Chemistry of L-Ascorbic Acid: Regioselective and Stereocontrolled 2-C- and 3-C-Allylation *via* Thermal Claisen Rearrangement

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We report the convenient preparation of 3-O- and 2-O-allylated derivatives of 5,6-O-isopropylidene-L-ascorbic acid (1) with various allyl substituents in high yield and their quantitative thermal Claisen rearrangement to the corresponding 2-C- and 3-C-allylated derivatives with high regio- and stereoselectivity under relatively mild conditions. This reaction will now allow the synthesis of heretofore unknown 3-C-allylated derivatives of L-ascorbic acid in high yield. The high chiral induction at the substituents of the allylic carbon, especially in the case of the 3-*O*-methyl-2-*O*-crotyl derivative, is intriguing. This general method of preparation of 2-C- and 3-C-allylated derivatives of ascorbic acid may have important applications in synthetic organic and pharmaceutical chemistry.

Introduction

Ascorbic acid, an antioxidant and radical scavenger widely distributed in aerobic organisms, is known to protect cellular components against oxidative damage by free radicals and oxidants.[1] It also serves as a reductant for several important enzymatic biotransformations.[2,3] In addition, there is considerable evidence that biological antioxidants including ascorbic acid play an important role in the prevention of a large number of chronic diseases such as cancer, heart disease, brain dysfunction, and AIDS.[4] Furthermore, numerous simple derivatives of ascorbic acid have been synthesized and shown to possess important pharmacological properties. For example, 5,6-O-modified ascorbic acid derivatives have been found to be clinically effective antitumor agents for various human cancers[5] and also induce apoptosis in tumor cells,[6] 2-C-alkylated derivatives have been shown to have immunostimulant activity,[7] and 2-O- and 3-O-alkylated lipid soluble derivatives are known to protect against the lipid peroxidation of the biomembrane.[8] Therefore, the understanding of the chemistry and biochemistry of ascorbic acid and its derivatives would be helpful in the development of pharmacologically important agents with optimal activities. The chemistry of this important molecule has probably not been developed to expectations due to the complexity of its chemical properties.[9]

Preparation and characterization of O-alkylated and acetylated derivatives of L-ascorbic acid[8,9] and the C-2-alkylation of ascorbic acid[10,11] with various alkylating agents have been reported. Particularly, a Michael addition of ascorbic acid with α,β-unsaturated aldehydes and ketones has been observed.[10a-d] Moreno-Manas *et al.* have recently described a general method for the C-2-allylation of L-ascorbic acid by allyl carbonates in the presence of palladium(0) catalyst.[11] However, to our knowledge there is no general method available for the synthesis of C-3-alkylated derivatives of L-ascorbic acid. In the present work, we report a general method for the preparation of both 2-C- and 3-C-allylated derivatives of L-ascorbic acid selectively in high yield *via* thermal Claisen rearrangements. The chemistry, stereochemistry, and spectroscopic properties of these compounds are also discussed.

Results and Discussion

Several reports have appeared in the literature recently regarding the direct C-2-alkylation of ascorbic acid with powerful alkylating agents such as allyl bromides and cinnamyl bromide in aqueous or polar solvents (e.g., DMSO), especially when the reactions were carried out for a longer period of time.[12] However, the exact mechanism for the formation of C-allylated products rather than the expected kinetically controlled, corresponding O-allylated products has not been discussed. On the other

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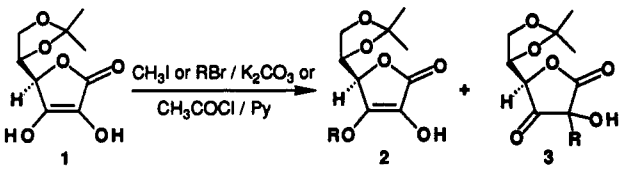
Table 1. 3-O-Alkylation of 5,6-*O*-Isopropylideneascorbic Acid



1 2 3

entry	products	R	yield[a] (%) (2:3 ratio)[b]
1	**2a, 3a**	CH_2=$CHCH_2$	80 (80:20)
2	**2b, 3b**	CH_3CH=$CHCH_2$	72 (70:30)
3	**2c, 3c**	$C_6H_5CH_2$	86 (62:38)
4	**2d, 3d**	C_6H_5CH=$CHCH_2$	72 (35:65)
5	**2e**	CH_3	91 (-)
6	**2f**	CH_3CO	85 (-)

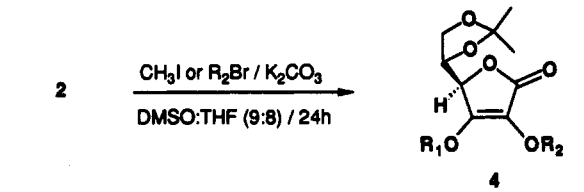
[a] All the yields are given for the chromatographically purified products. [b] Calculated based on the weights of the purified material or by ^{1}H-NMR for nonresolvable mixtures.

hand, Kato *et al.*[9b] have recently reported the direct O-alkylation of both 2-OH and 3-OH groups of ascorbic acid with primary alkyl halides in DMSO in the presence of K_2CO_3 or $NaHCO_3$, but there was no reported evidence for the formation of any C-alkylated products. Therefore, the formation of C-2-alkylated products appears to result mostly from the allylic alkylating agents.

In our recent studies[13] with several ascorbate-dependent key enzymes in the catecholamine neurotransmitter biosynthetic pathway we were interested in designing and synthesizing various ascorbate derivatives in order to probe the role of ascorbic acid in these systems. During the course of these studies it was observed that the 3-*O*-allyl or -crotyl derivative of 5,6-*O*-isopropylidene-L-ascorbic acid (1)[14] could be conveniently synthesized in high yield by reacting 1 with allyl or crotyl bromide in DMSO, in the presence of K_2CO_3 at room temperature[8,9b] (Table 1). Although it has been previously reported[12b] that the reaction of ascorbic acid with allyl bromide in aqueous KOH produces the 2-C-allylated product exclusively, we have observed the formation of only moderate amounts of the corresponding 2-C-allyl or -crotyl products under our reaction conditions (entries 1 and 2, Table 1). However, it was noticed that at longer reaction times and/or higher temperatures the 2-C-substituted product increased considerably and the yield of the 3-O-substituted product decreased. For example, the ^{1}H-NMR analysis of the crude reaction mixtures of allyl bromide and 1 showed that the yield of 2-C-allylated product was only 20% when the reaction was carried out at room temperature for 3 h and increased to 40% at 40 °C for 6 h. These results appear to indicate that the distribution of the products between 3-O- and 2-C-allylation is highly sensitive to the temperature and the reaction time. Therefore, it is possible that the kinetically favored initial 3-O-allylated product may rearrange to the thermodynamically more stable corresponding 2-C-allylated product under the reaction conditions, in a time- and temperature-dependent manner.

Heating of pure 5,6-*O*-isopropylidene-3-*O*-allyl-L-ascorbic acid (**2a**) in toluene to reflux for 6 h (Table 3) resulted in 100% conversion of the UV-active starting material to

Table 2. 2-O-Alkylation of L-Ascorbic Acid Derivatives



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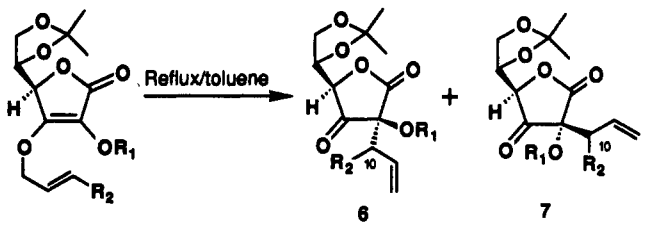
entry	product	R_1	R_2	yield[a] (%)
7	**4a**	CH_2=$CHCH_2$	CH_3	59
8	**4b**	CH_2=$CHCH_2$	CH_2=$CHCH_2$	61
9	**4c**	CH_3	CH_2=$CHCH_2$	66
10	**4d**	CH_3	CH_3CH=$CHCH_2$	65
11	**4e**	CH_3	C_6H_5CH=$CHCH_2$	71
12	**4f**	CH_3CO	CH_2=$CHCH_2$	70
13	**4g**	CH_3CO	CH_3CH=$CHCH_2$	78
14	**4h**	CH_3CO	C_6H_5CH=$CHCH_2$	76
15	**4i**	$C_6H_5CH_2$	CH_2=$CHCH_2$	81

[a] All the yields are given for the chromatographically purified products.

Table 3. 3-O to 2-C Rearrangement



6 7

reactant	R_1	R_2	products[a]	yield (%) (6:7)[b]
2a	H	H	**6a, 7a**	90:10
2b	H	CH_3	**6b, 7b**	81:19
4a	CH_3	H	**6c, 7c**	86:14
4b	CH_2=$CHCH_2$	H	**6d, 7d**	82:18

[a] 100% conversion of starting material was obtained. [b] Calculated from distinct ^{1}H-NMR signals of corresponding protons.

two less polar non-UV-active products with an approximate ratio of 90:10, based on TLC and ^{1}H-NMR of the crude reaction mixture. The ^{1}H-NMR of the major product showed that the two-proton doublet at δ 4.97 of the starting material has shifted upfield to a two-proton doublet at δ 2.66, suggesting that the O-allylic methylene protons have converted to C-allylic methylene protons during the rearrangement. This was further confirmed by the upfield shift of the methylene carbon triplet from δ 72.3 to δ 39.8 in ^{13}C-NMR. In addition, ^{13}C-NMR of the product revealed the presence of an isolated carbonyl carbon at δ 205.5 which was absent in the starting material. These observations confirm the structure of the major product as **6a**. The ^{1}H-NMR analysis of the partially purified minor product **7a** clearly indicated that it was the C-2 diastereomer of **6a**.

Pure samples of 5,6-*O*-isopropylidene-3-*O*-*trans*-crotyl-L-ascorbic acid (**2b**) and the 2-O-methylated derivative of **2a**, 5,6-*O*-isopropylidene-2-*O*-methyl-3-*O*-allyl-L-ascorbic acid (**4a**), were subjected to the rearrangement under similar conditions. The ^{1}H-NMR analysis of the crude reaction mixture from **2b** indicated that it was a mixture of only two products **6b** and **7b** with a ratio of 81:19 (Table 3). Both products contained an extra olefinic proton which was absent in the starting material. In addition, while the vinylic methyl group at δ 1.75 (dq) shifted upfield to δ 1.18 (d), the two-proton multiplet at δ 4.89 (O-allylic protons) collapsed to a one-proton multiplet at δ 2.70–2.80 (C-allylic proton). The presence of three olefinic protons in the ^{1}H-NMR and two olefinic carbons [δ 120.0(t) and δ 134.3-

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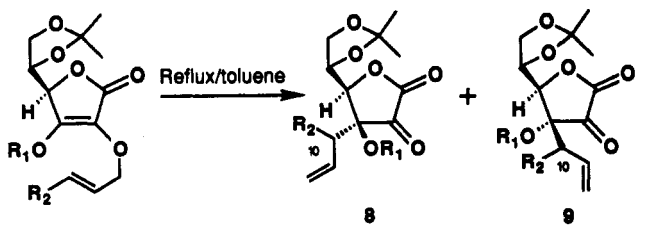
Table 4. 2-O to 3-C Rearrangement



reactant	R_1	R_2	products[a]	yield (%) (8:9)[b]
4c	CH_3	H	8c, 9c	82:18
4d	CH_3	CH_3	8d, 9d	51:49
4e	CH_2	C_6H_5	N/R	
4f	CH_3CO	H	8f, 9f	70:30
4g	CH_3CO	CH_3	four products[c]	
4h	CH_3CO	C_6H_5	four products[c]	
4i	$C_6H_5CH_2$	H	8i, 9i	73:27

[a] 100% conversion of starting material was obtained. [b] Calculated from distinct ^{1}H-NMR signals of corresponding protons. [c] Three products with a trace of a fourth [i.e., (10*R*)-8, (10*S*)-8, (10*R*)-9, and (10*S*)-9].

(d)] in the ^{13}C-NMR of the isolated major isomer confirmed the presence of a monosubstituted terminal double bond. On the basis of this information we propose **6b** as the major product of the rearrangement of **2b**. It is also evident from the spectroscopic data that the minor product **7b** is a C-2 diastereomer of **6b**. These results together with the observation that the corresponding 3-*O*-benzyl derivative **2c** is resistant to the rearrangement confirm that the above reaction is a concerted Claisen rearrangement.[15]

We have also examined the possibility of the rearrangement of 2-*O*-allyl derivatives of L-ascorbic acid to yield heretofore unknown corresponding 3-C-allyl derivatives which are synthetically and pharmacologically more demanding and inaccessible by direct alkylation methods. Since the alkylation or allylation at 2-O is not practical in the presence of a more acidic 3-OH group in the molecule, we have synthesized a series of 3-O-protected 2-O-allylated ascorbic acid derivatives **4a–i** (Table 2). The purified derivatives were subjected to the rearrangement under standard conditions (Table 4). In these experiments it was observed that the rearrangement is slower than that of the 3-*O*-allyl derivatives and was complete within 30 h giving only the expected products with no decomposition (Table 4). The rearrangement of 2,3-*O*-diallyl-L-ascorbate derivative **4b** gave more than 97% of the 2-C-allylated products with a diastereomeric ratio of 82:18 (Table 3) again suggesting that the 3-O to 2-C rearrangement is much more favorable than the 2-O to 3-C rearrangement under competitive reaction conditions. The crotyl derivative, 5,6-*O*-isopropylidene-2-*O*-*trans*-crotyl-3-*O*-methyl-L-ascorbic acid (**4d**), also underwent facile rearrangement giving only two easily separable diastereomers **8d** and **9d** (see below). The 2-O to 3-C migration of the allyl group in these reactions is unequivocally confirmed by the presence of a carbonyl adjacent to a lactone carbonyl as indicated by the characteristic ^{13}C resonance between 185 and 205 ppm.[16a,c] However, 5,6-*O*-isopropylidene-2-*O*-*trans*-cinnamyl-3-*O*-methyl-L-ascorbic acid (**4e**) was resistant to rearrangement even under vigorous conditions (refluxing in xylene for 72 h).

The above results clearly demonstrate that this rearrangement can be used to allylate 2-C or 3-C positions of L-ascorbic acid, selectively. In order to test whether relatively bulky 3-O blocking groups such as acetyl will retard or facilitate the reaction, 2-*O*-allyl (**4f**), 2-*O*-*trans*-crotyl (**4g**), and 2-*O*-*trans*-cinnamyl (**4h**) derivatives of 5,6-*O*-isopropylidene-3-*O*-acetyl-L-ascorbic acid were prepared (Table 2), purified, and subjected to the rearrangement (Table 4). The TLC monitoring of the progress of these reactions revealed that all the reactions were much faster than the corresponding 3-*O*-methyl derivatives (**4c**, **4d**, and **4e**) and quantitatively produced the expected products within 4 h. The rearranged products of **4f** were found to be a mixture of two diastereomers **8f** and **9f** with a ratio of 70:30, suggesting that even though the rearrangement is much faster, the face-selectivity is considerably less pronounced than that of the corresponding 3-*O*-methyl derivative. The rearrangement of 3-*O*-acetyl-2-*O*-*trans*-crotyl derivative **4g** yielded three (with a trace of a fourth) diastereomers in a ratio of 40:40:20 based on ^{1}H-NMR of the crude reaction mixture (see below). In contrast to the corresponding 3-*O*-methyl derivative **4e**, the 3-*O*-acetyl derivative of 2-*O*-*trans*-cinnamyl-L-ascorbic acid **4h** undergoes facile rearrangement under very mild conditions (even at room temperature, 100% conversion was observed within 20 days) giving a mixture of three (with a trace of a fourth) diastereomeric products with a ratio of 50:35:15 similar to **4g**. These results clearly suggest that the stereoselectivity of the rearrangement of 3-*O*-acetyl derivatives **4f**, **4g**, **4h** is much less specific than that of the corresponding 3-*O*-methyl derivatives.

Stereochemistry. The stereochemistry of most of the rearranged products could be assigned by the close examination of their characteristic spectroscopic differences. For example, the major difference between the two products, **6a** and **7a**, of the rearrangement of **2a** is the stereochemistry of the newly formed chiral sp^3 carbon of the β-keto lactone ring. While the allyl group at C-2 and the 5,6-*O*-isopropylidene group containing side chain at C-4 of the ring are *trans* to each other in **6a**, they are *cis* in **7a**. Therefore, it could be predicted that the major influence on the ^{13}C-NMR chemical shifts of the allylic methylene carbons of the two compounds should be mainly due to the differential steric interactions of these two bulky groups.[16a] The van der Waals repulsions between the allylic methylene carbon (C-10) and the side-chain carbon (C-5) should result in the shielding of the methylene carbon of the *cis* product in comparison to that of the *trans* product.[16] It is clear from the spectral data that the allylic carbon (C-10) signal of **6a** is about 11 ppm more downfield than the corresponding carbon signal of **7a**. Therefore, it is clear that the major product **6a** of the rearrangement must have the allyl group *trans* to the C-4 side chain of the β-keto lactone ring which is consistent with the previous literature reports.[10,17] Similarly, the major product **8c** of the rearrangement of **4c** showed a downfield shift of about 7 ppm for the C-10 signal relative to the corresponding carbon signal of the minor product **9c**, confirming **8c** as the major product of 2-O to 3-C rearrangement.

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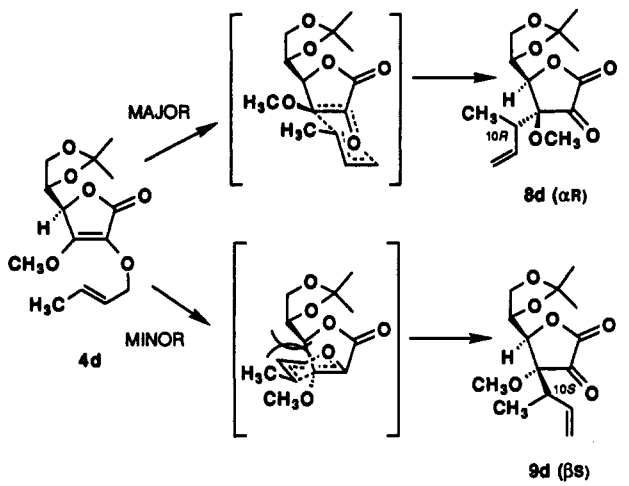
Scheme 1



The stereochemical control of the Claisen rearrangement has been extensively investigated and the stereochemical outcome of the reaction shown to be controlled by the steric factors in the transition state.[15,18,19] It is clear that the transition states shown in Scheme 1 are the most probable for 2-O to 3-C rearrangements (similar transition states could be envisioned for 3-O to 2-C rearrangement) and the major products should be derived from the α-face alkylation. The stereochemistry at the C-10 center must also be fixed during the rearrangement (Scheme 1) since the *trans*-R substituent of the allyl functionality should occupy only the equatorial position in the chairlike transition state (for examples see ref 15) and should yield only two rearranged products. In agreement with these predictions prototypic compound **4d** gives only two rearranged products, the absolute stereochemistry of which could be assigned as αR and βS (Scheme 1; the confirmation of these assignments is awaiting X-ray analysis). However, the behavior of 3-O-acetylated derivatives **4g** and **4h** is different from **4d** in both the stereoselectivity (see Table 4) and the facility for the rearrangement. We believe that the behavior of these two compounds may be due to the steric and/or electronic interactions of the 3-*O*-acetyl group of the molecule. The details of this unexpected behavior are currently under investigation.

Experimental Section

General. Elemental analyses were performed by MHW Laboratories, Phoenix, AZ. All chemical shifts were reported on the δ (ppm) scale relative to TMS (0.00 ppm) for ^{1}H-NMR and to $CDCl_3$ (77.00 ppm) for ^{13}C-NMR. Davisil grade 633 type 60A (200–425 mesh, Fisher) silica gel was used for column chromatography. TLC was performed on precoated silica gel GF plates (250 μm, Analtech), and the compounds were observed under UV light and/or by exposure to iodine vapor. All solvents were dried with appropriate drying agents and freshly distilled. Unless otherwise specified all the products were purified by normal-phase silica gel column chromatography using a mixture of ethyl acetate and *n*-hexane with varying ratios depending on the compound.

5,6-*O*-Isopropylidene-L-ascorbic Acid (1). This was synthesized in 82% yield according to the procedure of Jung *et al.*:[14] mp 204–206 °C (lit.[8] mp 201–203 °C); ^{1}H-NMR (D_2O) δ 1.37 (6H, s), 4.17 (1H, dd, J = 5.0, 9.1 Hz), 4.31 (1H, dd, J = 7.2, 9.1 Hz), 4.59 (1H, ddd, J = 2.3, 5.0, 7.3 Hz), 4.91 (1H, d, J = 2.4 Hz); ^{13}C-NMR (D_2O) δ 26.7 (q), 27.5 (q), 67.8 (t), 75.7 (d), 78.5 (d), 113.5 (s), 120.5 (s), 158.4 (s), 176.1 (s).

General Procedure for the Preparation of 2a–2e. A mixture of 1 and 1.2 equiv of K_2CO_3 in DMSO/THF (9:8) was stirred for 20 min at room temperature. The corresponding halide (1.2 equiv) in the same solvent was added dropwise, and the mixture was vigorously stirred for 4–6 h at room temperature. The reaction mixture was diluted with H_2O (4-fold) and extracted with ethyl acetate. The organic layer was thoroughly washed with H_2O, dried over anhydrous Na_2SO_4, and evaporated *in vacuo*. The products were purified by conventional silica gel column chromatography.

5,6-*O*-Isopropylidene-3-*O*-allyl-L-ascorbic Acid (2a). This was prepared from 1 and allyl bromide in 80% yield as a light greenish oil: ^{1}H-NMR ($CDCl_3$) δ 1.37 (3H, s), 1.40 (3H, s), 4.04 (1H, dd, J = 6.7, 8.6 Hz), 4.15 (1H, dd, J = 6.7, 8.6 Hz), 4.28 (1H, dt, J = 3.8, 6.6 Hz), 4.58 (1H, d, J = 3.8 Hz), 4.97 (2H, d, J = 5.7 Hz), 5.31 (1H, dq, J = 10.4, 1.3 Hz), 5.41 (1H, dq, J = 17.2, 1.4 Hz), 6.01 (1H, ddt, J = 17.2, 10.4, 5.7 Hz); ^{13}C-NMR ($CDCl_3$) δ 25.5 (q), 25.9 (q), 65.3 (t), 72.3 (t), 74.3 (d), 75.6 (d), 110.3 (s), 119.1 (t), 119.2 (s), 132.2 (d), 148.2 (s), 171.0 (s).

5,6-*O*-Isopropylidene-3-*O*-*trans*-crotyl-L-ascorbic Acid (2b). This was prepared from 1 and *trans*-crotyl bromide in 72% yield as a light yellow oil: ^{1}H-NMR ($CDCl_3$) δ 1.37 (3H, s), 1.40 (3H, s), 1.75 (3H, dq, J = 6.5, 1.5 Hz), 4.02 (1H, dd, J = 6.7, 8.6 Hz), 4.13 (1H, dd, J = 6.7, 8.6 Hz), 4.26 (1H, dt, J = 3.9, 6.7 Hz), 4.55 (1H, d, J = 3.9 Hz), 4.89 (2H, m), 5.68 (1H, dtq, J = 15.3, 6.6, 1.6 Hz), 5.90 (1H, dtq, J = 15.3, 1.1, 6.5 Hz); ^{13}C-NMR ($CDCl_3$) δ 17.8 (q), 25.6 (q), 25.9 (q), 65.3 (t), 72.4 (t), 74.4 (d), 75.7 (d), 110.3 (s), 119.1 (s), 125.2 (d), 132.6 (d), 148.6 (s), 171.8 (s).

5,6-*O*-Isopropylidene-3-*O*-benzyl-L-ascorbic Acid (2c). This was prepared from 1 and benzyl bromide in 86% yield as a semisolid: ^{1}H-NMR ($CDCl_3$) δ 1.36 (3H, s), 1.39 (3H, s), 4.02 (1H, dd, J = 6.8, 8.6 Hz), 4.10 (1H, dd, J = 6.7, 8.6 Hz), 4.26 (1H, dt, J = 3.8, 6.7 Hz), 4.57 (1H, d, J = 3.8 Hz), 5.52 (2H, two d), 7.35–7.42 (5H, m); ^{13}C-NMR ($CDCl_3$) δ 25.5 (q), 25.9 (q), 65.3 (t), 73.5 (t), 74.2 (d), 75.7 (d), 110.3 (s), 119.5 (s), 128.4 (d), 128.6 (d), 128.7 (d), 135.7 (s), 148.6 (s), 171.1 (s).

5,6-*O*-Isopropylidene-3-*O*-methyl-L-ascorbic Acid (2e). This was prepared from 1 and methyl iodide in 91% yield as a viscous oil: ^{1}H-NMR ($CDCl_3$) δ 1.37 (3H, s), 1.40 (3H, s), 4.02 (1H, dd, J = 6.6, 8.5 Hz), 4.13 (1H, dd, J = 6.7, 8.5 Hz), 4.18 (3H, s), 4.23 (1H, dt, J = 3.8, 6.7 Hz), 4.53 (1H, d, J = 3.8 Hz).

5,6-*O*-Isopropylidene-3-*O*-acetyl-L-ascorbic Acid (2f). A suspension of 1 and 1.4 equiv of pyridine in CH_2Cl_2 was stirred for 20 min at room temperature, and acetyl chloride (1.2 equiv) was added dropwise. The mixture was vigorously stirred until the solution became homogeneous and was further stirred for 2 h at room temperature. The reaction mixture was diluted with H_2O (4-fold) and extracted with ethyl acetate. The organic layer was thoroughly washed with H_2O, dried over anhydrous Na_2SO_4, and evaporated *in vacuo*. The resulting residue was purified by silica gel column chromatography to yield a colorless semisolid (85%): ^{1}H-NMR ($CDCl_3$) δ 1.38 (3H, s), 1.41 (3H, s), 2.29 (3H, s), 4.11 (1H, dd, J = 6.7, 8.7 Hz), 4.20 (1H, dd, J = 6.8, 8.6 Hz), 4.44 (1H, dt, J = 3.1, 6.7 Hz), 4.71 (1H, d, J = 3.1 Hz).

General Procedure for the Preparation of 4a–4i. A solution of 2 and 1.2 equiv of K_2CO_3 in DMSO/THF (9:8) was stirred for 20 min at room temperature. The corresponding halide (1.2 equiv) in the same solvent was added dropwise, and the mixture was vigorously stirred overnight at room temperature. The reaction mixture was diluted with H_2O (4-fold) and extracted with ethyl acetate. The organic layer was thoroughly washed with H_2O, dried over anhydrous Na_2SO_4, and evaporated *in vacuo*. The products were purified by conventional silica gel column chromatography.

5,6-*O*-Isopropylidene-3-*O*-allyl-2-*O*-methyl-L-ascorbic Acid (4a). This was prepared from **2a** and methyl iodide in 59% yield as a semisolid: ^{1}H-NMR ($CDCl_3$) δ 1.36 (3H, s), 1.40 (3H, s), 3.85 (3H, s), 4.04 (1H, dd, J = 6.6, 8.5 Hz), 4.14 (1H, dd, J = 6.7, 8.5 Hz), 4.30 (1H, dt, J = 3.3, 6.7 Hz), 4.53 (1H, d, J = 3.3 Hz), 4.93 (2H, dt, J = 5.6, 1.4 Hz), 5.33 (1H, dq, J = 10.5, 1.3 Hz), 5.40 (1H,

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dq, J = 17.2, 1.5 Hz), 5.98 (1H, ddt, J = 17.2, 10.5, 5.6 Hz); ^{13}C-NMR ($CDCl_3$) δ 25.5 (q), 25.8 (q), 59.9 (q), 65.3 (t), 72.2 (t), 74.0 (d), 74.6 (d), 110.3 (s), 118.8 (t), 123.0 (s), 131.8 (d), 155.1 (s), 168.7 (s).

5,6-*O*-Isopropylidene-2,3-*O*-diallyl-L-ascorbic Acid (4b). This was prepared from **2a** and allyl bromide in 61% yield as a light yellow oil: ^{1}H-NMR ($CDCl_3$) δ 1.36 (3H, s), 1.39 (3H, s), 4.04 (1H, dd, J = 6.6, 8.5 Hz), 4.14 (1H, dd, J = 6.7, 8.5 Hz), 4.30 (1H, dt, J = 3.2, 6.7 Hz), 4.55 (1H, d, J = 3.2 Hz), 4.62 (2H, two ddt), 4.94 (2H, dt, J = 5.6, 1.4 Hz), 5.27 (1H, dq, J = 10.8, 1.5 Hz), 5.31 (1H, dq, J = 10.5, 1.3 Hz), 5.35 (1H, dq, J = 17.2, 1.5 Hz), 5.39 (1H, dq, J = 17.3, 1.5 Hz), 5.98 (1H, ddt, J = 17.3, 10.5, 5.6 Hz), 5.99 (1H, ddt, J = 17.2, 10.3, 6.1 Hz); ^{13}C-NMR ($CDCl_3$) δ 25.6 (q), 25.9 (q), 65.3 (t), 72.3 (t), 72.5 (t), 74.0 (d), 74.7 (d), 110.3 (s), 118.9 (t), 119.2 (t), 121.5 (s), 131.9 (d), 132.9 (d), 155.7 (s), 168.9 (s).

5,6-*O*-Isopropylidene-2-*O*-allyl-3-*O*-methyl-L-ascorbic Acid (4c). This was prepared from **2e** and allyl bromide in 66% yield as a light yellow viscous oil: ^{1}H-NMR ($CDCl_3$) δ 1.36 (3H, s), 1.39 (3H, s), 4.03 (1H, dd, J = 6.4, 8.6 Hz), 4.13 (1H, dd, J = 6.7, 8.5 Hz,), 4.15 (3H, s), 4.28 (1H, dt, J = 3.1, 6.6 Hz), 4.52 (1H, d, J = 3.1 Hz), 4.61 (2H, two ddt), 5.28 (1H, dq, J = 10.3, 1.5 Hz), 5.36 (1H, dq, J = 17.2, 1.5 Hz), 6.00 (1H, ddt, J = 17.2, 10.3, 6.2 Hz); ^{13}C-NMR ($CDCl_3$) δ 25.5 (q), 25.8 (q), 59.6 (q), 64.2 (t), 72.7 (t), 73.8 (d), 74.5 (d), 110.3 (s), 119.3 (t), 121.5 (s), 132.8 (d), 157.1 (s), 169.9 (s).

5,6-*O*-Isopropylidene-2-*O*-*trans*-crotyl-3-*O*-methyl-L-ascorbic Acid (4d). This was prepared from **2e** and *trans*-crotyl bromide in 65% yield as a yellow viscous oil: ^{1}H-NMR ($CDCl_3$) δ 1.36 (3H, s), 1.39 (3H, s), 1.74 (3H, dq, J = 6.4, 1.3 Hz), 4.03 (1H, dd, J = 6.5, 8.5 Hz), 4.13 (1H, dd, J = 6.7, 8.5 Hz), 4.14 (3H, s), 4.27 (1H, dt, J = 3.1, 6.7 Hz), 4.51 (1H, d, J = 3.1 Hz), 4.52 (2H, m), 5.66 (1H, dtq, J = 15.3, 6.7, 1.5 Hz), 5.82 (1H, dtq, J = 15.3, 0.9, 6.4 Hz) ^{13}C-NMR ($CDCl_3$): δ 17.8 (q), 25.6 (q), 25.8 (q), 59.6 (q), 65.2 (t), 72.6 (t), 73.9 (d), 74.5 (d), 110.3 (s), 121.4 (s), 125.8 (d), 132.4 (d), 157.3 (s), 169.1 (s).

5,6-*O*-Isopropylidene-2-*O*-*trans*-cinnamyl-3-*O*-methyl-L-ascorbic Acid (4e). This was prepared from **2e** and *trans*-cinnamyl bromide in 71% yield as colorless crystals: mp 114–115 °C; ^{1}H-NMR ($CDCl_3$) δ 1.32 (3H, s), 1.36 (3H, s), 4.03 (1H, dd, J = 6.6, 8.5 Hz), 4.12 (1H, dd, J = 6.7, 8.5 Hz), 4.16 (3H, s), 4.27 (1H, dt, J = 3.0, 6.7 Hz), 4.51 (1H, d, J = 3.0 Hz), 4.74 (1H, ddd, J = 12.1, 6.8, 1.2 Hz), 4.81 (1H, ddd, J = 12.1, 6.6, 1.2 Hz), 6.36 (1H, dt, J = 15.9, 6.7 Hz), 6.68 (1H, d, J = 15.9 Hz), 7.23–7.36 (3H, m), 7.37–7.42 (2H, m); ^{13}C-NMR ($CDCl_3$) δ 25.5 (q), 25.8 (q), 59.6 (q), 65.2 (t), 72.4 (t), 73.8 (d), 74.5 (d), 110.3 (s), 121.1 (s), 123.8 (d), 126.7 (d), 128.1 (d), 128.6 (d), 135.1 (d), 136.2 (s), 157.4 (s), 169.0 (s). Anal. Calcd for $C_{19}H_{22}O_6$: C, 65.89; H, 6.40. Found: C, 65.67; H, 6.27.

5,6-*O*-Isopropylidene-3-*O*-acetyl-2-*O*-allyl-L-ascorbic Acid (4f). This was prepared from **2f** and allyl bromide in 70% yield as a colorless semisolid: ^{1}H-NMR ($CDCl_3$) δ 1.37 (3H, s), 1.41 (3H, s), 2.27 (3H, s), 4.08 (1H, dd, J = 6.4, 8.6 Hz), 4.16 (1H, dd, J = 6.8, 8.6 Hz), 4.38 (1H, dt, J = 3.0, 6.6 Hz), 4.69 (1H, d, J = 3.0 Hz), 4.81 (2H, two ddt), 5.35 (1H, dq, J = 10.6, 1.2 Hz), 5.40 (1H, dq, J = 18.1, 1.6 Hz), 5.95 (1H, ddt, J = 17.2, 10.5, 5.5 Hz); ^{13}C-NMR ($CDCl_3$) δ 20.3 (q), 25.5 (q), 25.8 (q), 65.2 (t), 72.5 (t), 73.7 (d), 75.3 (d), 110.6 (s), 114.6 (s), 119.6 (t), 131.0 (d), 159.5 (s), 166.8 (s), 167.6 (s).

5,6-*O*-Isopropylidene-3-*O*-acetyl-2-*O*-*trans*-crotyl-L-ascorbic Acid (4g). This was prepared from **2f** and *trans*-crotyl bromide in 78% yield as a yellow semisolid: ^{1}H-NMR ($CDCl_3$) δ 1.36 (3H, s), 1.40 (3H, s), 1.76 (3H, dq, J = 6.5, 1.6 Hz), 2.27 (3H, s), 4.07 (1H, dd, J = 6.4, 8.6 Hz), 4.15 (1H, dd, J = 6.8, 8.6 Hz), 4.36 (1H, dt, J = 3.1, 6.5 Hz), 4.66 (1H, d, J = 3.1 Hz), 4.73 (2H, m), 5.62 (1H, dtq, J = 15.4, 6.4, 1.6 Hz), 5.87 (1H, dtq, J = 15.3, 1.2, 6.5 Hz); ^{13}C-NMR ($CDCl_3$) δ 17.7 (q), 20.2 (q), 25.5 (q), 25.7 (q), 65.2 (t), 72.6 (t), 73.7 (d), 75.3 (d), 110.5 (s), 114.4 (s), 124.0 (d), 133.2 (d), 159.7 (s), 167.0 (s), 167.6 (s).

5,6-*O*-Isopropylidene-2-*O*-*trans*-cinnamyl-3-*O*-acetyl-L-ascorbic Acid (4h). This was prepared from **2f** and *trans*-cinnamyl bromide in 76% yield as a viscous oil: ^{1}H-NMR ($CDCl_3$) δ 1.36 (3H, s), 1.41 (3H, s), 2.28 (3H, s), 4.09 (1H, dd, J = 6.4, 8.6 Hz), 4.17 (1H, dd, J = 6.8, 8.6 Hz), 4.40 (1H, dt, J = 2.9, 6.6 Hz), 4.70 (1H, d, J = 2.9 Hz), 4.90–5.03 (2H, m), 6.29 (1H, dt, J = 15.9, 6.3 Hz), 6.71 (1H, d, J = 15.9 Hz), 7.23–7.36 (3H, m), 7.37–7.42 (2H, m); ^{13}C-NMR ($CDCl_3$) δ 20.2 (q), 25.5 (q), 25.7 (q), 65.2 (t), 72.6 (t), 73.6 (d), 75.3 (d), 110.6 (s), 114.7 (s), 121.6 (d), 126.7 (d), 128.6 (d), 128.7 (d), 129.3 (s), 135.5 (d), 159.7 (s), 166.9 (s), 167.6 (s).

5,6-*O*-Isopropylidene-2-*O*-allyl-3-*O*-benzyl-L-ascorbic Acid (4i). This was prepared from **2c** and allyl bromide in 81% yield as a colorless semisolid: ^{1}H-NMR ($CDCl_3$) δ 1.36 (3H, s), 1.38 (3H, s), 4.03 (1H, dd, J = 6.7, 8.6 Hz), 4.11 (1H, dd, J = 6.7, 8.5 Hz), 4.30 (1H, dt, J = 3.2, 6.7 Hz), 4.54 (2H, m), 4.55 (1H, d, J = 3.2 Hz), 5.26 (1H, dq, J = 10.3, 1.6 Hz), 5.34 (1H, dq, J = 17.2, 1.5 Hz), 5.48 (2H, br.s), 5.94 (1H, ddt, J = 17.2, 10.3, 6.1 Hz), 7.37 (5H, br.s); ^{13}C-NMR ($CDCl_3$) δ 25.6 (q), 25.8 (q), 65.2 (t), 72.5 (t), 73.5 (d), 73.9 (t), 74.7 (d), 110.3 (s), 119.3 (t), 121.4 (s), 127.7 (d), 128.5 (d), 128.7 (d), 129.1 (s), 132.8 (d), 155.9 (s), 168.8 (s).

3-*O*-Acetyl-2-*O*-allyl-L-ascorbic Acid (5). This was obtained by acid-catalyzed removal of 5,6-*O*-isopropylidene group of **4f** as a colorless viscous oil: ^{1}H-NMR ($CDCl_3$) δ 2.27 (3H, s), 3.20 (2H, br s), 3.77 (1H, dd, J = 5.3, 11.5 Hz), 3.84 (1H, dd, J = 6.2, 11.5 Hz), 4.04 (1H, dt, J = 2.4, 5.7 Hz), 4.81 (2H, m), 4.86 (1H, d, J = 2.3 Hz), 5.34 (1H, dq, J = 10.5, 1.2 Hz), 5.40 (1H, dq, J = 17.3, 1.5 Hz), 5.95 (1H, ddt, J = 17.3, 10.5, 5.5 Hz); ^{13}C-NMR ($CDCl_3$) δ 20.3 (q), 63.0 (t), 69.9 (d), 72.6 (t), 76.6 (d), 114.2 (s), 119.6 (t), 131.0 (d), 160.9 (s), 167.7 (s), 168.0 (s).

5,6-*O*-Isopropylidene-3-keto-2-(1-prop-2-enyl)-L-galactono-γ-lactone (6a, Major Isomer). This was isolated as a major product from the crude reaction mixture of rearranged **2a**: ^{1}H-NMR ($CDCl_3$) δ 1.35 (3H, s), 1.41 (3H, s), 2.66 (2H, d, J = 7.4 Hz), 4.08 (1H, dd, J = 6.9, 8.7 Hz), 4.19 (1H, dd, J = 6.9, 8.7 Hz), 4.54 (1H, dt, J = 2.0, 6.9 Hz), 4.66 (1H, d, J = 1.9 Hz), 5.26 (1H, dq, J = 16.8, 1.4 Hz), 5.28 (1H, dq, J = 10.4, 1.0 Hz), 5.69 (1H, ddt, J = 16.7, 10.4, 7.5 Hz); ^{13}C-NMR ($CDCl_3$) δ 25.3 (q), 25.5 (q), 39.8 (t), 64.8 (t), 72.0 (s), 74.5 (d), 81.5 (d), 111.3 (s), 122.9 (t), 127.6 (d), 172.6 (s), 205.5 (s). Anal. Calcd for $C_{12}H_{16}O_6$: C, 56.25; H, 6.29. Found: C, 56.44; H, 6.14.

5,6-*O*-Isopropylidene-3-keto-2-(2-but-3-enyl)-L-galactono-γ-lactone (6b, Major Isomer). This was isolated as a major product from the crude reaction mixture of rearranged **2b**: ^{1}H-NMR ($CDCl_3$) δ 1.18 (3H, d, J = 6.9 Hz), 1.34 (3H, s), 1.40 (3H, s), 2.70–2.80 (1H, m), 4.07 (1H, dd, J = 6.8, 8.7 Hz), 4.18 (1H, dd, J = 6.9, 8.7 Hz), 4.53 (1H, dt, J = 2.1, 6.8 Hz), 4.60 (1H, d, J = 2.2 Hz), 5.26 (1H, dt, J = 17.9, 0.9 Hz), 5.28 (1H, dt, J = 9.7, 0.9 Hz), 5.75 (1H, ddd, J = 17.8, 9.7, 8.2 Hz); ^{13}C-NMR ($CDCl_3$) δ 12.5 (q), 25.3 (q), 25.4 (q), 44.3 (d), 64.8 (t), 74.3 (s), 74.4 (d), 81.8 (d), 111.0 (s), 120.0 (t), 134.3 (d), 172.8(s), 205.7 (s).

5,6-*O*-Isopropylidene-3-keto-2-*O*-methyl-3-(1-prop-2-enyl)-L-galactono-γ-lactone (6c, Major Isomer). This was isolated as a major product from the crude reaction mixture of rearranged **4a**: mp 104.5–105.5 °C; ^{1}H-NMR ($CDCl_3$) δ 1.32 (3H, s), 1.38 (3H, s), 2.63 (2H, two ddt), 3.34 (3H, s), 4.06 (1H, dd, J = 7.0, 8.5 Hz), 4.17 (1H, dd, J = 7.0, 8.5 Hz), 4.54 (1H, d, J = 1.7 Hz), 4.65 (1H, dt, J = 1.7, 6.9 Hz), 5.20 (1H, dt, J = 18.2, 1.3 Hz), 5.25 (1H, dt, J = 10.1, 0.7 Hz), 5.73 (1H, dddd, J = 18.1, 10.2, 7.9, 7.0 Hz); ^{13}C-NMR ($CDCl_3$) δ 25.5 (q), 25.6 (q), 41.0 (t), 55.8 (q), 64.9 (t), 74.3 (d), 80.4 (s), 81.5 (d), 110.9 (s), 122.1 (t), 127.8 (d), 171.2 (s), 206.1 (s). Anal. Calcd for $C_{13}H_{18}O_6$: C, 57.77; H, 6.71. Found: C, 57.69; H, 6.55.

5,6-*O*-Isopropylidene-3-keto-2-*O*-(1-prop-2-enyl)-2-(1-prop-2-enyl)-L-galactono-γ-lactone (6d, Major Isomer). This was isolated as a major product from the crude reaction mixture of rearranged **4b**: ^{1}H-NMR ($CDCl_3$) δ 1.33 (3H, s), 1.39 (3H, s), 2.67 (2H, two ddt), 3.98 (2H, m), 4.06 (1H, dd, J = 6.9, 8.6 Hz), 4.17 (1H, dd, J = 6.9, 8.6 Hz), 4.54 (1H, d, J = 1.8 Hz), 4.64 (1H, dt, J = 1.8, 6.9 Hz), 5.19 (1H, dq, J = 10.5, 1.3 Hz), 5.20 (1H, dq, J = 16.9, 1.3 Hz), 5.25 (1H, dq, J = 10.7, 1.3 Hz), 5.30 (1H, dq, J = 17.2, 1.6 Hz), 5.74 (1H, dddd, J = 17.0, 10.1, 7.9, 6.9 Hz), 5.89 (1H, ddt, J = 17.2, 10.4, 5.7 Hz); ^{13}C-NMR ($CDCl_3$) δ 25.4 (q), 25.7 (q), 41.2 (t), 64.9 (t), 69.2 (t), 74.2 (d), 79.9 (s), 81.5 (d), 110.9 (s), 118.0 (t), 122.2 (t), 127.8 (d), 133.2 (d), 171.4 (s), 206.1 (s). Anal. Calcd for $C_{15}H_{20}O_6$: C, 60.80; H, 6.80. Found: C, 60.66; H, 6.70.

5,6-*O*-Isopropylidene-3-keto-2-*O*-methyl-3-(1-prop-2-enyl)-L-idono-γ-lactone (7c, Minor Isomer). This was isolated as a minor product from the crude reaction mixture of rearranged **4a**: ^{1}H-NMR ($CDCl_3$) δ 1.36 (3H, s)1.41 (3H, s), 2.73 (2H, m), 3.34 (3H, s), 4.08 (1H, dd, J = 7.1, 8.6 Hz), 4.19 (1H, dd, J = 6.8, 8.6 Hz), 4.50 (1H, dt, J = 1.9, 7.0 Hz), 4.61 (1H, d, J = 1.9 Hz), 5.15

(1H, dq, J = 17.1, 1.6 Hz), 5.21 (1H, dq, J = 10.2, 1.1 Hz), 5.88 (1H, ddt, J = 17.2, 10.1, 7.1 Hz); ^{13}C-NMR ($CDCl_3$) δ 25.5 (q), 25.7 (q), 30.1 (t), 54.4 (q), 65.2 (t), 73.8 (d), 78.9 (s), 82.2 (d), 111.0 (s), 120.4 (t), 128.9 (d), 170.7 (s), 205.2 (s).

5,6-*O*-Isopropylidene-2-keto-3-*O*-(1-prop-2-enyl)-3-(1-prop-2-enyl)-L-galactono-γ-lactone (8b). This was isolated as a third product (less favored 2 to 3 migration product of **4b**, only 2%) from the crude reaction mixture of rearranged **4b**: ^{1}H-NMR ($CDCl_3$) δ 1.32 (6H, s), 2.52 (1H, dd, J = 14.8, 8.3 Hz), 2.65(1H, ddt, J = 14.9, 5.7, 1.4 Hz), 3.99 (1H, dd, J = 7.2, 8.3 Hz), 4.14 (1H, dd, J = 7.1, 8.3 Hz), 4.40 (1H, ddt, J = 12.5, 5.3, 1.5 Hz), 4.53 (1H, dt, J = 1.2, 7.1 Hz), 4.60 (1H, d, J = 1.2 Hz), 4.66 (1H, ddt, J = 12.5, 4.9, 1.7 Hz), 5.19 (1H, dq, J = 10.5, 1.5 Hz), 5.20 (1H, dq, J = 17.1, 1.2 Hz), 5.31 (1H, dq, J = 10.7, 1.2 Hz), 5.32 (1H, dq, J = 17.3, 1.7 Hz), 5.78 (1H, dddd, J = 17.0, 10.2, 8.4, 5.7 Hz), 5.91 (1H, ddt, J = 17.2, 10.4, 5.2 Hz); ^{13}C-NMR ($CDCl_3$) δ 24.8 (q), 25.2 (q), 36.3 (t), 65.0 (t), 65.9 (t), 72.6 (d), 79.4 (s), 79.5 (d), 111.2 (s), 116.6 (t), 121.8 (t), 129.2 (d), 133.8 (d), 159.8 (s), 191.9 (s).

5,6-*O*-Isopropylidene-2-keto-3-*O*-methyl-3-(1-prop-2-enyl)-L-galactono-γ-lactone (8c, Major Isomer). This was isolated as a major product from the crude reaction mixture of rearranged **4c**: ^{1}H-NMR ($CDCl_3$) δ 1.33 (6H, s), 2.51 (1H, dd, J = 15.0, 8.3 Hz), 2.66 (1H, ddt, J = 14.9, 5.6,1.4 Hz), 3.70 (3H, s), 3.99 (1H, dd, J = 6.8, 8.4 Hz), 4.14 (1H, dd, J = 7.2, 8.4 Hz), 4.49 (1H, dt, J = 1.3, 7.0 Hz), 4.58 (1H, d, J = 1.3 Hz), 5.26 (1H, dq, J = 17.1, 1.2 Hz), 5.31 (1H, dq, J = 10.5, 1.2 Hz), 5.75 (1H, dddd, J = 17.0, 10.3, 8.3, 5.6 Hz); ^{13}C-NMR ($CDCl_3$) δ 24.7 (q), 25.2 (q), 34.9 (t), 52.8 (q), 65.0 (t), 72.5 (d), 79.3 (s), 79.5 (d), 111.3 (s), 121.7 (t), 129.1 (d), 159.9 (s), 192.2 (s). Anal. Calcd for $C_{13}H_{18}O_6$: C, 57.77; H, 6.71. Found: C, 57.54; H, 6.80.

5,6-*O*-Isopropylidene-2-keto-3-*O*-methyl-3-(2-but-3-enyl)-L-galactono-γ-lactone (8d, Major Isomer). This was isolated as a major product from the crude reaction mixture of rearranged **4d**: mp 127–128 °C; ^{1}H-NMR ($CDCl_3$) δ 1.10 (3H, d, J = 6.8 Hz), 1.33 (6H, s), 2.70 (1H, dq, J = 9.0, 6.8 Hz), 3.73 (3H, s), 3.98 (1H, dd, J = 7.3, 8.3 Hz), 4.14 (1H, dd, J = 7.1, 8.3 Hz), 4.45 (1H, dt, J = 1.3, 7.2 Hz), 4.63 (1H, d, J = 1.3 Hz), 5.14 (1H, dt, J = 17.0, 1.3 Hz), 5.17 (1H, dt, J = 10.3, 1.3 Hz), 5.69 (1H, ddd, J = 17.0, 10.2, 9.1 Hz); ^{13}C-NMR ($CDCl_3$) δ 13.6 (q), 24.9 (q), 25.4 (q), 42.3 (d), 54.6 (q), 65.2 (t), 72.9 (d), 78.5 (d), 81.1 (s), 111.2 (s), 119.3 (t), 135.9 (d), 159.8 (s), 192.6 (s). Anal. Calcd for $C_{14}H_{20}O_6$: C, 59.12; H, 7.09. Found: C, 58.98; H, 7.17.

5,6-*O*-Isopropylidene-2-keto-3-*O*-acetyl-3-(1-prop-2-enyl)-L-galactono-γ-lactone (8f, Major Isomer). This was isolated as a major product from the crude reaction mixture of rearranged **4f**: ^{1}H-NMR ($CDCl_3$) δ 1.37 (3H, s), 1.42 (3H, s), 2.16 (3H, s), 2.80 (2H, m), 4.10 (1H, dd, J = 7.3, 8.5 Hz), 4.20 (1H, dd, J = 6.9, 8.5 Hz), 4.53 (1H, dt, J = 1.6, 7.1 Hz), 4.87 (1H, d, J = 1.7 Hz), 5.19 (1H, dq, J = 17.0, 1.5 Hz), 5.26 (1H, dq, J = 10.2, 1.5 Hz), 5.90 (1H, ddt, J = 17.2, 10.1, 7.0 Hz); ^{13}C-NMR ($CDCl_3$) δ 19.2 (q), 25.5 (q), 25.8 (q), 34.5 (t), 65.2 (t), 73.7 (d), 73.8 (s), 82.1 (d), 110.8 (s), 120.8 (t), 128.3 (d), 169.7 (s), 170.9 (s), 201.0 (s). Anal. Calcd for $C_{14}H_{18}O_7$: C, 56.37; H, 6.08. Found: C, 56.30; H, 6.02.

5,6-*O*-Isopropylidene-2-keto-3-*O*-acetyl-3-(2-but-2-enyl)-L-galactono-γ-lactone (8g, Major Isomer). This was isolated as a major product from the crude reaction mixture of rearranged **4g**: ^{1}H-NMR ($CDCl_3$) δ 1.22 (3H, d, J = 6.8 Hz), 1.38 (3H, s), 1.48 (3H, s), 2.16 (3H, s), 2.90 (1H, dq, J = 7.8, 6.8 Hz), 4.08–4.18 (2H, m), 4.46–4.55 (2H, m), 5.28 (1H, dt, J = 17.0, 1.1 Hz), 5.31 (1H, dt, J = 10.4, 1.0 Hz), 5.71 (1H, ddd, J = 17.0, 10.4, 7.8 Hz); ^{13}C-NMR ($CDCl_3$) δ 12.3 (q), 19.2 (q), 25.3 (q), 26.7 (q), 41.4 (d), 65.2 (t), 75.1 (d), 77.3 (s), 84.8 (d), 110.0 (s), 120.6 (t), 132.9 (d), 169.3 (s), 170.3 (s), 200.9 (s).

5,6-*O*-Isopropylidene-2-keto-3-*O*-acetyl-3-(1-phenyl-1-prop-2-enyl)-L-galactono-γ-lactone (8h, Major Isomer). This was isolated as a major product from the crude reaction mixture of rearranged **4h**: ^{1}H-NMR ($CDCl_3$) δ 1.27 (3H, s), 1.45 (3H, s), 2.13 (3H, s), 2.97 (1H, dt, J = 6.1, 6.7 Hz), 3.82 (1H, dd, J = 6.6, 8.8 Hz), 3.97 (1H, dd, J = 7.2, 8.8 Hz), 4.05 (1H, d, J = 8.7 Hz), 4.75 (1H, d, J = 5.8 Hz), 5.17 (1H, dt, J = 17.0, 1.1 Hz), 5.30 (1H, dt, J = 10.3, 1.1 Hz), 6.43 (1H, ddd, J = 17.0, 10.2, 8.6 Hz), 7.21–7.27 (2H, m), 7.32–7.40 (3H, m); ^{13}C-NMR ($CDCl_3$) δ 19.3 (q), 25.4 (q), 26.4 (q), 51.3 (d), 64.9 (t), 72.7 (d), 76.0 (s), 83.9 (d), 110.2 (s), 119.9 (t), 128.5 (d), 129.0 (d), 129.3 (d), 129.8 (d), 132.5 (d), 134.9 (s), 169.3(s), 170.6 (s), 201.5 (s).

5,6-*O*-Isopropylidene-2-keto-3-(1-prop-2-enyl)-L-galactono-γ-lactone (8i, Major Isomer). This was isolated as a major product from the crude reaction mixture of rearranged **4i**: ^{1}H-NMR ($CDCl_3$) δ 1.34 (3H, s), 1.35 (3H, s), 2.57 (1H, dd, J = 14.8, 8.5 Hz), 2.75 (1H, ddt, J = 14.8, 5.5, 1.4 Hz), 4.00 (1H, dd, J = 7.3, 8.3 Hz), 4.11 (1H, dd, J = 7.1, 8.3 Hz), 4.55 (1H, dt, J = 1.2, 7.2 Hz), 4.63 (1H, d, J = 1.2 Hz), 4.90 (1H, d, J = 10.9 Hz), 5.25 (1H, dm, J = 10.5 Hz), 5.30 (1H, d, J = 10.8 Hz), 5.31 (1H, d, J = 18.6 Hz), 5.82 (1H, dddd, J = 18.8, 10.3, 8.5, 5.5 Hz), 7.30 (5H, br s); ^{13}C-NMR ($CDCl_3$) δ 24.9 (q), 25.4 (q), 36.3 (t), 64.9 (t), 67.1 (t), 72.7 (d), 79.3 (s), 79,4 (d), 111.2 (s), 121.9 (t), 127.5 (d), 127.9 (d), 128.4 (d), 129.2 (s), 137.5 (d), 159.8 (s), 192.2 (s).

5,6-*O*-Isopropylidene-2-keto-3-*O*-methyl-3-(1-prop-2-enyl)-L-idono-γ-lactone (9c, Minor Isomer). This was isolated as a minor product from the crude reaction mixture of rearranged **4c**: ^{1}H-NMR ($CDCl_3$) δ 1.29 (3H, s), 1.31 (3H, s), 2.46 (1H, ddt, J = 17.0, 8.2, 1.1 Hz), 3.00 (1H, ddt, J = 17.0, 5.2,2.0 Hz), 3.19 (3H, s), 4.04 (1H, dd, J = 6.9, 8.4 Hz), 4.12 (1H, dd, J = 6.9, 8.4 Hz), 4.41 (1H, dt, J = 0.9, 6.9 Hz), 4.61 (1H, d, J = 0.9 Hz), 5.30 (1H, dq, J = 10.3, 1.0 Hz), 5.33 (1H, dq, J = 17.3, 2.0 Hz), 5.83 (1H, dddd, J = 17.3 10.4, 8.2, 5.2 Hz); ^{13}C-NMR ($CDCl_3$) δ 24.8 (q), 25.2 (q), 27.6 (t), 51.2 (q), 64.9 (t), 72.7 (d), 77.2 (s), 82.6 (d), 111.4 (s), 120.3 (t), 129.5 (d), 160.0 (s), 186.0 (s).

5,6-*O*-Isopropylidene-2-keto-3-*O*-methyl-3-(2-but-3-enyl)-L-idono-γ-lactone (9d, Minor Isomer). This was isolated as a minor product from the crude reaction mixture of rearranged **4d**: ^{1}H-NMR ($CDCl_3$) δ 1.11 (3H, d, J = 6.9 Hz), 1.33 (6H, s), 2.89 (1H, pentet, J = 1.2, 6.9 Hz), 3.70 (3H, s), 3.98 (1H, dd, J = 7.2, 8.3 Hz), 4.14 (1H, dd, J = 7.1, 8.3 Hz), 4.47 (1H, dt, J = 1.4, 7.1 Hz), 4.58 (1H, d, J = 1.4 Hz), 5.17 (1H, dt, J = 17.3, 1.3 Hz), 5.24 (1H, dt, J = 10.5, 1.1 Hz), 5.81 (1H, ddd, J = 17.3, 10.5, 6,9 Hz); ^{13}C-NMR ($CDCl_3$) δ 13.2 (q), 24.9 (q), 25.4 (q), 41.7 (d), 53.9 (q), 65.2 (t), 73.0 (d), 79.2 (d), 80.9 (s), 111.1 (s), 118.3 (t), 135.6 (d), 159.8 (s), 193.1 (s).

5,6-*O*-Isopropylidene-2-keto-3-*O*-acetyl-3-(1-prop-2-enyl)-L-idono-γ-lactone (9f, Minor Isomer). This was isolated as a minor product from the crude reaction mixture of rearranged **4f**: ^{1}H-NMR ($CDCl_3$) δ 1.38 (3H, s), 1.48 (3H, s), 2.16 (3H, s), 2.68 (1H, dd, J = 13.6, 8.0 Hz), 2.76 (1H, ddq, J = 13.6, 6.9, 1.1 Hz), 4.10 (1H, dd, J = 7.3, 8.5 Hz), 4.20 (1H, dd, J = 6.9, 8.5 Hz), 4.53 (1H, dt, J = 1.6, 7.1 Hz), 4.56 (1H, d, J = 1.7 Hz), 5.29 (1H, dq, J = 17.0, 1.3 Hz), 5.33 (1H, dq, J = 10.4, 1.1 Hz), 5.72 (1H, dddd, J = 17.0, 10.2, 7.9, 6.9 Hz); ^{13}C-NMR ($CDCl_3$) δ 19.2 (q), 25.3 (q), 26.7 (q), 37.1 (t), 65.1 (t), 73.8 (s), 75.1 (d), 84.7 (d), 110.1 (s), 123.3 (t), 126.4 (d), 169.2(s), 170.3 (s), 201.3 (s).

5,6-*O*-Isopropylidene-2-keto-3-*O*-acetyl-3-(1-phenyl-1-prop-2-enyl)-L-galactono-γ-lactone (9h, Second Major Isomer). This was isolated as the second major product from the crude reaction mixture of rearranged **4h**: ^{1}H-NMR ($CDCl_3$) δ 1.29 (6H, s), 2.15 (3H, s), 3.15 (1H, d, J = 8.3 Hz), 3.88 (1H, d, J = 8.4 Hz), 3.91 (1H, dd, J = 5.9, 9.2 Hz), 3.99 (1H, dd, J = 6.4, 9.2 Hz), 4.37 (1H, dt, J = 8.3, 6.2 Hz), 5.28 (1H, dt, J = 16.9, 1.2 Hz), 5.36 (1H, dt, J = 10.3, 1.0 Hz), 6.42 (1H, ddd, J = 17.0, 10.3, 8.4 Hz), 7.17–7.22 (2H, m), 7.32–7.40 (3H, m); ^{13}C-NMR ($CDCl_3$) δ 19.2 (q), 25.2 (q), 26.5 (q), 53.5 (d), 65.0 (t), 74.7 (d), 77.1 (s), 84.6 (d), 109.7 (s), 120.5 (t), 128.7 (d), 129.0 (d), 129.3 (d), 132.0 (d), 133.4 (s), 168.3(s), 170.3 (s), 202.1 (s).

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Supplementary Material Available: Copies of ^{1}H and ^{13}C NMR spectra of many compounds (36 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.