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Tin-Mediated Regioselective Benzylation and Allylation of Polyols: Applicability of a Catalytic Approach Under Solvent-Free Conditions

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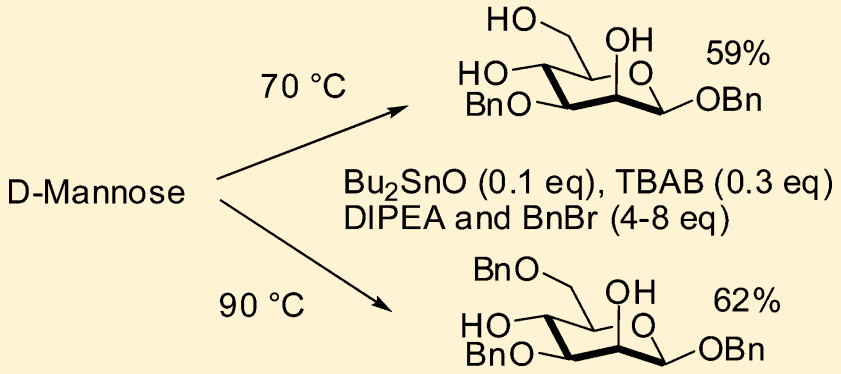
Supporting Information



ABSTRACT: The first catalytic version of the stannylene-mediated benzylation and allylation of polyols is reported. The methodology is based on a simple solvent-free protocol that significantly advances, in terms of both experimental ease and synthetic scope, the applicability of tin-promoted selective protections. The described approach is indeed endowed with a very large number of advantages over routine protocols: use of a low catalytic loading of cheap Bu_2SnO, a single-step process with avoided use of solvents, a minimally demanding experimental procedure with reactions performed under air, reduced reaction times, a much simpler work up, a wide target scope, and yields that, in many cases, compare favorably to routine protocols. In addition, the catalytic solvent-free approach extends the scope of stannylene chemistry to unprecedented applications to reducing sugars and in the synthesis of highly benzylated building blocks otherwise accessed through much more demanding procedures. From a conceptual point of view, the described results indicate that solvent-free conditions can assist the development of catalytic approaches otherwise ineffective in solution.

INTRODUCTION

Carbohydrates are widely available molecules in nature and are thereby frequently used as convenient precursors of multifunctionalized chiral targets. Owing to their multifunctional nature, lengthy procedures are often needed for setting the suitable profile of protecting groups in saccharide residues, and this task can even take most of the experimental work in a synthetic project. The enormous relevance of carbohydrates in several fields of organic chemistry and other scientific areas is thus still spurring the development of ever more efficient protocols for the rapid discrimination of the numerous reactive sites. In this frame, effective sequential procedures have recently been proposed to streamline the access to partially protected sugars either in a few rapid steps or via one-pot protocols;[1,2] however, the need for experimentally demanding conditions is a frequent issue for the most straightforward one-pot protocols, as reactions are often performed under an inert atmosphere and in the presence of highly sensitive acidic reagents. In addition, preactivation of substrates through a per-O-silylation preliminary step is necessary in most examples.

The benzyl group is, along with acetyl, the most popular protecting group for carbohydrates and polyols; consequently, the selective partial benzylation of polyols can represent a key step for accessing valuable saccharide building blocks. Regioselective O-benzylation approaches are mainly based on transient metal chelates where the nucleophilic reactivity of the committed carbinol sites is largely discriminated. In this regard, use of stannylene acetals has been by far the most adopted strategy in recent decades,[3] and the current impact of such a methodology is demonstrated by the large number of applications and mechanistic studies still reported in the recent literature.[4] Despite this popularity, stannylene-mediated regioselective alkylations suffer from numerous practical issues such as (a) the employment of toxic tin reagents in stoichiometric or excess amounts; (b) a laborious multistep sequence entailing the preliminary generation of the tin acetal, the removal of the initial solvent (in most cases), and the execution of the subsequent alkylation step; alternatively, an appropriate apparatus for the removal of the water is necessary in the preliminary acetalization step to avoid the change of solvent; and (c) the requirement, in the final alkylation steps, of

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high-boiling solvents (mainly toluene or DMF), high temperatures, prolonged reaction times, and a laborious workup.

More recently, a very interesting alternative for regioselective alkylation of polyols was developed through the employment of catalytic borinic acids in combination with stoichiometric Ag_2O.[5] This strategy was especially effective in discriminating the reactivity of secondary carbinols within the same molecules, but complex mixtures were instead found in the presence of both primary and secondary carbinols. In addition, the reactions required especially prolonged times (48 h).

In this article, we report a new approach to regioselective alkyl protections of carbohydrates that is endowed with multiple practical advantages such as the unprecedented use of catalytic amounts of tin reagents, the application of a single-step protocol with avoided use of solvents, a minimally demanding experimental procedure with reactions performed under air, reduced reaction times, and a wide target scope. The procedure was inspired by the recent development of a practical protocol for the regioselective benzylation of polyols at the primary position,[6] which is based on the use of a moderate excess of diisopropylethyl amine (DIPEA) and benzyl bromide (both added portionwise) and a substoichiometric amount (0.3 equiv) of tetrabutylammonium iodide (TBAI) at 90 °C.[7] Remarkably, these reactions were conducted under air and in the absence of any solvent. To expand the scope of these solvent-free protections, we focused on the regioselective protection of secondary carbinols. Dibutyltin oxide is the most used reagent for the generation of stannylene acetals owing to its cheapness and ease of handling, but its catalytic applications are restricted to a few examples of regioselective protections conducted with especially reactive acylating or sulfonylating agents[8] in the presence of polar solvents.[9]

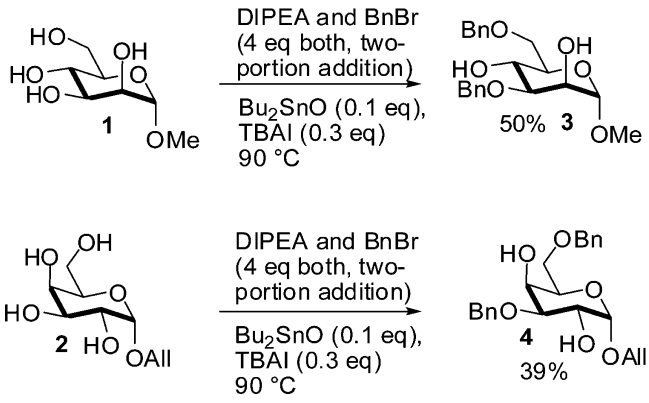
To the best of our knowledge, only a single example of tin-mediated catalytic benzylation of polyols has been reported to date. That procedure was applied to the benzylation of two primary carbinol sites of a partially protected alditol and required the preliminary generation of the catalyst, $Bu_2Sn(OMe)_2$, and a prolonged reaction at a high temperature.[4d] In this article, we show the wide scope of a catalytic procedure based on commercial Bu_2SnO.

RESULTS AND DISCUSSION

In our initial trials, the previously optimized protocol for the regioselective protection of primary carbinols[6] was re-examined in the presence of a low catalytic loading of Bu_2SnO (0.1 equiv). Upon exposure of manno- and galacto-glycosides **1** and **2** under such conditions, the expected protection of the corresponding primary sites was indeed accompanied by the regioselective O-3 protection of both precursors in promising yields (Scheme 1).

These results are fully consistent with the hypothesized preferential generation in situ of stannylene acetals from vicinal-cis diols and also highlight that no preliminary generation of the saccharide-derived stannylene is necessary for the benzylations to occur regioselectively; additionally, the appreciable yields of di-O-benzylated products **3** and **4** indicate that solvent-free conditions allow for a fast scrambling of the dibutyltin group between the polyol molecules, which is decisive for securing the catalytic efficiency of the approach. Other preliminary experiments at 90 °C evidenced that other liquid bases, such as TEA, lutidine, *N*-ethyl morpholine, and collidine, were much less effective than DIPEA. In addition, TBAB and TBAI additives

Scheme 1. Preliminary Experiments of Solvent-Free Tin-Catalyzed Regioselective Benzylations



were found to perform similarly, so TBAB was selected for the following studies.

To assess the nucleophilic reactivity of the dibutylstannylene acetals under conditions in which primary carbinols are slowly benzylated, several experiments were conducted at a temperature lower than 90 °C, and we were pleased to find that even at 70 °C the stannylene-mediated reactions were fast enough to ensure the selective mono-O-benzylation of a very large set of glycosides and polyols bearing 2−4 free hydroxyls (Table 1) and even the selective functionalization of more polar substrates (Table 2). As shown in Table 1, a moderate excess of DIPEA and BnBr (2 equiv of each) was sufficient for achieving high-yielding protections of diols and triols within a few hours (entries 1−9), whereas a slightly higher excess of both reagents (2.5 equiv of DIPEA and 4 equiv of benzyl bromide) was found to be optimal with the more polar tetrol substrates (entries 10−12). Remarkably, the temperature of these reactions (70 °C) was sensibly lower than that typically reported for the benzylation of preformed stannylene acetals in high-boiling solvents.[3,4] Furthermore, the reactions were also much shorter.

The regioselectivity trend recorded with this straightforward catalytic and solvent-free procedure was again consistent with that of conventional multistep protocols; owing to the favorite generation of transient five-membered stannylene acetals, benzylation occurred preferentially either at equatorial carbinol sites with an adjacent syn-hydroxyl groups (entries 3−7 and 10−12) or at primary carbinols incorporated into terminal 1,2 diol motifs (entries 1 and 9). Moreover, the expected mono-O-benzylation was observed in an excellent yield with D-tartrate diester **7** (entry 2), bearing two contiguous secondary carbinols. The critical role of solvent-free conditions for achieving successful protections was confirmed by the poor conversions observed when mannoside **1** was submitted under the same conditions as in entry 10 but in the presence of toluene (1 mL/mmol substrate).

With substrates devoid of a 1,2-cis diol moiety, such as methyl xyloside **19** (entry 8) and methyl glucoside **26** (entry 13), reactions proved relatively slower and poorly selective, with the generation of complex mixtures of monoprotected regioisomers in both cases. These represented the only found cases where the traditional stepwise and stoichiometric approach performs better.[4a,10] The methodology herein presented proved to be ineffective with thioglycosides, probably because of degradation processes triggered by the S-benzylation of substrates, a possible competition process suggested by the

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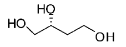
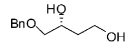
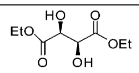
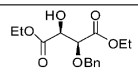
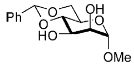
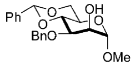
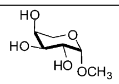
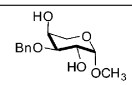
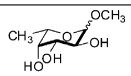
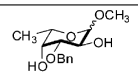
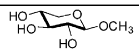
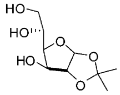
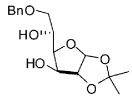
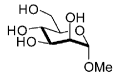
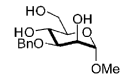
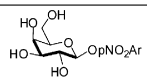
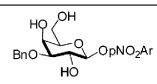
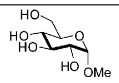
Table 1. Solvent-Free Mono-O-Benzylation of Polyols Catalyzed by Bu_2SnO[a]

Entry	Substrate	Time (h)	Product, yield
1	 **5**	3	 **6**, 70%
2	 **7**	1	 **8**, 93%
3	 **9**	5	 **10**, 84%
4	 **11**	3.5	 **12**, 87%[b]
5	 **13**	2.5	 **14**, 64%
6	 **15**	4.5	 **16**, 72%
7	 **17**	6	 **18**, 51%
8	 **19**	13	Complex mixture[c]
9	 **20**	5	 **21**, 75%
10	 **1**	4.5	 **22**, 64%
11	 **2**	3	 **23**, 68%
12	 **24**	2.5	 **25**, 67%[d]
13	 **26**	10	Complex mixture[e]

[a]General conditions: Bu_2SnO (0.1 equiv), TBAB (0.3 equiv), 70 °C, under air; for entries 1–9: DIPEA (2 equiv), BnBr (2 equiv); for entries 10–13: DIPEA (2.5 equiv), BnBr (4 equiv). [b]The product contained ca. 10% of the 3-*O*-Bn regioisomer. [c]An approximately equimolar mixture of 2-*O*-Bn, 3-*O*-Bn, and 4-*O*-Bn regioisomers (overall yield ca. 50%) was formed. [d]The product was characterized in the per-O-acetylated form. [e]An approximately equimolar mixture of 2-*O*-Bn, 3-*O*-Bn, and 6-*O*-Bn regioisomers (overall yield ca. 50%) was formed.

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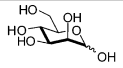
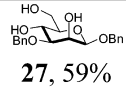
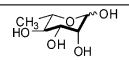
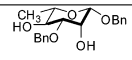
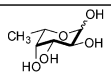
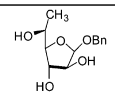
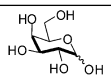
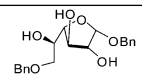
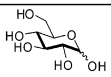
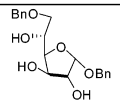
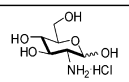
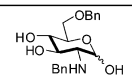
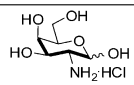
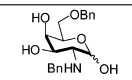
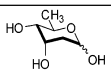
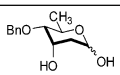
Table 2. Solvent-Free Regioselective Benzylation of Reducing Sugars[b]

Entry	Substrate	Time (h)	Product, yield
1	 D-mannose	3	 **27**, 59%
2	 L-rhamnose	4	 **28**, 70%
3	 L-fucose	2	 **29**, 68%
4	 D-galactose	5	 **30**, 36%
5	 D-glucose	5	 **31**, 53%[b]
6	 D-glucosamine hydrochloride	6	 **32**, 30%
7	 D-galactosamine hydrochloride	3	 **33**, 47%[c]
8	 D-digitoxose	7.5	 **34**, 81%

[a]General conditions: Bu_2SnO (0.1 equiv), TBAB (0.3 equiv), 70 °C, under air; for entries 1−3: DIPEA (2.5 equiv), BnBr (4 equiv); for entries 4−6: DIPEA (4 equiv), BnBr (4 equiv); for entry 7: DIPEA (3.5 equiv), BnBr (4 equiv); for entry 8: DIPEA (2 equiv), BnBr (2 equiv). [b]The product contained ca. 20% of 2,6-di-O-benzylated glucopyranose. [c]The product was also composed of minor amounts of the corresponding furanose isomers.

literature.[11] However, in addition to the very large number of practical advantages observed, it should be noted that the reaction yields of the proposed procedure are often similar to or even compare favorably with those previously reported. For example, the longer conventional approach based on stoichiometric stannylene precursors afforded 3-O-benzylated mannoside **22** (entry 10) and galactoside **23** (entry 11) in 57−73[12] and 53%[13] yields, respectively.[14] The catalytic and solvent-free method also offered unprecedented synthetic opportunities, the first of which was the selective mono 3-O-benzylation of D-galactal **13** (Table 1, entry 5) otherwise not possible with alternative procedures, preferentially leading to the corresponding 3,6-di-O-benzylated derivative.[5a,15]

An unprecedented extension in the scope of this chemistry was recorded with the application to reducing sugars (Table 2), a class of especially challenging substrates because of the presence of multiple equilibrating forms. A first set of experiments evidenced a different behavior between manno- and non-manno-configured derivatives. In particular, D-mannose and L-rhamnose were smoothly converted into the corresponding β-1,3-di-O-benzylated pyranoside products in high yields and short times (Table 2, entries 1 and 2). The β-configuration of these products points to the feasible generation of stannylene intermediates engaging the β-O-1 and O-2 sites, with the equatorial one ending up benzylated.[12c,16] The high rate at 70 °C of the double benzylation may be ascribed to the facile regeneration of the 1,2-stannylene (or the 2,3-stannylene) once the first benzylation event occurs at O-3 (or O-1), as both events lead to a 2-O-bromostannylated intermediate prone to recyclization with an adjacent syn-hydroxyl.[17] As to gluco- and galacto-configured precursors (Table 2, entries 3−5), the reaction mainly provided the corresponding 1,6-di-O-benzylated α-furanosides (only anomeric benzylation occurred in the case of 6-deoxy sugar fucose, entry 3). These results evidence the feasible generation of transient furanose 1,2- and 5,6-*O*-stannylene acetals from glucose and galactose; in this regard, it is worth pointing out the preference for both fucose and galactose to close in a furanoside form despite the presence of a

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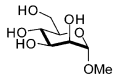
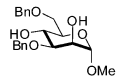
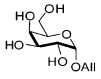
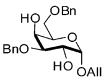
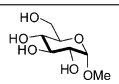
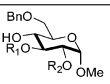
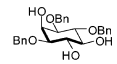
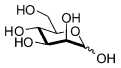
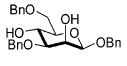
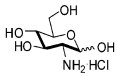
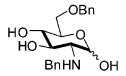
Table 3. Regioselective Poly-O-Benzylation of Polyols[a]

Entry	Substrate	Condition,[a] overall time (h)	Product, yield
1	 **1**	A, 10	 **3**, 67%
2	**1**	B, 7	**3**, 62%
3	 **2**	A, 9.5	 **4**, 57%
4	**2**	B, 6	**4**, 47%
5	 **26**	B, 6.5	 **35** R_1: H, R_2: Bn; 56% **36** R_1: Bn, R_2: H; 14%
6	 **13**	C, 9	 **37**, 64%
7	 (+/-)-myo-inositol	C, 9	 (+/-)-**38**, 40%
8	 D-mannose	A, 9	 **39**, 62%
9	 D-glucosamine hydrochloride	C, 4	 **32**, 44%

[a]General conditions: Bu_2SnO (0.1 equiv). Conditions A: TBAB (0.3 equiv), DIPEA (2.5 equiv) and BnBr (4 equiv) at 70 °C, after 4 h, addition of DIPEA (1.5 equiv) and heating at 90 °C, after a further 2 h, addition of DIPEA and BnBr (2 equiv of each). Conditions B: TBAB (0.3 equiv) (only for entry 5), DIPEA and BnBr (4 equiv of each) at 85 °C, after 3 h, addition of DIPEA and BnBr (2 equiv of each), after a further 1 h, heating at 95 °C. Conditions C: 90 °C, TBAB (0.3 equiv). For entry 6: DIPEA and BnBr (4 equiv of each), after 2.5 h, addition of DIPEA and BnBr (2 equiv of each). For entry 7: DIPEA and BnBr (6 equiv of each), after 2.5 h, addition of DIPEA and BnBr (2 equiv of each). For entry 9: DIPEA (5 equiv) and BnBr (4 equiv) and no further addition.

cis 3,4-diol in the pyranose form potentially capable of forming a reactive dibutylstannylene acetal. Another peculiar behavior was exhibited by unprotected amino sugars (enries 6 and 7); regardless of the gluco or galacto configuration, the reaction mainly afforded a product benzylated both at O-6 and N-2. The result from galactosamine (entry 7) was somehow surprising owing to the potentiality of the substrate to generate a 3,4-*O*-stannylene acetal from the pyranose form, which would be preferentially benzylated at O-3 rather than at O-6 (Table 1). An especially high yield was observed from the 2,6-dideoxy sugar digitoxose (entry 8), which, expectedly, did not give furanose derivatives owing to the structural impossibility to generate either 1,2- or 5,6-stannylene acetals.

As suggested by preliminary experiments in Scheme 1, the solvent-free and catalytic methodology was also useful at higher temperatures (about 90 °C) for the regioselective di-*O*-benzylation of glycosides by taking advantage of both the activating ability of the dibutyl tin acetals and the inherent reactivity of primary carbinols. An extended screening of conditions on manno and galacto substrates **1** and **2** (Table 3, entries 1−4) evidenced that procedures entailing both the portionwise addition of reagents and a gradual raising of the temperature led to more satisfying yields. As shown in Table 3, entries 1−4, when reactions were conducted in the 70−90 °C temperature range (conditions A), slightly higher yields were achieved. However, on starting from a higher temperature (85 °C, conditions B), reactions took shorter times and could even be performed in the absence of TBAB without detrimental effects on the overall rate. This latter result might be rationalized by considering that bromide anions needed for the opening of stannylene intermediates (with consequent generation of the reactive nucleophilic alkoxy sites)[4a,b,d] can be

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Scheme 2. Solvent-Free Tin-Catalyzed Synthesis of Highly O-Benzylated Building Blocks

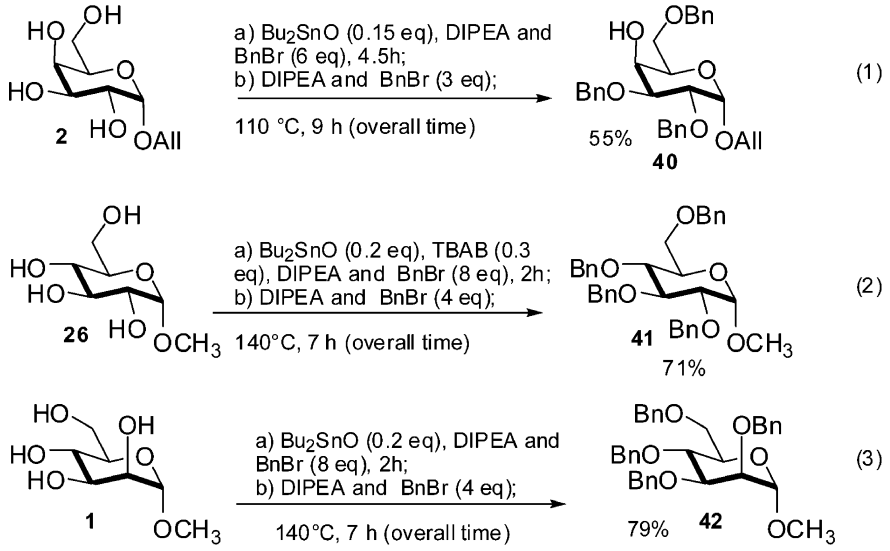
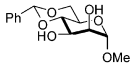
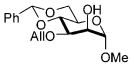
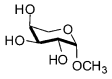
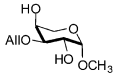
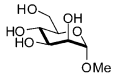
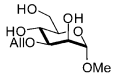
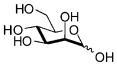
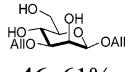


Table 4. Solvent-Free Regioselective Allylation Catalyzed by Bu_2SnO[a]

Entry	Substrate	Time (h)	Product, yield
1	 **9**	5	 **43**, 90%
2	 **15**	1.5	 **44**, 78%
3	 **1**	3.5	 **45**, 65%
4	 D-mannose	2.5	 **46**, 61%

[a]General conditions: Bu_2SnO (0.1 equiv), TBAB (0.3 equiv), 90 °C. For entries 1−2: DIPEA (2.5 equiv), AllBr (8 equiv). For entries 3−4: DIPEA (4 equiv), AllBr (8 equiv).

initially generated at higher temperatures by the tin-uncatalyzed benzylation of the primary sites.[6] As to gluco-pyranoside **26** (Table 3, entry 5), the same effect was not observed, and in this case, substoichiometric TBAB significantly accelerated the reaction (see also reaction 2 in Scheme 2).[18]

Besides glycoside (entries 1−5), glycal (entry 6), and polyol (entry 7) substrates, unprecedented applications of the solvent-free multi-O-benzylation protocol were again found starting from reducing sugars. Remarkably, tri-O-benzylated *β*-mannoside **39** (entry 8) was prepared in an excellent yield from D-mannose in a single operation. It is also worth noting that exposure of glucosamine hydrochloride under similar conditions gave dibenzylated product **32** in a higher yield than at 70 °C (compare entry 9 of Table 3 with entry 6 of Table 2).

The synthetic applications of tin acetals reported in the literature are restricted, with a few exceptions,[17] to the selective installation of 1 to 2 benzyl groups. Examples reported in Tables 1−3 indicate that temperature plays a prominent role for tuning the extent of benzylation of polyols under catalytic solvent-free conditions, whereas the stoichiometric amount of Bu_2SnO is mainly important in the case of conventional multistep approaches.[4a] As an ancillary result of this investigation, we have realized that a moderate increase of the catalyst loading and a higher temperature can occasionally be useful for achieving the straightforward synthesis of valuable building blocks with a high benzyl content or even the per-O-benzylation of glycosides. As shown in Scheme 2, application of the solvent-free protocol with 0.15 equiv at 110 °C (in the absence of TBAB) made possible the simple generation in a good yield of tri-O-benzylated galactoside **40** from **2**.[19] Furthermore, use of 0.2 equiv of dibutyltin oxide at 140 °C allowed per-O-benzylated products **41** and **42** to be obtained in good yields, as shown in reactions 2 and 3. Interestingly, when mannoside **1** (Scheme 2, reaction 3) was submitted under similar conditions but in the absence of the tin reagent,[7] neither the corresponding per-O-benzylated product **42** nor highly O-

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benzylated intermediates could be detected from the reaction mixture. An analogous unproductive outcome was observed when glucoside **26** was exposed under the same conditions as reaction 2 but in the absence of TBAB.

It should be noted that this simple protocol may be a valuable alternative to the standard per-O-benzylation procedure entailing the use of both the high-boiling and toxic DMF solvent and NaH as a strong and sensitive base.

Besides regioselective benzylations, the tin-catalyzed and solvent-free protocol proved to be also effective for the regioselective installation of the allyl group, an especially useful synthetic opportunity in view of the orthogonal nature of this group with respect to the benzyl group. In comparison to O-benzylations, allyl protections required a higher temperature (90 °C) to occur within a few hours (Table 4). Furthermore, a higher excess of allyl bromide was needed owing to its relatively low boiling point. In all of the examined examples, with a set of substrates of variable polarity, regioselectivity favored again the protection of equatorial secondary sites flanked by axially oriented hydroxyl groups, also in the presence of primary carbinols (entries 3 and 4).

■ CONCLUSIONS

We have developed the first wide scope tin-catalyzed approach for regioselective benzylation or allylation of sugars or polyols, which is endowed with a very wide set of advantages over the frequently applied traditional methodologies. Among these advantages are a low catalytic loading of tin reagent, reactions performed in a single step (without preliminary generation of stannylene intermediates) and in the absence of any solvent, and a minimally demanding experimental procedure. Besides being much less laborious, the described protocols also entailed lower temperatures and shorter reaction times and in many cases even resulted in improved yields. The solvent-free approach also offered a significant extension in the scope of stannylene chemistry with the straightforward obtainment of a large number of valuable building blocks directly from sugars in reducing form.

The results of this work underscore the concept that solvent-free conditions can assist the development of catalytic approaches otherwise ineffective in solution. It is expected that such an idea will be pursued in the future with the development of new useful catalytic transformations in chemical synthesis.

■ EXPERIMENTAL SECTION

General Methods. When necessary, the regiochemistry of benzylation and allylation protection was confirmed by acetylation of the main products (pyridine/acetic anhydride 2:1 v:v, overnight, rt) and by NMR analysis of the resulting acetylated products.

Typical Procedure of Regioselective Protection. To a mixture of the substrate (0.5−1 mmol), Bu_2SnO, and (if needed) TBAB (see the tables for the stoichiometric proportion), weighed in a round-bottomed flask, were sequentially added under air DIPEA and benzyl bromide (or ally bromide) (see the tables for proportions). The flask was sealed with a glass stopper and then immersed in an oil bath set at the desired temperature. Upon heating, the initial slurry gradually turned to a mixture composed of a syrupy phase and an immiscible transparent phase. Further addition of reagents or an increase of the temperature was performed when required (entries in Table 3 and Scheme 2). When TLC analysis indicated optimal conversion, the flask was cooled, and volatiles were removed in vacuo. The residue was dissolved in a suitable solvent (DCM or MeOH) and adsorbed by evaporation of the solvent to a pad of silica gel that was loaded to the top of a silica-gel column. Flash chromatography provided pure products (unless specified in the tables) in the yields indicated.

Spectroscopic data of known products (**3**, **6**, **10**, **12**, **16**, **18**, **21**, **22**, **23**, **27**, **35**, **37**, **38**, **40**−**43**, and **45**) were in accordance with those reported in the literature.

*Methyl 3,6-Di-O-benzyl-β-D-manno-pyranoside (**3**).*[4a,d] Flash chromatography (eluent: hexane/ethyl acetate 55:45) afforded **3** (178 mg, 67%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40−7.20 (aromatic H), 4.77 (bs, 1H), 4.72−4.57 (2 × AB, 4H), 3.99 (bs, 1H), 3.92 (bt, J = 9.2 Hz, 1H), 3.78 − 3.70 (overlapped signals, 3H), 3.67 (dd, J = 3.2, 9.2 Hz, 1H), 3.37 (s, 3H), 2.89 and 2.83 (2s, 2H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 137.9 and 137.8 (ipso C), 128.5−127.5 (aromatic CH), 100.4 (C-1), 79.4, 73.5, 71.8, 70.4, 70.3, 67.7, 67.6, 54.8. Anal. Calcd for $C_{21}H_{26}O_6$: C, 67.36; H, 7.00. Found: C, 67.45; H, 6.95.

*Allyl 3,6-Di-O-benzyl-α-D-galacto-pyranoside (**4**).* Flash chromatography (eluent: hexane/ethyl acetate 1:1) afforded **4** (151 mg, 57%) as an oil. $[\alpha]_D^{25}$ + 82 (c 1.4, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.45−7.25 (aromatic H), 6.00−5.90 (m, 1H), 5.31 (bd, J = 17.0 Hz, 1H), 5.21 (bd, J = 10.5 Hz, 1H), 5.01 (d, J = 4.0 Hz, 1H), 4.75−4.65 (4H, 2 × AB), 4.23 (bdd, J = 4.5, 12.5 Hz, 1H), 4.10−3.84, (overlapped signals, 3H), 3.96 (bt, J = 5.5 Hz, 1H), 3.80−3.70 (m, 2H), 3.66 (dd, J = 2.5, 10.0 Hz, 1H), 2.71 (bs, 1H), 2.31 (d, J = 8.5 Hz, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 137.9 and 137.8 (aromatic C), 133.6 (−CH═CH_2), 128.4−127.5 (aromatic CH), 117.7 (−CH═CH_2), 97.6 (C-1), 78.3, 73.4, 71.9, 69.4, 68.8, 68.4 (×2), 67.1. MALDI-MS [M + Na]$^+$ calcd for ($C_{23}H_{28}O_6$), 423.18; found, 423.35. Anal. Calcd for $C_{23}H_{28}O_6$: C, 68.98; H, 7.05. Found: C, 69.10; H, 7.00.

*1-O-Benzyl-1,2,4-butan-triol (**6**).*[20] Flash chromatography (eluent: ethyl acetate/hexane 4:1) afforded **6** (110 mg, 70%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45−7.20 (aromatic H), 4.51 (s, 2H), 4.04−3.95 (m, 1H), 3.78−3.68 (m, 2H), 3.66 and 3.56 (2 x bs, 2H), 3.43 (dd, J = 3.5, 7.6 Hz, 1H), 3.37 (dd, J = 5.6, 7.6 Hz, 1H), 1.20−1.35 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 137.7 (aromatic C), 128.4−127.6 (aromatic CH), 74.3, 73.3, 69.9, 60.6, 34.8. Anal. Calcd for $C_{11}H_{16}O_3$: C, 67.32; H, 8.22. Found: C, 67.25; H, 8.25.

*2-O-Benzyl-diethyl-D-tartrate (**8**).* Flash chromatography (eluent: hexane/ethyl acetate from 2:1 to 1:1) afforded **8** (143 mg, 93%) as an oil. $[\alpha]_D^{25}$ −75 (c 1.7, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40−7.20 (aromatic H), 4.86 (d, J = 12.0 Hz, 1H), 4.58 (dd, J = 2.4, 8.8 Hz, 1H), 4.42 (d, J = 12.0 Hz, 1H), 4.32 (d, J = 2.4 Hz, 1H), 4.35−4.00 (m, 4H), 3.20 (d, J = 8.8 Hz, 1H), 1.29 and 1.16 (2t, J = 7.2 Hz, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.0 and 169.2 (2 × CO), 136.7 (aromatic C), 128.5−128.0 (aromatic CH), 78.1, 72.8, 72.2, 61.9. Anal. Calcd for $C_{15}H_{20}O_6$: C, 60.80; H, 6.80. Found: C, 60.65; H, 6.90. MALDI-MS [M + Na]$^+$ calcd for ($C_{15}H_{20}O_6$), 319.13; found, 319.30.

*Methyl 3-O-Benzyl-4,6-benzylidene-α-D-manno-pyranoside (**10**).*[21] Flash chromatography (eluent: ethyl acetate/hexane 1:1) afforded **10** (190 mg, 84%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.60−7.30 (aromatic H), 5.65 (s, 1H), 4.90−4.74 (AB, J = 11.6 Hz, 2H,), 4.77 (s, 1H), 4.31 (dd, J = 3.6, 10.2 Hz, 1H), 4.15 (t, J = 10.2 Hz, 1H), 4.05 (bd, J = 3.5 Hz, 1H), 3.95−3.80 (overlapped signals, 3H), 3.40 (s, 3H), 2.92 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 137.9 and 137.5 (aromatic C), 128.8−125.9 (aromatic CH), 101.5, 101.0, 78.7, 75.6, 73.0, 69.7, 68.8, 63.1, 54.8. Anal. Calcd for $C_{21}H_{24}O_6$: C, 67.73; H, 6.50. Found: C, 67.75; H, 6.45.

*4-O-Benzyl-1,6-anhydro-galacto-D-pyranose (**12**).*[5a] Flash chromatography (eluent: ethyl acetate) afforded **12** (155 mg, 87%) as an oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.39−7.30 (aromatic H), 5.35 (s, 1H), 4.69−4.60 (AB, J = 12.0 Hz, 2H), 4.39 (d, J = 4.5 Hz, 1H), 4.29 (d, J = 7.5 Hz, 1H), 4.00 (bd, J = 4.0 Hz, 1H), 3.84−3.78 (m, 2H), 3.62 (dd, J = 4.5, 7.5 Hz, 1H), 2.88 and 2.86 (2s, 2H). ^{13}C NMR (125 MHz, $CDCl_3$): δ 137.2, 128.6−127.8 (aromatic CH), 101.4, 72.5, 71.6, 71.2, 69.7, 64.0. Anal. Calcd for $C_{13}H_{16}O_5$: C, 61.90; H, 6.39. Found: C, 61.75; H, 6.40.

*3-O-Benzyl-D-galactal (**14**).* Flash chromatography (eluent: ethyl acetate/hexane 4:1) afforded **14** (97 mg, 64%) as a white foam. $[\alpha]_D^{25}$ −17 (c 1.3, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.45−7.25 (aromatic H), 6.42 (bd, J = 5.5 Hz, 1H), 4.71 (bd, J = 5.5 Hz, 1H),4.65−4.55 (AB, J = 11.0 Hz, 2H), 4.19 (bs, 1H), 4.11 (bs, 1H),

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3.96 (bdd, J = 5.5, 11.0 Hz, 1H), 3.90−3.80 (overlapped signals, 2H), 2.95 (bs, 1H), 2.89 (s, 1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 144.9, 137.4, 128.5−127.7 (aromatic CH), 99.3, 76.2, 70.5, 70.4, 63.4, 62.4. MALDI-MS $[M + Na]^+$ calcd for ($C_{13}H_{16}O_4$), 259.10; found, 259.00. Anal. Calcd for $C_{13}H_{16}O_4$: C, 66.09; H, 6.83. Found: C, 66.20; H, 6.95.

*Methyl 3-O-Benzyl-β-L-arabino-pyranoside (**16**).*[5a,10] Flash chromatography (eluent: ethyl acetate) afforded **16** (124 mg, 72%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45−7.30 (aromatic CH), 4.77 (d, J = 3.6 Hz, 1H), 4.75−4.68 (AB, J = 11.6 Hz, 2H), 4.05−3.95 (overlapped signals, 2H), 3.75−3.60 (m, 2H), 3.65 (dd, J = 3.2, 9.2 Hz, 1H), 3.41 (s, 3H), 2.74 (s, 1H), 2.46 (d, J = 7.2 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 137.7, 128.4, 127.9 and 127.8 (aromatic CH), 99.8 (C-1), 77.7, 72.1, 68.4, 66.7, 61.6, 55.4. Anal. Calcd for $C_{13}H_{18}O_5$: C, 61.40; H, 7.14. Found: C, 61.30; H, 7.15.

*Methyl 3-O-Benzyl-α/β-L-fuco-pyranoside (**18**).*[5a,22] Flash chromatography (eluent: from hexane/ethyl acetate 9:1 to ethyl acetate) afforded **18** (88 mg, 51%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40−7.20 (aromatic H), 4.77 (d, J = 3.2 Hz, 1H), 4.77−4.70 (2 × AB), 4.14 (d, J = 8.0 Hz, 1H), 3.55 (m, 1H), 3.87 (bq, J = 6.8 Hz, 1H), 3.82 (bs, 1H), 3.77 (bs, 1H), 3.73 (bt, J = 8.0 Hz, 1H), 3.63 (dd, J = 3.2, 9.6 Hz, 1H), 3.57 (bq, J = 7.2 Hz, 1H), 3.54 (s, 3H), 3.43 (dd, J = 3.6, 9.6 Hz, 1H), 3.41 (s, 3H), 1.36 (d, J = 7.2 Hz, 3H), 1.30 (d, J = 6.8 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 137.6, 128.6−127.7 (aromatic CH), 103.7 and 99.5 (C-α and β), 80.7, 78.6, 71.9, 70.6, 70.3, 69.4, 68.8, 68.2, 65.3, 56.8, 55.3, 16.2. Anal. Calcd for $C_{14}H_{20}O_5$: C, 62.67; H, 7.51. Found: C, 62.75; H, 7.45.

*6-O-Benzyl-1,2-O-isopropylidene-α-D-glucopyranose (**21**).*[6] Flash chromatography (eluent: from hexane/ethyl acetate 4:6 to ethyl acetate) afforded **21** (186 mg, 75%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.35−7.15 (aromatic H), 5.91 (d, J = 3.6 Hz, 1H), 4.56 (s, 2H), 4.47 (d, J = 3.6 Hz, 1H), 4.32 (d, J = 2.4 Hz,), 4.20−4.15 (m, 1H), 4.07 (dd, J = 2.4, 7.8 Hz, 1H), 3.73 (dd, J = 3.2, 10.0 Hz, 1H), 3.61 (dd, J = 6.0, 10.0 Hz, 1H), 1.47 and 1.29 (2s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 137.5 (aromatic C), 128.4−127.6 (aromatic CH), 111.5, 104.7 (C-1), 84.9, 79.6, 75.1, 73.3, 71.5, 68.8, 26.6, 26.0. Anal. Calcd for $C_{16}H_{22}O_6$: C, 61.92; H, 7.15. Found: C, 61.80; H, 7.25.

*Methyl 3-O-Benzyl-α-D-manno-pyranoside (**22**).*[12] Flash chromatography (eluent: ethyl acetate) afforded **22** (144 mg, 64%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40−7.20 (aromatic CH), 4.71 (d, J = 1.2 Hz, 1H), 4.70−4.60 (AB, J = 11.6 Hz, 2H), 4.07 (bt, J = 9.6 Hz, 1H), 3.89 (bt, 1H), 3.87 (dd, J = 2.4, 12.0 Hz, 1H), 3.73 (dd, J = 2.5, 12.0 Hz, 1H), 3.68 (dd, J = 2.8, 9.6 Hz, 1H), 3.49 (m, 1H), 3.31 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 137.6, 128.3, 128.1 and 127.8 (aromatic CH), 100.6 (C-1), 79.5, 72.2, 71.8, 67.8, 65.0, 61.0, 54.7. Anal. Calcd for $C_{14}H_{20}O_6$: C, 59.14; H, 7.09. Found: C, 59.00; H, 7.10.

*Allyl 3-O-Benzyl-α-D-galacto-pyranoside (**23**).*[13] Flash chromatography (eluent: ethyl acetate) afforded **23** (120 mg, 68%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40−7.25 (aromatic H), 6.00−5.90 (m, 1H), 5.31 (bd, J = 17.2 Hz, 1H), 5.22 (bd, J = 10.0 Hz, 1H), 5.00 (d, J = 4.0 Hz, 1H), 4.77−4.70 (AB, J = 11.6 Hz, 2H), 4.25−3.90 (4H, overlapped signals), 3.91 (bdd, J = 7.2, 12.8 Hz, 1H), 3.85−3.75 (overlapped signals, 2H), 3.66 (dd, J = 3.2, 9.6 Hz, 1H), 2.90 (bs, 1H), 2.78 (bs, 1H), 2.31 (bd, J = 7.2 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 133.5 (−CH═CH_2), 128.5, 128.0 and 127.8 (aromatic CH), 118.0 (−CH=CH_2), 97.7 (C-1), 78.2, 72.2, 69.5, 68.6, 68.4, 68.2, 62.8. Anal. Calcd for $C_{16}H_{22}O_6$: C, 61.92; H, 7.15. Found: C, 61.80; H, 7.25.

*p-Nitrophenyl 2,4,6-Tri-O-acetyl-3-O-benzyl-β-D-galacto-pyranoside (**25Ac**).* Flash chromatography (eluent: ethyl acetate) afforded **25** a solid (80 mg, 67%). Acetylation of **25** with pyridine/acetic anhydride 2:1 afforded **25Ac** as a foam. $[\alpha]_D^{25}$ +39 (c 1.6, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.20−7.00 (aromatic H), 5.59 (bd, J = 3.0 Hz, 1H), 5.43 (dd, J = 8.0, 10.0 Hz, 1H), 5.07 (d, J = 8.0 Hz, 1H), 4.75−4.44 (AB, 2H), 4.21 (d, J = 6.5 Hz, 2H), 4.03 (bt, J = 6.5 Hz, 1H), 3.66 (dd, J = 3.5, 10.0 Hz, 1H), 2.20, 2.10, 2.04 (3s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.4, 170.3, and 169.2 (3-$COCH_3$), 161.4, 143.0, 137.0 (aromatic C), 128.5−127.7, 125.6, 116.6 (aromatic CH), 98.6 (C-1), 76.1, 71.6, 71.4, 69.7, 65.4, 61.9, 20.8−20.6. MALDI-MS $[M + Na]^+$ calcd for ($C_{25}H_{27}NO_{11}$), 540.15; found, 540.30. Anal. Calcd for $C_{25}H_{27}NO_{14}$: C, 58.02; H, 5.26. Found: C, 58.20; H, 5.25.

*Benzyl 3-O-Benzyl-β-D-manno-pyranoside (**27**).*[12b] Flash chromatography (eluent: ethyl acetate) afforded **27** (177 mg, 59%) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50−7.20 (aromatic H), 5.02−4.65 (2 × AB, 4H), 4.50 (s, 1H), 4.18 (t, J = 9.6 Hz, 1H), 4.10 (d, J = 2.4 Hz, 1H), 4.05−3.95 (m, H_2-6, 2H), 3.41 (dd, 1H), 3.30 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 137.7 and 136.8 (ipso C), 128.5−127.5 (aromatic CH), 98.3 (C-1), 80.8, 75.9, 71.1, 70.4, 68.1, 68.0, 65.7, 61.5. Anal. Calcd for $C_{20}H_{24}O_6$: C, 66.65; H, 6.71. Found: C, 66.75; H, 6.65.

*Benzyl 3-O-Benzyl-β-D-rhamno-pyranoside (**28**).* Flash chromatography (eluent: hexane/ethyl acetate 3:2) afforded **28** (157 mg, 70%) as a foam. $[\alpha]_D^{25}$ +119 (c 1.8, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40−7.20 (aromatic H), 5.06−4.60 (2 × AB, 4H), 4.53 (s, 1H), 4.21 (d, J = 2.8 Hz, 1H), 3.76 (t, J = 9.2 Hz, 1H), 3.40−3.25 (overlapped signals, 2H), 1.51 (d, J = 6.0 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 137.5 and 136.8 (ipso C), 128.5−127.7 (aromatic CH), 97.9 (C-1), 80.9, 71.7, 71.1, 70.7, 70.2, 67.6, 17.6. MALDI-MS $[M + Na]^+$ calcd for ($C_{20}H_{24}O_5$), 367.15; found, 367.35. Anal. Calcd for $C_{20}H_{24}O_5$: C, 69.75; H, 7.02. Found: C, 69.65; H, 7.05.

*Benzyl α-L-Fuco-furanoside (**29**).* Flash chromatography (eluent: ethyl acetate) afforded **29** (100 mg, 68%) as a foam. $[\alpha]_D^{25}$ −64 (c 1.2, CH_3OH). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45−7.20 (aromatic H), 5.03 (d, J = 4.4 Hz, 1H, H-1), 4.85−4.65 (AB, J = 11.6 Hz, 2H, −CH_2Ph), 4.20 (t, J = 7.2 Hz, 1H, H-3), 4.12 (dd, J = 4.4, 7.2 Hz, 1H, H-2), 3.83 (m, 1H, H-5), 3.70 (t, J = 7.2 Hz, 1H, H-4), 1.25 (d, J = 7.2 Hz, 3H, CH_3-6). ^{13}C NMR (100 MHz, $CDCl_3$) δ 136.9 (ipso C), 128.6−128.1 (aromatic CH), 100.3 (C-1), 85.2, 77.9, 75.2, 70.4, 68.1, 18.7. MALDI-MS $[M + Na]^+$ calcd for ($C_{13}H_{18}O_5$), 277.11; found, 277.00. Anal. Calcd for $C_{13}H_{18}O_5$: C, 61.40; H, 7.14. Found: C, 61.55; H, 7.15.

*Benzyl 6-O-Benzyl-α-D-galacto-furanoside (**30**).* Flash chromatography (eluent: from ethyl acetate/hexane 4:1 to ethyl acetate) afforded **30** (104 mg, 36%) as an oil. $[\alpha]_D^{25}$ +55 (c 1.5, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40−7.25 (aromatic H), 5.05 (d, J = 4.8 Hz, 1H), 4.86−4.59 (2 × AB, 4H), 4.33 (t, J = 7.2 Hz, 1H), 4.33 (bt, J = 7.2 Hz, 1H), 4.15 (m, 1H), 3.96 (overlapped signals, 2H), 3.67−3.58 (2H, m). ^{13}C NMR (100 MHz, $CDCl_3$) δ 137.6, 136.9 (aromatic C), 129.0−127.6 (aromatic CH), 100.3 (C-1), 82.3, 77.6, 75.1, 73.4, 71.1, 70.4. 70.2. MALDI-MS $[M + Na]^+$ calcd for ($C_{20}H_{24}O_6$), 383.16; found, 383.25. Anal. Calcd for $C_{20}H_{24}O_6$: C, 66.65; H, 6.71. Found: C, 66.50; H, 6.65.

*Benzyl 6-O-Benzyl-α-D-gluco-furanoside (**31**).* Flash chromatography (eluent: from ethyl acetate/hexane 3:2 to ethyl acetate) afforded **31** (141 mg, 53%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50−7.30 (aromatic H), 5.24 (d, J = 4.0 Hz, 1H), 4.90−4.55 (overlapped signals, 5H), 4.45 (t, J = 3.6 Hz, 1H), 4.25−4.15 (overlapped signals, 2H), 3.87−3.62 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 137.6, 137.0 (aromatic C), 128.3−127.6 (aromatic CH), 100.1 (C-1), 78.2, 77.4, 76.9, 73.3, 71.4, 69.8. 69.6, 18.1, 18.0. MALDI-MS $[M + Na]^+$ calcd for ($C_{20}H_{24}O_6$), 383.16; found, 383.30. Anal. Calcd for $C_{20}H_{24}O_6$: C, 66.65; H, 6.71. Found: C, 66.60; H, 6.65.

*Di-2-N,3-O-benzyl-2-deoxy-α,β-D-glucosamino-pyranose (β/α ca. 1.5) (**32**).* Flash chromatography (eluent: ethyl acetate/hexane 1:1) afforded **32** (139 mg, 44%) as an oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.40−7.10 (aromatic H), 5.41 (d, J = 3.0 Hz, 1H), 4.91 (d, J = 8.5 Hz, 1H), 4.58−4.50 (2 × AB, 4H), 4.15−4.05 (overlapped signals, 2H), 4.07−3.77 (2 × AB, 4H), 3.79−3.73 (m, 2H), 3.65−3.55 (3H), 3.50−3.45 (m, 1H), 3.36−3.30 (2H), 2.72 (dd, J = 3.0, 9.0 Hz, 1H), 2.50 (dd, J = 8.5, 10.0 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 139.7, 139.1, 137.7, 137.6 (C ipso), 129.2−127.1 (aromatic CH), 95.7 and 91.7 (C-1 β and α), 74.4, 73.6 (×2), 72.5, 72.0, 70.2, 70.1, 69.6, 69.1, 63.2, 61.4, 54.7, 54.5. MALDI-MS $[M + Na]^+$ calcd for ($C_{20}H_{25}NO_5$), 382.16; found, 382.40. Anal. Calcd for $C_{20}H_{25}NO_5$: C, 66.83; H, 7.01. Found: C, 66.70; H, 6.95.

*Di-2-N,3-O-benzyl-2-deoxy-α,β-D-galactosamine (Mixture of Furanose and Pyranose Anomers) (**33**).* Flash chromatography (eluent: ethyl acetate/hexane 1:1) afforded **33** (86 mg, 47%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$), significant signals of prevalent pyranose anomers at δ 5.51 (d, J = 2.8 Hz, 1H), 4.90 (d, J = 8.0 Hz, 1H), 4.61−4.52 (2 × AB, 4H), 4.24 (m, 1H), 4.17 (dd, J = 3.2, 10.8 Hz, 1H),

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4.06−3.75 (2 × AB, 4H), 3.98 (bd, J = 2.8 Hz, 1H), 3.90 (bd, J = 2.8 Hz, 1H), 3.80−3.55 (6H), 3.16 (dd, J = 2.8, 10.8 Hz, 1H), 2.86 (dd, J = 8.0, 10.4 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$), significant signals of prevalent pyranose anomers at δ 139.6, 139.2, 137.7 (×2) (C ipso), 129.2−127.1 (aromatic CH), 96.2 and 91.7 (C-1 β and α), 73.6 (×2), 70.4, 69.7, 69.0, 68.8, 68.2, 67.9, 65.1, 60.2, 54.7, 54.5. MALDI-MS [M + Na]$^+$ calcd for ($C_{20}H_{25}NO_5$), 382.16; found, 382.35. Anal. Calcd for $C_{20}H_{25}$ NO_5: C, 66.83; H, 7.01. Found: C, 66.75; H, 7.00.

*4-O-Benzyl-α/β-D-digitoxo-pyranose (α/β ca. 1) (**34**).* Flash chromatography (eluent: ethyl acetate/hexane 3:1) afforded **34** (116 mg, 81%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40−7.20 (aromatic H), 5.22 (d, J = 9.6 Hz, 1H), 5.12 (m, 1H), 4.66−4.51 (2 × AB, 4H), 4.30−4.10 (overlapped signals, 3H), 3.87 (m, 1H), 3.23 (1H), 3.12 (dd, J = 2.8, 9.6 Hz, 2H), 2.60 (1H), 2.20 (m, 2H), 1.79 (m, 1H), 1.59 (m, 1H), 1.30 and 1.28 (2d, J = 6.4 Hz, 6H,). ^{13}C NMR (100 MHz, $CDCl_3$) δ 137.3 (aromatic C), 128.4−127.9 (aromatic CH), 91.7 and 91.5 (C-1 α and β), 80.2, 80.0, 71.6, 71.5, 68.1, 65.2, 64.5. 61.5, 18.1, and 18.0. MALDI-MS [M + Na]$^+$ calcd for ($C_{13}H_{18}O_4$), 261.12; found, 261.00. Anal. Calcd for $C_{13}H_{18}O_4$: C, 65.53; H, 7.61. Found: C, 65.45; H, 7.65.

*Methyl 2,6-Di-O-benzyl-α-D-gluco-pyranoside (**35**).*[4a,22] Flash chromatography (eluent: hexane/ethyl acetate from 7:3 to 1:1) afforded **35** (159 mg, 56%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40−7.20 (aromatic CH), 4.77 (d, J = 3.6 Hz, 1H), 4.75−4.55 (2 × AB, 4H), 3.93 (t, J = 9.6 Hz, 1H), 3.75−3.70 (overlapped signals, 3H), 3.57 (bt, J = 9.6 Hz, 1H), 3.38 (dd, J = 3.6, 9.6 Hz, 1H), 3.34 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 137.9 (C ipso), 128.3−127.4 (aromatic CH), 97.6 (C-1), 79.0, 73.3, 72.9 (×2), 70.5, 69.9, 69.2, 55.0. Anal. Calcd for $C_{21}H_{26}O_6$: C, 67.36; H, 7.00. Found: C, 67.25; H, 7.05.

*Methyl 3,6-Di-O-benzyl-α-D-gluco-pyranoside (**36**).* Flash chromatography (eluent: hexane/ethyl acetate from 7:3 to 1:1) afforded **36** (40 mg, 14%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40−7.20 (aromatic CH), 4.79 (d, J = 3.6 Hz, 1H), 5.00−4.57 (2 × AB, 4H), 3.75−3.55 (ovelapped signals, 6H), 3.45 (s, 3H), 2.57 (bs, 1H), 2.25 (d, J = 8.4 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 138.5 and 137.8 (C ipso), 128.5−127.5 (aromatic CH), 99.4 (C-1), 82.6, 74.9, 73.5, 72.4, 70.8, 70.0, 69.6, 55.2. Anal. Calcd for $C_{21}H_{26}O_6$: C, 67.36; H, 7.00. Found: C, 67.35; H, 7.10.

*3,6-Di-O-benzyl-D-galactal (**37**).*[15] Flash chromatography (eluent: hexane/ethyl acetate from 3:1 to 1:1) afforded **37** (113 mg, 64%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45−7.25 (aromatic H), 6.45 (bd, J = 5.6 Hz, 1H), 4.74 (bd, J = 5.6 Hz, 1H), 4.70−4.55 (2 × AB, 4H), 4.22 (m, 1H), 4.13 (m, 1H), 4.05 (bt, J = 6.0 Hz, 1H), 3.85−3.75 (m, 2H), 2.64 (1H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 144.9 (C-1), 137.7 and 137.5 (aromatic C), 128.4−127.7 (aromatic CH), 99.4 (C-2), 75.3, 73.6, 70.6, 70.3, 69.2, 62.9. Anal. Calcd for $C_{20}H_{22}O_4$: C, 73.60; H, 7.00. Found: C, 73.50; H, 7.05.

*DL-1,3,4-Tri-O-benzyl-myo-inositol (**38**).*[4d] Flash chromatography (eluent: from ethyl acetate/hexane 3:2 to ethyl acetate) afforded **38** (204 mg, 40%) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50−7.30 (aromatic H), 5.01−4.70 (3 × AB, 6H), 4.27 (bs, 1H), 4.02 (t, J = 10.0 Hz, 1H), 3.88 (t, J = 10.0 Hz, 1H), 3.50−3.40 (overlapped signals, 2H), 3.26 (dd, J = 2.0, 9.5 Hz, 1H). ^{13}C NMR (100 Hz, $CDCl_3$), δ 138.6, 137.7, 137.6 (aromatic C), 128.6−127.6 (aromatic CH), 80.4, 79.6, 79.0, 75.4, 74.2, 72.4, 72.2, 71.9, 66.9. Anal. Calcd for $C_{27}H_{30}O_6$: C, 71.98; H, 6.71. Found: C, 72.05; H, 6.70.

*Benzyl 3,6-Di-O-benzyl-β-D-manno-pyranoside (**39**).* Flash chromatography (eluent: ethyl acetate/hexane 1:1) afforded **39** (179 mg, 62%) a solid. $[\alpha]_D^{25}$ −76 (c 1.7, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.50−7.20 (aromatic H), 4.98−4.60 (3 × AB, 6H, 3 × $-CH_2Ph$), 4.47 (s, 1H, H-1), 4.11 (bs, 1H, H-2), 4.11 (bt, J = 9.5 Hz, 1H, H-4), 3.89 (dd, J = 3.5, 11.0 Hz, 1H, H-6a), 3.80 (dd, J = 4.4, 11.0 Hz, 1H, H-6b), 3.43 (m, 1H, H-5), 3.34 (dd, J = 2.5, 9.5 Hz, 1H, H-3), 2.87 and 2.61 (2H, 2s, OH-2 and OH-4). ^{13}C NMR (125 MHz, $CDCl_3$) δ 137.9, 137.6, and 136.7 (ipso C), 128.4−127.5 (aromatic CH), 98.0 (C-1), 80.8, 74.7, 73.5, 71.1, 70.3, 70.2, 67.7, 67.6. MALDI-MS [M + Na]$^+$ calcd for ($C_{27}H_{30}O_6$), 473.19; found, 473.30. Anal. Calcd for $C_{27}H_{30}O_6$: C, 71.98; H, 6.71. Found: C, 72.10; H, 6.65.

*Allyl 2,3,6-Tri-O-benzyl-α-D-galacto-pyranoside (**40**).*[19] Flash chromatography (eluent: ethyl acetate/hexane 1:3) afforded **40** (143 mg, 55%) as an oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.45−7.15 (aromatic H), 5.95−5.80 (m, 1H), 5.26 (bd, J = 17.0 Hz, 1H), 5.14 (bd, J = 10.5 Hz, 1H), 4.82 (d, J = 3.0 Hz, 1H), 4.75−4.48 (3 × AB, 6H), 4.11 (bdd, J = 5.0 , 12.5 Hz, 1H), 4.02 (bs, 1H), 3.98 (bdd, J = 6.5, 12.5 Hz, 1H), 3.91 (bt, J = 5.5 Hz, 1H), 3.88−3.80 (overlapped signals, 2H), 3.70−3.60 (m, 2H), 2.52 (bs, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 138.3, 138.1, and 137.9 (aromatic C), 133.7 ($-CH{=}CH_2$), 128.3−127.5 (aromatic CH), 117.9 ($-CH{=}CH_2$), 96.0 (C-1), 77.6, 75.6, 73.4, 73.2, 72.7, 69.5, 68.4, 68.2, 67.9. Anal. Calcd for $C_{30}H_{34}O_6$: C, 73.45; H, 6.99. Found: C, 73.55; H, 6.95.

*Methyl 2,3,4,6-Tetra-O-benzyl-α-D-gluco-pyranoside (**41**).*[23] Flash chromatography (eluent: hexane/ethyl acetate from 9:1 to 1:1) afforded **41** (236 mg, 71%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50−7.20 (aromatic H), 5.00−4.52 (4 × AB, 8H), 4.70 (d, J = 3.6 Hz, 1H), 4.06 (bt, J = 9.6 Hz, 1H), 3.85−3.73 (overlapped signals, 2H), 3.72−3.65 (overlapped signals, 2H), 3.63 (d, J = 3.6, 9.6 Hz, 1H), 3.44 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 138.7, 138.1, 138.0, 137.8 (aromatic C), 128.4−127.4 (aromatic CH), 98.0 (C-1), 82.0, 79.7, 77.5, 75.6, 74.9, 73.3, 73.2, 69.9, 68.4, 55.0. Anal. Calcd for $C_{35}H_{38}O_6$: C, 75.79; H, 6.91. Found: C, 75.65; H, 7.00.

*Methyl 2,3,4,6-Tetra-O-benzyl-α-D-manno-pyranoside (**42**).*[24] Flash chromatography (eluent: hexane/ethyl acetate from 85:15 to 4:1) afforded **42** (256 mg, 79%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.55−7.20 (aromatic H), 5.05−4.65 (4 × AB, 8H), 4.93 (d, J = 2.0 Hz, 1H), 4.14 (t, J = 9.6 Hz, 1H), 4.04 (dd, J = 3.2, 9.6 Hz, 1H), 3.96 (dd, J = 2.0, 3.5 Hz, 1H), 3.95−3.87 (3H), 3.48 (s, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 138.5 (×2), 138.3, 138.2 (aromatic C), 128.4−127.3 (aromatic CH), 98.9 (C-1), 80.2, 75.0, 74.8, 74.5, 73.3, 72.5, 72.0, 71.6, 69.2, 54.7. Anal. Calcd for $C_{35}H_{38}O_6$: C, 75.79; H, 6.91. Found: C, 75.85; H, 6.95.

*Methyl 3-O-Allyl-4,6-benzylidene-α-D-manno-pyranoside (**43**).*[25] Flash chromatography (eluent: hexane/ethyl acetate from 8:2 to 7:3) afforded **43** (174 mg, 90%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.55−7.30 (aromatic H), 6.00−5.75 (m, 2H), 5.60 (s, 1H), 5.32 (bd, J = 17.2 Hz, 1H), 5.20 (bd, J = 10.4 Hz, 1H), 4.79 (d, J = 0.8 Hz, 1H), 4.40−4.16 (overlapped signals, 3H), 4.10−4.03 (overlapped signals, 2H), 3.90−3.79 (overlapped signals, 3H), 3.40 (s, 3H), 2.78 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 137.5 (aromatic C), 134.5 ($-CH{=}CH_2$), 128.9, 128.2, 126.0, 117.4 ($-CH{=}CH_2$), 101.5, 101.0, 78.8, 75.1, 71.8, 69.9, 68.8, 63.1, 54.9. Anal. Calcd for $C_{17}H_{22}O_6$: C, 63.34; H, 6.88. Found: C, 63.45; H, 6.80.

*Methyl 3-O-Allyl-β-L-arabino-pyranoside (**44**).* Flash chromatography (eluent: ethyl acetate) afforded **44** (127 mg, 78%) as a foam. $[\alpha]_D^{25}$ +194 (c 1.3, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.00−5.75 (m, 2H), 5.29 (bd, J = 17.2 Hz, 1H), 5.18 (bd, J = 10.0 Hz, 1H), 4.75 (d, J = 3.6 Hz, 1H), 4.20−4.05 (m, 2H), 3.99 (m, 1H), 3.90 (m, 1H), 3.71 (d, J = 2.0 Hz, 2H), 3.56 (dd, J = 3.6, 9.6 Hz, 1H), 3.39 (s, 3H), 2.79 (s, 1H), 2.55 (d, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 134.4 ($-CH{=}CH_2$), 117.8 ($-CH{=}CH_2$), 99.5 (C-1), 77.3, 70.8, 68.1, 66.6, 61.7, 55.4. MALDI-MS [M + Na]$^+$ calcd for ($C_9H_{16}O_5$), 227.10; found, 227.05. Anal. Calcd for $C_9H_{16}O_5$: C, 52.93; H, 7.90. Found: C, 53.05; H, 7.85.

*Methyl 3-O-Allyl-α-D-manno-pyranoside (**45**).*[12b,26] Flash chromatography (eluent: ethyl acetate/methanol from 95:5 to 9:1) afforded **45** (137 mg, 65%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.00−5.90 (m, 1H), 5.32 (bd, J = 17.2 Hz, 1H), 5.21 (bd, J = 17.2 Hz, 1H), 4.74 (bs, 1H), 4.25−4.10 (m, 2H), 4.02−3.90 (overlapped signals, 3H), 3.77 (bd, J = 12.0 Hz, 1H), 3.59 (dd, J = 3.2, 9.6 Hz, 1H), 3.51 (m, 1H), 3.34 (s, 3H, $-OCH_3$). ^{1}H NMR (100 MHz, $CDCl_3$) δ 134.4 ($-CH{=}CH_2$), 118.0 ($-CH{=}CH_2$), 100.7 (C-1), 79.0, 72.2, 70.9, 67.9, 64.7, 60.9, 54.8. Anal. Calcd for $C_{12}H_{20}O_6$: C, 55.37; H, 7.74. Found: C, 55.25; H, 7.80.

*Allyl 3-O-Allyl-β-D-manno-pyranoside (**46**).* Flash chromatography (eluent: ethyl acetate/methanol from 9:1 to 6:1) afforded **46** (140 mg, 61%) as an oil. $[\alpha]_D^{25}$ −68 (c 1.3, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.00−5.75 (m, 2H), 5.35−5.10 (overlapped signals, 4H), 4.47 (s, 1H), 4.40−4.05 (overlapped signals, 4H), 4.06 (bs, 1H), 3.96 (bt, J = 9.6 Hz, 1H), 3.90−3.80 (m, 2H), 3.31 (dd, J = 2.8, 9.6 Hz,

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1H), 3.23 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 134.5 and 133.6 (2 × −CH═CH_2), 118.0 (×2) (2 × −CH═CH_2), 98.8 (C-1), 80.8, 75.9, 70.6, 69.9, 68.1, 65.4, 61.4. MALDI-MS $[M + Na]^+$ calcd for ($C_{12}H_{20}O_6$), 283.13; found, 283.25. Anal. Calcd for $C_{12}H_{20}O_6$: C, 55.37; H, 7.74. Found: C, 55.35; H, 7.70.

■ ASSOCIATED CONTENT

Supporting Information

List of yields reported in the literature for regioselective approaches leading to known products herein synthesized. ^{1}H and ^{13}C NMR spectra of all synthesized compounds. 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.

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