68.1, 70.1, 72.8 (CH_2), 73.8 (CH_2), 128.1, 128.7, 137.9; HRMS [ES$^+$, (M + H)$^+$] for $C_{18}H_{28}NO_3$ found 306.2081, calcd 306.2069.

Compound 15c. Following the general procedure, compound **8c** (0.1 g, 0.36 mmol) was converted to **15c** (0.047 g, 49% in two steps). [Eluent: EtOAc:pet ether (1:1)] Yellowish gum; $[\alpha]_D^{26}$ −8.0 (c1.2 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.02 (d, 3H, J = 6.4 Hz), 1.09 (d, 3H, J = 6.0 Hz), 1.57−1.70 (m, 3H), 1.85−1.90 (m, 1H), 2.00−2.05 (m, 1H), 3.53−3.65 (m, 3H), 3.72−3.75 (m, 1H), 3.85−3.90 (m, 1H), 4.58 (q, 2H, J = 11.6 Hz), 7.29−7.37 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 22.0, 22.2, 43.7, 43.9, 60.4, 61.7 (CH_2), 70.0, 72.9 (CH_2), 73.8 (CH_2), 128.1, 128.7, 137.9; HRMS [ES$^+$, (M + H)$^+$] for $C_{15}H_{24}NO_3$ found 266.1784, calcd 266.1756.

Compound 16. Following the general procedure, compound **12a** (0.07 g, 0.25 mmol) was converted to **16** (0.041 g, 61% in two steps). [Eluent: EtOAc:pet ether (3:2)] Colorless gum: $[\alpha]_D^{26}$ −42.2 (c 1.00 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$)δ 2.30−2.36 (m, 1 H), 2.48−2.53 (m, 1 H), 3.29 (bs, 1H), 3.40−3.73 (m, 5 H), 4.02−4.07 (m, 1 H), 4.13−4.16 (m, 1 H), 4.57 (s, 2 H), 7.30−7.39 (m, 5 H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 30.2, 31.1, 59.0 (CH_2), 61.7, 68.3, 73.1 (CH_2), 73.8 (CH_2), 128.1, 128.3, 128.8, 137.4; HRMS [ES$^+$, (M + Na)$^+$] for $C_{13}H_{17}NO_5Na$ found 290.1003, calcd 290.1004.

Compound 17. Following the general procedure, compound **13b** (0.07 g, 0.2 mmol) was converted to **17** (0.039 g, 58% in two steps). [Eluent: EtOAc:pet ether (3:2)] Colorless gum: $[\alpha]_D^{26}$ +26.2 (c 1.00 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.23−1.28 (m, 3 H), 2.20 (s, 3 H), 3.20 (t, 1 H, J = 8.0 Hz), 3.36 (dd, 1 H, J = 3.2, 9.2 Hz), 3.46−3.72 (m, 3 H), 3.93 (dd, 1 H, J = 5.4, 12.4 Hz), 4.02−4.07 (m, 2 H), 4.11−4.17 (m, 2 H), 4.52 (s, 2 H), 4.62−4.68 (m, 1 H), 7.29−7.37 (m, 5 H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 14.5, 14.9, 46.5, 60.0 (CH_2), 60.4 (CH_2), 69.8, 72.8 (CH_2), 73.7 (CH_2), 86.1, 104.0, 128.0, 128.1, 128.7, 137.8, 166.2, 170.9; HRMS [ES$^+$, (M + Na)$^+$] for $C_{18}H_{24}O_6Na$ found 359.1460, calcd 359.1470.

General Procedure for Synthesis of Furans 20a and 20e from Vinyl Selenone 1. To a solution of pyrrole or thymine (2 equiv) in THF (20 mL/mmol vinyl selenone), ^{t}BuOK (2 equiv) was added, and the mixture was stirred at room temperature for 10 min. Vinyl selenone **1** (1 equiv) was added to the solution and stirred at appropriate temperature. After completion of reaction (TLC) volatile matter was evaporated under vacuum, and the residual mixture was partitioned between EtOAc and satd. aq. NH_4Cl solution. Organic layers were pooled together, dried over anhyd. Na_2SO_4, and filtered, and the filtrate was evaporated to dryness to give a residue. The residue was purified over silica gel column to afford corresponding product.

General Procedure for Synthesis of Furans 20c and 20d from Vinyl Selenone 1. To a solution of 1,2,4-triazole or 1-*H*-tetrazole (2 equiv) in THF (20 mL/mmol vinyl selenone), K_2CO_3 (2 equiv) was added, and the mixture was stirred at room temperature for 10 min. Vinyl selenone **1** (1 equiv) was added to the solution and stirred at appropriate temperature. After completion of the reaction (TLC) volatile matter was evaporated under vacuum, and the residual mixture was partitioned between EtOAc and satd. aq. NH_4Cl solution. Organic layers were pooled together, dried over anhyd. Na_2SO_4, and filtered, and the filtrate was evaporated to dryness to give a residue. The residue was purified over silica gel column to afford corresponding product.

Compound 20a. Following the general procedure, pyrrole (0.05 mL, 0.72 mmol) was reacted with **1** (0.15 g, 0.36 mmol) in the presence of ^{t}BuOK (0.123 g, 0.72 mmol) at room temperature for 1 h to afford **20a** (0.067 g, 73%). [Eluent: EtOAc:pet ether (1:5)] Brownish gum; ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.54 (s, 2H), 4.57 (s, 2H), 6.29−6.30 (m, 2H), 6.52 (d, 1H, J = 1.6 Hz), 6.92−6.93 (m, 2H), 7.29−7.36 (m, 5H), 7.39 (d, 1H, J = 2.0 Hz); ^{13}C NMR (50 MHz, $CDCl_3$): δ 61.9 (CH_2), 72.5 (CH_2), 108.2, 110.0, 121.6, 128.1, 128.3, 128.7, 137.8, 142.2, 142.4; HRMS [ES$^+$, (M + Na)$^+$] for $C_{16}H_{15}NO_2Na$ found 276.1018, calcd 276.1000.

Compound 20b. A mixture of vinyl selenone **1** (0.15 g, 0.36 mmol) and imidazole (0.075 g, 1.1 mmol) in water (10 mL) was heated at 80 °C for 6 h. The reaction mixture was partitioned between EtOAc (3 × 15 mL) and satd. aq. NH_4Cl solution (50 mL). Organic layers were pooled together, dried over anhyd. Na_2SO_4, and filtered, and the filtrate was evaporated to dryness to give a residue. The residue was purified over silica gel column to afford **20b** (0.08 g, 86%). [Eluent: EtOAc:pet ether (1:1)] Colorless gum; ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.46 (s, 2H), 4.54 (s, 2H), 6.50 (d, 1H, J = 2.0 Hz), 7.14 (d, 2H, J = 8.4 Hz), 7.26−7.35 (m, 5H), 7.42 (d, 1H, J = 2.0 Hz), 7.71 (s, 1H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 61.3 (CH_2), 72.6 (CH_2), 108.0, 119.8, 124.0, 128.0, 128.5, 129.9, 137.3, 142.7, 143.5; HRMS [ES$^+$, (M + H)$^+$] for $C_{15}H_{15}N_2O_2$ found 255.1130, calcd 255.1134.

Compound 20c. Following the general procedure, 1,2,4-triazole (0.051 g, 0.72 mmol) was reacted with **1** (0.15 g, 0.36 mmol) in the presence of K_2CO_3 (0.1 g, 0.72 mmol) at room temperature for 2 h to afford **20c** (0.075 g, 80%). [Eluent: EtOAc:pet ether (1:5)] White solid; mp 120 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.52 (s, 2H), 4.58 (s, 2H), 6.64 (d, 1H, J = 1.6 Hz), 7.23−7.30 (m, 5H), 7.40 (d, 1H, J = 2.0 Hz), 8.01 (s, 1H), 8.35 (s, 1H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 61.9 (CH_2), 72.7 (CH_2), 107.2, 124.1, 128.1, 128.7, 137.4, 142.9, 143.5, 152.7; HRMS [ES$^+$, (M + H)$^+$] for $C_{14}H_{14}N_3O_2$ found 256.1085, calcd 256.1086.

DOI: 10.1021/acs.joc.5b01192
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Compound 20d. Following the general procedure, 1-*H*-tetrazole (0.051 g, 0.72 mmol) was reacted with **1** (0.15 g, 0.36 mmol) in the presence of K_2CO_3 (0.1 g, 0.72 mmol) at 70 °C for 10 h to afford **20d** (0.071 g, 76%). [Eluent: EtOAc:pet ether (1:5)] Yellowish gum; ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.61 (s, 2H), 4.94 (s, 2H), 7.00 (s, 1H), 7.26−7.31 (m, 5H), 7.52 (s, 1H), 8.61 (s, 1H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 62.2 (CH_2), 73.0 (CH_2), 106.4, 128.1, 128.6, 137.7, 143.3, 144.4, 153.0; HRMS [ES$^+$, $(M + H)^+$] for $C_{13}H_{13}N_4O_2$ found 257.1054, calcd 257.1039.

Compound 20e. Following the general procedure, thymine (0.092 g, 0.72 mmol) was reacted with **1** (0.15 g, 0.36 mmol) in the presence of ^{t}BuOK (0.082 g, 0.72 mmol) at room temperature for 10 h to afford **20e** (0.073 g, 64%). [Eluent: EtOAc:pet ether (2:3)] White solid; mp 106 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.88 (s, 3H), 4.46 (s, 2H), 4.55 (s, 2H), 6.50 (s, 1H), 7.13 (s, 1H), 7.29−7.33 (m, 5H), 7.42 (s, 1H), 9.13 (s, 1H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 12.4, 62.0 (CH_2), 73.0 (CH_2), 110.1, 111.2, 124.3, 128.1, 128.3, 128.7, 137.4, 141.4, 142.5, 146.6, 150.0, 164.2; HRMS [ES$^+$, $(M + H)^+$] for $C_{17}H_{17}N_2O_4$ found 313.1204, calcd 313.1188.

General Procedure for Synthesis of Isonucleosides 22a and 22b from Vinyl Selenone 1. To the solution of thymine or uracil (2 equiv) in DMF (15 mL/mmol vinyl selenone), TMG (1.6 equiv) was added, and the mixture was stirred at room temperature for 10 min. Vinyl selenone **1** (1 equiv) was added to the solution and stirred for 2 h at the same temperature. The mixture was partitioned between EtOAc and satd. aq. NH_4Cl solution. The organic layers were pooled together, dried over anhyd. Na_2SO_4, and filtered, and the filtrate was evaporated to get a residue. The residue was purified by column chromatography over silica gel to afford the corresponding product.

Compound 22a[19] Following the general procedure, thymine (0.061 g, 0.48 mmol) was reacted with **1** (0.1 g, 0.24 mmol) in the presence of TMG (0.048 g, 0.38 mmol) to afford **22a** (0.054 g, 64%). [Eluent: EtOAc:pet ether (1:1)] White solid; ^{1}H NMR (400 MHz, $CDCl_3$): δ1.91 (s, 3H), 3.39 (s, 3H), 3.49 (s, 1H), 3.84 (dd, 1H, J = 4.4, 9.6 Hz), 4.37−4.41 (m, 1H), 4.56 (q, 2H, J = 11.4 Hz), 4.90 (dd, 1H, J = 4.0, 7.2 Hz), 5.17−5.19 (m, 2H), 7.26 (s, 1H overlap), 7.33−7.41 (m, 5H).

Compound 22b. Following the general procedure, uracil (0.054 g, 0.48 mmol) was treated with **1** (0.1 g, 0.24 mmol) in the presence of TMG (0.048 g, 0.38 mmol) to afford **22b** (0.05 g, 63%). [Eluent: EtOAc:pet ether (3:2)] White solid; mp 132 °C; $[\alpha]_D^{26}$ +18.2 (*c*1.00 in $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.70 (bs, 1H), 3.34 (s, 3H), 3.36−3.39 (m, 1H), 3.73−3.77 (m, 1H), 4.33−4.37 (m, 1H), 4.51 (q, 2H, J = 12.0 Hz), 5.02−5.05 (m, 1H), 5.11 (s, 1H), 5.21 (d, 1H, J = 7.2 Hz), 5.80 (d, 1H, J = 7.2 Hz), 7.26−7.36 (m, 5H); ^{13}C NMR (50 MHz, $CDCl_3$): δ 55.2, 63.3, 66.0 (CH_2), 74.1 (CH_2), 76.9, 86.0, 105.5, 109.1, 128.3, 128.5, 128.8, 136.6, 137.3, 160.8, 172.0; HRMS [ES$^+$, $(M + H)^+$] for $C_{17}H_{19}N_2O_5$ found 331.1273, calcd 331.1294.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.5b01192.

(CIF)
(CIF)
(CIF)
Additional information, NMR spectra, and crystal structures; COSY and 1D NOE experiments for structure determination of **12a** (PDF)

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Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

A.B. thanks the Council of Scientific and Industrial Research (CSIR), New Delhi, India for a fellowship. Financial support by the Council of Scientific and Industrial Research (CSIR), New Delhi, India is gratefully acknowledged. The Department of Science and Technology, New Delhi, India is also thanked for the creation of 400 MHz facility under IRPHA program and DST-FIST for single crystal X-ray facility.

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DOI: 10.1021/acs.joc.5b01192
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