Methyl Ricinoleate as Platform Chemical for Simultaneous Production of Fine Chemicals and Polymer Precursors

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The modification of methyl ricinoleate by etherification of the hydroxyl group was accomplished by using a nonclassical ruthenium-catalyzed allylation reaction and also by esterification. Methyl ricinoleate derivatives were engaged in ring-closing metathesis (RCM) reactions leading to biosourced 3,6-dihydropyran and \( \alpha,\beta \)-unsaturated lactone derivatives with concomitant production of polymer precursors. Sequential RCM/hydrogenation and RCM/cross-metathesis were also implemented as a straightforward method for the synthesis of tetrahydropyran and lactone derivatives as well as valuable monomers (i.e., polyamide precursors).

Introduction

The sustainable utilization of biomass as a renewable source of raw materials is a domain of strong economic and environmental interest in a context of fossil-resource shortage. Owing to their long carbon chains, fatty acid methyl esters (FAMEs) offer interesting perspectives for the polymer industry and for the preparation of surfactants. Typically, these compounds can be derivatized by \( \mathrm{C} = \mathrm{C} \) bond transformations, among which efficient and selective catalytic processes are preferable. Since the early seventies, olefin metathesis has been used for the transformation of FAMEs, but it is only recently that the incorporation of functional groups by olefin metathesis was made possible thanks to the development of highly active and functional-group tolerant catalysts. For example, cross-metathesis reactions with methyl acrylate have been first reported by Meier et al., whereas our group focused on cross-metathesis transformations with acrylonitrile to produce polyamide monomers. In particular, we reported the direct synthesis of amino esters by a tandem cross-metathesis/\( \mathrm{C} = \mathrm{C} \) bond and CN hydrogenation reaction. We have become interested in the transformation of methyl ricinoleate (R-12-hydroxy-cis-9-octadecenonic acid methyl ester) as it presents the double advantage of being a nonedible oil derivative and incorporating a hydroxyl functional group, which enables a thermal rearrangement towards the valuable methyl 10-undecenoate and 1-heptanal.

To the best of our knowledge, the preliminary derivatization of methyl ricinoleate through the hydroxyl group by ring-closing metathesis (RCM) has not been reported. We envisioned that the introduction of allylic ethers or acrylic ester substituents (Scheme 1) would lead to 3,6-dihydropyran and \( \alpha,\beta \)-unsaturated lactone derivatives, which are compounds of interest in medicine, pharmacology, and flavors. These products would be obtained with coproduction of methyl 9-decenolate, another important raw material for the polymer industry (Scheme 2). Herein, we report on the transformation of methyl ricinoleate into designed diene derivatives and their RCM reaction leading to dihydropyran and unsaturated lactone derivatives. We show that the choice of catalysis can drive the selectivity of the reaction and that domino ring-closing/cross-metathesis and tandem RCM/hydrogenation can be implemented, leading to a variety of products of interest for fine chemistry and polymer synthesis.

Results and Discussion

Methyl ricinoleate derivatization

The allylation of the hydroxyl group of methyl ricinoleate was attempted by a standard NaH deprotonation in the presence of allyl bromide, but this method failed to provide the desired product 2a in good yield due to competitive transesterification reactions. Other Pd\(^0\)-catalyzed allylation methods were also unsuccessful. The catalytic allylation of methyl ricinoleate directly with branched allyl alcohol was successfully achieved by extension of a recently reported procedure using [RuCp\(\mathrm{DPPSA}\)(\(\eta^1\)-propenyl)] (Cp = cyclopentadienyl, DPPSA = ortho-diphenylphosphinesulfonate) as a catalyst (Scheme 1). Structural diversity was achieved by the utilization of various allylic alcohols, which regioselectively provided the products featuring a terminal allylic group in good to high yields using 2.5−5 mol% of catalyst at 45−100 °C. Various solvents including...
dimethyl carbonate (DMC) and diethyl carbonate (DEC) were used as greener alternatives to the conventional dichloromethane and dichloroethane. The esterification of methyl ricinoleate was achieved using acryloyl chloride in dichloromethane to yield the desired diester in 75% yield (Scheme 1).

**Ring Closing Metathesis transformations**

The RCM of 2a was first attempted as a model reaction using the second generation Hoveyda catalysts (HII) in DMC. This reaction led almost quantitatively to the desired dihydropyran (3a) isolated in 99% yield and to the mono- and diesters 4 and 5 obtained in a 1/9 ratio on the basis of yields calculated by GC (Scheme 2). As other diesters, 5 is an interesting compound for the production of polyesters and is accessible by self-metathesis of methyl oleate or fermentation of oleic acid. In this case, 5 was most likely obtained by self-metathesis of 4 producing also ethylene through a secondary metathesis reaction rather than by self-metathesis of the starting 2a because no trace of 7,12-(bis-allyloxy)octadec-8-ene could be detected.

With this first result we envisioned the same reaction in the presence of the first generation Hoveyda catalyst (H). Indeed, first generation catalysts are generally effective for promoting RCM reactions, but they are less efficient in promoting cross-metathesis transformations and should thus lead to the same dihydropyran 3a and the two esters 4 and 5, but with a reverse selectivity relative to HII. Thus, in the reaction of 2a with H at 50°C in DMC for 3 h, 2a was fully transformed and 3a was again isolated in high yield, but as anticipated the monoester 4 was now obtained as the major coproduct (4/5 = 9:1, Scheme 2). It was thus demonstrated that it is possible to select one of the reaction products (polymer precursor) without interfering with the synthesis of the other product (fine chemical) simply by switching between first and second generation ruthenium catalysts.

**Scheme 1. Preparation of methyl ricinoleate derivatives.**

**Scheme 2. RCM of O-allyl methyl ricinoleate.**
Although the molecular structure of the 3,6-dihydropyran derivative was imposed at the α-ether position by the nature of the starting methyl ricinoleate, molecular diversity was obtained using derivatives 2b–d. In the presence of HII (0.5 mol%), these compounds were efficiently transformed into the corresponding 3,6-dihydropyran derivatives in high yields with concomitant formation of diester 5, whereas monoester 4 was detected in low amounts as in the case of 2a (Scheme 3).

The transformation of precursor 2e into the corresponding α,β-unsaturated lactone was next attempted. As pointed out in the literature, the formation of lactones by RCM does not perform very well and usually requires high catalyst loadings. In our case, catalyst loadings of 3 mol% were necessary to ensure high conversions. When HII was used at 50 °C in DMC for 14 h, the reaction proceeded with full conversion, but led to the formation of side products arising from double bond migration in the main chain. HII was thus used in toluene at 80 °C for 14 h and indeed furnished a cleaner reaction mixture, but with lower efficiency (conversion of 45%) leading to 3e in 40% yield. Recently, we and others have reported on a new family of first generation olefin-metathesis catalysts based on a chelating indenylidene architecture (Scheme 4, III). More specifically, we have shown that the combination of high thermal stability and slow activation of complex III resulted in some cases in improved RCM performance.

Thus, when the RCM of 2e was attempted with III, the reaction proceeded smoothly reaching 75% conversion in 14 h and furnishing 3e in 72% yield (Scheme 4). As with the synthesis of 3a in the presence of HII, 4 was the major coproduct (4/5 = 6:1 by GC analysis). This first example constitutes an entry towards other unsaturated lactones with molecular diversity in terms of substitution pattern and ring sizes that could be accessible using the same synthetic strategy.

Tandem RCM/Hydrogenation

Having demonstrated the efficiency of the RCM reaction for the production of various 3,6-dihydropyran derivatives, the tandem RCM/hydrogenation sequence was attempted to prepare tetrahydropyran and lactone derivatives that are also compounds of interest in various domains, such as fragrance and pharmacy. For that purpose, the RCM reactions of 2a and 2e were repeated as already described (Scheme 2 and 4) and the crude reaction mixtures were transferred into a high pressure reactor. After 14 h at 75 °C under H2 (10 bar), products 6 and 7 were isolated in 92 and 66% yield, respectively, with concomitant production of a mixture of the saturated monoester 8 and diester 9 (8/9 = 1:9) by GC analysis for the transformation of 2a and 6:1 by H1 NMR analysis for the transformation of 2e resulting from the hydrogenation of 4 and 5, respectively (Scheme 5).

Cascade RCM/cross-metathesis

As mentioned earlier, the RCM reactions of methyl ricinoleate derivatives 2a–d furnished compounds 3a–d with concomitant formation of mono- and diesters 4 and 5 that are useful reagents or raw materials for the polymer industry. For example, 5 and methyl 10-undecenoate (one extra carbon atom with regard to 4) have recently been used for the preparation of polyamide monomers through cross-metathesis reactions with acrylonitrile. Examples of diester synthesis by cross-metathesis of FAMEs with methyl acrylate have also been recently reported. The synthesis of the same compounds (i.e., α,ω-nitrile ester and α,ω-diester) was attempted in a cascade RCM/cross-metathesis sequence involving the initial RCM reaction of 2a leading to 3,6-dihydropyran 3a, followed by a cross-metathesis reaction with methyl acrylate and acrylonitrile (Scheme 6). Compound 2a underwent a RCM reaction in the presence of methyl acrylate (2 equiv) at 100 °C in toluene.
cascade reaction with methyl acrylate proceeded with full conversion of 2a furnishing the RCM product 3a in 93% yield and a fine chemical and a polymer precursor are produced efficiently and simultaneously in a one-pot reaction.

Figure 1. Methyl ricinoleate as a platform chemical.
Conclusions

We have shown that methyl ricinoleate can be used as a platform chemical for the synthesis of a variety of functional compounds of interest both in fine chemistry and polymer synthesis (Figure 1). These products were prepared using efficient olefin metathesis transformations performed as a single reaction or by sequential transformations. These first examples open up the route towards further utilization of methyl ricinoleate for the production of a broad range of functional molecules potentially accessible by the appropriate initial derivatization of the hydroxyl group preferentially using efficient and selective catalytic methods.

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Keywords: hydrogenation · lactones · metathesis · renewable resources · ruthenium


During the preparation of this manuscript, the synthesis of lactone derivatives by ruthenium-catalyzed allylation and RCM reactions was reported. K. Takii, N. Kanbayashi, K. Onitsuka, Chem. Commun. 2012, 48, 3872.

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