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Efficient synthesis of fumaric amides through cross-metathesis of acrylic amides with the NHC Grubbs ruthenium catalyst

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Abstract

Application of the second generation Grubbs metathesis catalyst for the homo-cross-metathesis of acroyl amides from chiral amines is reported. This efficient and high-yielding reaction provides a side-product free synthesis of fumaric acid diamides which are formed with complete (*E*)-selectivity under the reaction conditions. In particular, products which cannot be synthesized from the corresponding fumaroyl chloride via classic condensation route can now be provided in excellent yields (88–98%) with a catalyst loading from 2.5 mol% to even 0.375 mol%.

Keywords: Metathesis; Catalysis; Fumaric amides; Ruthenium; Carbene ligand

1. Introduction

Olefin metathesis has come a long way from the detection of the first metal carbenes to initiate this type of reaction [1] to the development of defined monomeric precatalysts, some of which are currently commercially available [2]. Here, the seminal work by Grubbs and his development of air-stable ruthenium carbene complexes such as **1** and **2** (Fig. 1), which are commonly known as first and second generation Grubbs catalysts, has had major impact on the field [2–4]. As a consequence, catalytic olefin metathesis is now recognized as a major synthetic tool in various areas of modern synthesis. For example, its broad applicability and high functional group tolerance has rendered it an almost ubiquitous tool in current natural product synthesis [3,5], comparable to the popularity of the Sharpless epoxydation [6] in the 1980s.

We recently became interested in the synthesis of chiral non-racemic fumaric amides and quickly discovered that a direct synthetic approach from fumaroyl chloride and the respective amine does not represent a feasible, widely applicable synthetic solution.

In order to accomplish a general synthesis of fumaric amides, attention was turned to the concept of olefin metathesis. In principle, fusing two acrylic amides through metathesis would furnish the target compounds together with one molecule of ethylene. Such an overall process would fall into the range of cross-metathesis of two identical molecules. It is a rather less common process within the broad area of metathesis reactions which included cross-metathesis of different monomers (CM), ring-opening metathesis (ROM), ring-closing metathesis (RCM) [2].

As an interesting precedence, application of a Ru catalyst related to **2** had already proven successful in cross-metathesis reactions of acrylic amides with other olefins [7].

We here present an efficient procedure for the rapid and productive synthesis of symmetrical fumaric amides via cross-metathesis of two acrylic amide units themselves.

An initial screening was carried out employing *N*-benzyl acrylic amide as test substrate (Scheme 1). Attempts to employ the first generation Grubbs catalyst **1** met with unsatisfactory results. For example, in the presence of 2.5 mol%

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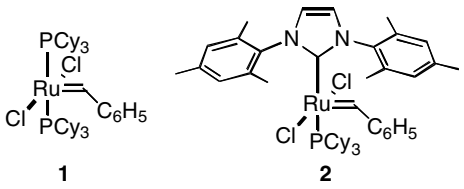
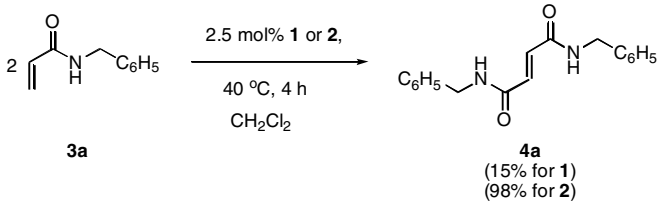


1 2

Fig. 1. Ruthenium-based precatalysts for olefin metathesis.



Scheme 1. Olefin metathesis of acrylic amide with ruthenium catalysts **1** and **2**. Yields refer to calculated conversion values according to ^{1}H nmr of the reaction crude.

of this Ru catalyst, only a low amount of olefin was consumed and after a prolonged reaction period of 24 h, the desired fumaric amide **4a** was isolated in a low yield of around 15%. Changing to the second generation catalyst **2**, which was synthesised from **1** via the standard literature procedure [8], the reaction of **3a**–**4a** was complete after 5 h in refluxing dichloromethane. It is important to note that under these conditions the product readily precipitates from the reaction mixture. After cooling to room temperature, the product could be collected by simple filtration which significantly facilitates the overall process.

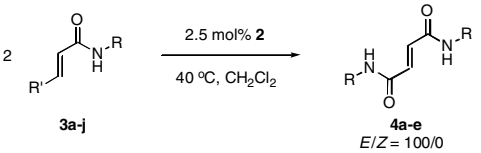
Nevertheless, the reaction was checked by ^{1}H NMR of an untreated crude reaction mixture which revealed complete conversion of the acrylic amide starting material and, more importantly, confirmed the formation of a single isomer. This was identified as the (*E*)-configured fumaric amide **4a**.

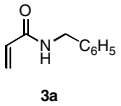
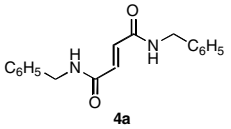
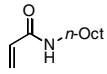
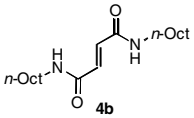
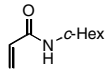
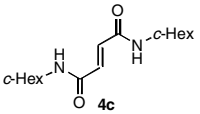
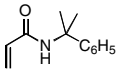
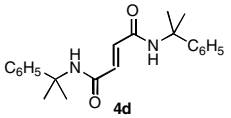
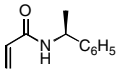
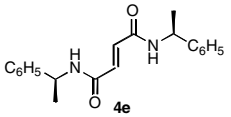
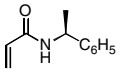
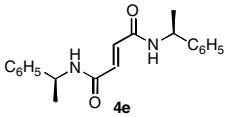
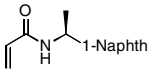
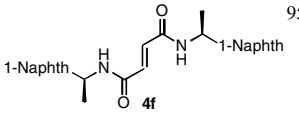
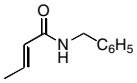
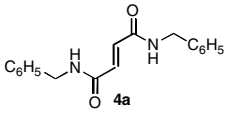
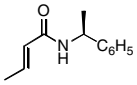
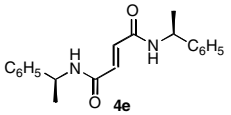
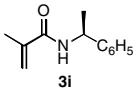
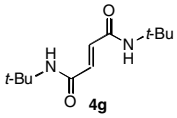
These results show that the N-heterocyclic carbene ligand in ruthenium catalyst **2** is responsible for the expected enhanced reactivity, an observation which is in complete agreement with earlier reactivity studies [2,3].

The reaction proofed viable for a variety of other acrylic amides as starting materials as well (Table 1).

Thus, other aliphatic substituents such as n-octyl and cyclohexyl gave excellent conversion and complete selectivity regarding the newly generated olefinic double bond (entries 2 and 3). Even a tertiary substituent such as 2-phenyl-2-propyl was tolerated and the corresponding fumaric amide **4d** was obtained quantitatively as a single isomer (entry 4). Importantly, chiral, non-racemic amides could be employed as well. Thus, the respective acrylic amides **3e** and **3f** from phenyl ethylamine and naphthyl ethylamine, respectively, gave the corresponding enantiomerically pure fumaric amides **4e** and **4f**, respectively, as single isomers and in excellent yields (entries 5 and 7). These reactions are of particular importance since the synthesis of these fumaric amides via the conventional aminolysis of fumaroyl chloride did not meet with success and led

Table 1
Metathesis of acrylic amides to yield fumaric amides



Entry	Starting material	Product[a]	Yield [%]
1	 **3a**	 **4a**	98
2	 **3b**	 **4b**	93
3	 **3c**	 **4c**	96
4	 **3d**	 **4d**	94
5	 **3e**	 **4e**	95
6[c]	 **3e**	 **4e**	94
7	 **3f**	 **4f**	95
8	 **3g**	 **4a**	88
9	 **3h**	 **4e**	92
10	 **3i**	—	—
11	 **3j**	 **4g**	<10[b]

[a] Isolated product obtained from reactions in the presence of 2.5 mol% catalyst with regards to total amount of starting material.
[b] Conversion determined by ^{1}H NMR of the reaction crude.
[c] With catalyst loading of 0.375 mol% with regards to total amount of **3e**.

to complicated mixtures which consisted of several products. Chiral non-racemic fumaric esters have been employed in a variety of different cycloaddition reactions [9]

and one might expect a similarly successful application for compounds **4e** and **4f**. Moreover, the present catalytic reactions do not require amounts of 2.5 mol% precatalyst. While these were normally employed for sake of convenience, the amount of carbene **2** could be lowered to 0.375 mol% without loss of reactivity, selectivity and yield (entry 6). Below this catalyst loading, the selectivity in favour of (*E*)-configuration is maintained, but yields start to diminish and the reactions require longer reaction times.

Finally, crotonyl amides can serve as starting materials as well without any general loss of selectivity and yields in comparison to the respective acrylic amides (entries 8 and 9 vs. 1 and 5). This is a particularly attractive feature of the present reaction, since crotylic amides are significantly easier to handle and show a more pronounced stability than acrylic amides.

Unfortunately, methacrylic amide **3i** did not show any reactivity under the present reaction conditions. Tetrasubstituted olefins are therefore not available from our cross-metathesis protocol.

The overall catalytic cycle in its simplest form is depicted in Fig. 2. Thus, precatalyst **2** is activated in the usual form to generate a low-coordinated ruthenium carbene which adds to the acrylic amide in a cycloaddition. Within a reversible manner, styrene is displaced from this first intermediate to form a ruthenium carbene intermediate with amide substituent. All subsequent catalytic cycles involve displacement of ethylene or 2-butene, respectively, at this step which is therefore irreversible. The ruthenium carbene intermediate could not be detected so far, however, it might be stabilised through an interaction with the amide functionality which will enhance the electron density at the metal centre and ultimately induce a more pronounced nucleophilic, Schrock-type character. Within this reactivity pattern, high regioselectivity might be obtained within the subsequent cycloaddition to an acrylic amide substrate to yield the observed 1,2-disubstituted ruthenacyclobutane intermediate. The demanded *trans*-positioning of the two substituents as required by the observed (*E*)-configuration of the products might arise from stereoelectronic reasons. Elimination of the fumaric amide generates a ruthenium methylene complex which represents the actual catalyst for this reaction and turns around until quantitative product formation is achieved. The final step of fumaric amide formation is believed to be irreversible due to the poor solubility of the products. In addition, minor amounts of the (*Z*)-configured compound, if formed at all, should be equilibrated under the reversible conditions of the metathesis reaction.

Incidentially, *N*-*tert*-butyl acrylic amide behaved as an exception and did not give any high conversion in this metathesis employing catalyst **2** (entry 11). Instead, unconverted starting material was recovered, even after prolongated reaction time. While this unreactivity is unexpected, the desired fumaric amide represents one of the easier available compounds through conventional amidation of

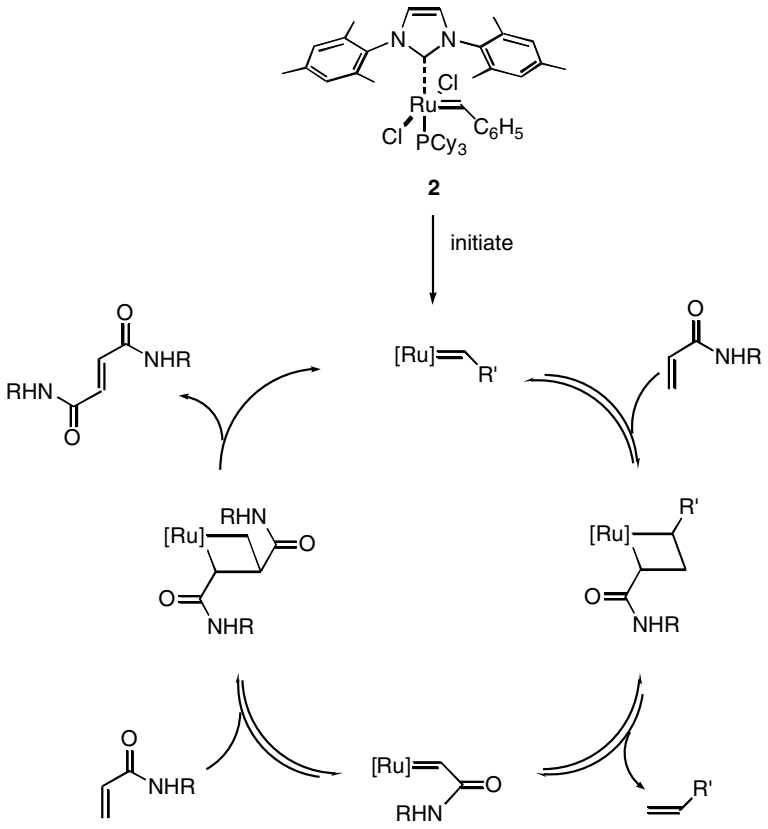


Fig. 2. Catalytic cycle for metathesis of acrylic amides to fumaric amides. $R' = C_6H_5$ (first cycle), H (subsequent cycles).

fumaroyl chloride [10]. Hence, the metathesis route toward fumaric amides as described within this work might be complimentated by the more conventional method of aminolysis of fumaroyl chloride in certain cases.

In summary, we have described the efficient synthesis of fumaric amides through cross-metathesis of acrylic and crotylic amides, respectively, employing catalytic amounts of Grubbs catalys **2** in the range of 0.375–2.5 mol% with regards to starting material. The reaction occurs readily in dichloromethane and gives the expected fumaric amide products in high yields and with complete (*E*)-configuration.

2. Experimental

All reactions employing organometallic reagents were conducted under an inert atmosphere of argon using standard Schlenk technique. Ru complex **1** was purchased from Aldrich Chemical Company. Ru complex **2** was synthesised from **1** according to the literature protocol [8]. Dichloromethane was freshly distilled from calcium hydride prior to use. Triethylamine was distilled from calcium hydride and stored under argon. Hexanes solvent was reagent grade and used as received. Column chromatography was performed with silica gel (Merck, type 60, 0.063–0.2 mm and Machery Nagel, type 60, 0.015–0.025 mm). IR Spectra in the range of 400–4000 cm^{-1} were obtained on a Nicolet Magna 550 FT-IR Spectrometer with KBr discs. The ^{1}H and ^{13}C NMR spectra were recorded on a Bruker DPX 300 MHz or a Bruker DPX 400 MHz spectrometer. The given ^{1}H and ^{13}C chemical shifts refer to solvent signals (^{1}H: $CDCl_3 = 7.26$ ppm, DMSO-$d_6 = 2.49$ ppm, methanol-$d_4 = 3.30$ ppm; ^{13}C: $CDCl_3 = 77.00$ ppm, DMSO-$d_6 = 39.50$ ppm, methanol-$d_4 = 49.00$ ppm). The mass-spectra and the high resolution mass data were measured on a Kratos MS 50 mass spectrometer. All optical rotation values were obtained from a Perkin–Elmer PE-241 polarimeter with a sample-length of $d = 10$ cm. All measurements were obtained at room temperature using a Na-lamp with a wavelength at 589 nm.

2.1. General procedures

2.1.1. Representative procedure for the synthesis of fumaric amides

A flame-dried Schlenk-flask was equipped with a magnetic stirrer bar, a reflux condenser and set under argon atmosphere. Grubbs 2nd generation catalyst **2** (0.05 equiv.) was dissolved in absolute dichloromethane and the respective acrylic amide was added to the dark-violet solution (2.00 equiv. [amide] = ~ 0.5 mmol/mL). The reaction mixture was refluxed for about 6 h, whereby the metathesis reaction initiated after a couple of minutes. When the reaction was finished (monitoring by TLC control), the solvent was removed under reduced pressure and the conversion was estimated from the crude NMR. The crude precipitate was recrystallised from dichloromethane/hexanes and the product obtained as a white solid.

Compounds **3a** [10], **3b** [12], **3c** [13], **3d** [14], **3e** [11], **3f** [15], **3g** [16], **3h**[17], **3i** [18] and **3j** [19] represent the literature known compounds and their analytical data was in general agreement with the reported data. More detailed analytical data for **3d** and **3f** is given below.

2.1.2. Acrylic amide *3d*: [14]

^{1}H NMR (300 MHz, $CDCl_3$): δ (ppm) = 1.73 (s, 6H), 5.58 (dd, $J = 1.9$, 10.0 Hz, 1H), 5.94 (s, 1H), 6.08 (dd, $J = 10.0$,17.0 Hz, 1H), 6.22 (dd, $J = 1.9$,17.0 Hz, 1H), 7.22 (tt, $J = 2.5$, 7.2 Hz, 1H), 7.29–7.41 (m, 4H). ^{13}C NMR (75 MHz, $CDCl_3$): δ (ppm) = 29.00, 56.09, 124.72, 126.13, 126.71, 128.40, 131.58, 146.61, 164.50. IR (KBr): ν (cm^{-1}) = 3315, 3286, 3062, 3030, 2980, 2929, 2866, 1660, 1624, 1547, 1402, 1248, 766, 702.

2.1.3. Acrylic amide *3f*: [15]

^{1}H NMR (300 MHz, $CDCl_3$): δ (ppm) = 1.59 (d, $J = 7.0$ Hz, 3H), 5.50 (dd, $J = 1.5$, 10.2 Hz, 1H), 5.92 (q, $J = 7.0$ Hz, 1H), 5.96 (dd, $J = 10.2$, 17.0 Hz, 1H), 6.19 (dd, $J = 1.5$, 17.0 Hz, 1H), 7.34–7.45 (m, 4H), 7.70 (d, $J = 8.1$ Hz, 1H), 7.77 (d, $J = 7.5$ Hz, 1H), 8.00 (d, $J = 8.2$ Hz, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): δ (ppm) = 20.60, 44.71, 122.69, 123.43, 125.19, 125.94, 126.62, 126.72, 128.37, 128.83, 130.77, 131.22, 134.01, 138.11, 164.54.

2.1.4. Representative procedure for the synthesis of N-monosubstituted acrylic and crotylic amides

A flame-dried Schlenk-flask was equipped with a magnetic stirrer bar and set under argon atmosphere. 100 mL of absolute dichloromethane and then triethylamine (6.23 mL, 45 mmol, 4.5 equiv.) were added. The primary amine (1.0 equiv, 10 mmol) was dissolved and the mixture cooled to −10 °C. Then acrylic chloride (1.22 mL, 15 mmol, 1.5 equiv.) was added dropwise. The solution was warmed to room temperature and stirred for further 4 h. The colour changed from a light green-yellow to orange-red. The reaction was quenched by the addition of aqueous HCl (3.5%-solution in water), additionally washed with HCl (3.5%-solution in water) and the organic layer was washed several times with saturated Na_2CO_3-solution. The organic phases were separated, dried over $MgSO_4$ and the solvent was removed under reduced pressure. The crude product was purified by flash-chromatography where appropriate. Compound **4g** was synthesised for comparison according to the literature method [10b].

2.1.5. Fumaric amide *4a*: [20]

Prepared using the general procedure. ^{1}H NMR (300 MHz, DMSO-d_6): δ (ppm) = 4.36 (d, $J = 5.8$ Hz, 4H), 6.92 (s, 2H), 7.24–7.35 (m, 10H), 8.88 (t, $J = 5.7$ Hz, 2 NH). ^{13}C NMR (75 MHz, DMSO-d_6): δ (ppm) = 42.30,

126.85, 127.24, 128.29, 132.74, 138.88, 163.67. MS (EI, eV): *m*/*z* (%): 294.2 $[M]^+$, 189.1 (5), 160.1 (7), 117.1 (4), 106.1 (100), 91.1 (36), 65.1 (3). HRMS: calc.: 294.1368, found: 294.1375. IR (KBr): ν (cm^{-1}) = 3282, 3086, 3032, 2970, 2927, 1630, 1564, 1454, 1433, 1338, 1261, 1242, 1192, 1082, 1036, 987, 800, 714, 694.

2.1.6. Fumaric amide **4b**: [21]

Prepared using the general procedure. ^{1}H NMR (300 MHz, Methanol-d_4): δ (ppm) = 0.89 (t, J = 7.0 Hz, 6H), 1.32 (m, 20H), 1.54 (m, 4H), 4.51 (m, 4H), 6.85 (s, 2H), 7.87 (s, 2NH). MS (EI, eV): *m*/*z* (%): 338.2 $[M]^+$, 309.2 (3), 295.2 (3), 281.2 (10), 267.1 (20), 253.1 (6), 239.1 (8), 227.1 (8), 211.1 (100), 184.1 (4), 182.1 (12), 168.1 (4), 140.1 (3), 129.1 (6), 128.1 (64), 112.0 (3), 98.0 (10), 71.1 (4), 57.1 (6). HRMS: calc.: 338.2933, found: 338,2937. IR (KBr): ν (cm^{-1}) = 3294, 3066, 2958, 2924, 2873, 2852, 1622, 1551, 1470, 1329, 1192, 999, 673.

2.1.7. Fumaric amide **4c**

Prepared using the general procedure. ^{1}H NMR (300 MHz, DMSO-d_6): δ (ppm) = 1.10–1.77 (m, 20H), 3.59 (m, 2H), 6.79 (s, 2H), 8.19 (d, J = 7.34 Hz, 2H). MS (EI, eV): *m*/*z* (%): 278.1 $[M]^+$, 197.1 (100), 180.0 (12), 152.0 (8), 115.0 (32), 98.0 (49), 83.0 (8), 67.0 (3), 56.0 (10). HRMS: calc.: 278.1994, found: 278.1990. IR (KBr): ν (cm^{-1}) = 3284, 3076, 2931, 2856, 1632, 1545, 1455, 1344, 1194, 1096, 1003.

2.1.8. Fumaric amide **4d**

Prepared using the general procedure. ^{1}H NMR (300 MHz, DMSO-d_6): δ (ppm) = 1.57 (s, 12H), 6.86 (s, 2H), 7.16-7.32 (m, 10H), 8.53 (s, 2 NH). ^{13}C NMR (75 MHz, DMSO-d_6): δ (ppm) = 29.24, 55.06, 124.61, 125.78, 127.85, 133.31, 147.31, 162.85. MS (EI, eV): *m*/*z* (%): 350.1 $[M]^+$, 335.1 (8), 293.1 (3), 232.1 (5), 231.1 (6), 215.1 (10), 200.0 (2), 188.1 (3), 175.0 (6), 160.0 (8), 134.1 (8), 120.1 (100), 98.0 (6), 91.0 (22), 79.0 (4), 58.1 (5). HRMS: calc.: 350.1994, found: 350.1986. IR (KBr): ν (cm^{-1}) = 3300, 3062, 3026, 3003, 2981, 2943, 2877, 1645, 1551, 1495, 1446, 1385, 1336, 1254, 1207, 1171, 1105, 1032, 987, 759, 694, 669.

2.1.9. Fumaric amide **4e**: [22]

Prepared by the general procedure. $[\alpha]^D = -140$ (c = 0.10 g/100 mL, methanol). ^{1}H NMR (300 MHz, DMSO-d_6): δ (ppm) = 1.36 (d, J = 7.0 Hz, 6H), 4.98 (pseudo quin, J = 7.0 Hz, 2H), 6.88 (s, 2H), 7.28–7.30 (m, 10H), 8.13 (d, J = 8,34 Hz, 2NH). ^{13}C NMR (75 MHz, DMSO-d_6): δ (ppm) = 22.37, 48.17, 125.91, 126.74, 128.31, 132.88, 144.23, 162.85. MS (EI, eV): *m*/*z* (%): 322.2 $[M]^+$, 307.2 (20), 279.2 (1), 203.1 (2), 174.1 (1), 160.1 (0), 149.1 (2), 131.1 (3), 120.1 (100), 105.1 (44), 99.0 (10), 91.1 (2), 77.1 (4), 55.1 (2). HRMS calc.: 322.1681, found: 322.1689. IR (KBr): ν (cm^{-1}) = 3278, 3066, 2968, 2929, 1632, 1549, 1448, 1356, 1261, 1209, 1192, 1105, 1020, 993, 802, 696.

2.1.10. Fumaric amide **4f**

Prepared by the general procedure. $[\alpha]^D = +34$ (c = 0.14 g/100 mL, DMSO). ^{1}H NMR (300 MHz, DMSO): δ (ppm) = 1.51 (d, J = 7.0 Hz, 6H), 5.77 (quin, J = 7.2 Hz, 2H), 6.92 (s, 2H), 7.47–7.57 (m, 8H), 7.81 (dd, J = 1.3, 7.5 Hz, 2H), 7.93 (dd, J = 1.9, 7.5 Hz, 2H), 8.10 (dd, J = 1.3, 7.9 Hz, 2H), 8.97 (d, J = 8.10 Hz, 2H). ^{13}C NMR (75 MHz, DMSO-d_6): δ (ppm) = 21.42, 44.31, 122.26, 122.94, 125.39, 126.14, 127.28, 128.59, 130.22, 132.81, 133.31, 139.67, 162.63. MS (EI, eV): *m*/*z* (%): 422.2 (8) $[M]^+$, 171.1 (15), 170.1 (100), 155.0 (50), 129.0 (5). HRMS: calc.: 422,1994, found: 422.2005. IR (KBr): ν (cm^{-1}) = 3278, 3070, 3060, 2972, 2931, 2873, 1621, 1541, 1452, 1348, 1192, 1119, 1005, 798, 775.

2.1.11. Fumaric amide **4g**: [10b]

Prepared by the general procedure. ^{1}H NMR (300 MHz, DMSO): δ (ppm) = 1.28 (s, 18H), 6.78 (s, 2H), 7.97 (br s, 2H).

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References

[1] (a) D. Astruc, New J. Chem. 28 (2005) 42;
(b) T.J. Katz, Angew. Chem. 117 (2005) 3070;
(c) Angew. Chem Int. Ed. 44 (2005) 3010.
[2] R.H. Grubbs (Ed.), Handbook of Metathesis, 1–3, Wiley–VCH, Weinheim, 2003.
[3] (a) R.H. Grubbs, Tetrahedron 60 (2004) 7117;
(b) T.M. Trnka, R.H. Grubbs, Acc. Chem. Res. 3 (2001) 18;
(c) S.J. Connon, S. Blechert, Angew. Chem. 115 (2003) 1944;
(d) Angew. Chem Int. Ed. 42 (2003) 1900;
(e) A. Deiters, S.F. Martin, Chem. Rev. 104 (2004) 2199;
(f) R.H. Grubbs, S. Cheng, Tetrahedron 54 (1998) 4413;
(g) M.D. McReynolds, J.M. Dougherty, P.R. Hanson, Chem. Rev. 104 (2004) 2239;
(h) S.K. Armstrong, J. Chem. Soc., Perkin Trans 1 (1998) 371.
[4] (a) Schrock has developed defined molybdenum carbene catalysts, which usually surpass the ruthenium catalyst with regard to activity, but show a less general functional group tolerance. R.R. Schrock, Chem. Commun. (in press);
(b) R.R. Schrock, A.H. Hoveyda, Angew. Chem. 115 (2003) 4740;
(c) Angew. Chem Int. Ed. 42 (2003) 4592.
[5] (a) A. Fürstner, Angew. Chem. 115 (2003) 3706;
(b) Angew. Chem Int. Ed. 42 (2003) 3582.
[6] T. Katsuki, V.S. Martin, Org. React. 48 (1996) 1.
[7] T.-L. Choi, A.K. Chatterjee, R.H. Grubbs, Angew. Chem. 113 (2001) 1317.
[8] M. Scholl, S. Ding, C.W. Lee, R.H. Grubbs, Org. Lett. 1 (1999) 953.
[9] (a) K. Furuta, K. Iwanaga, H. Yamamoto, Tetrahedron Lett. 27 (1986) 4507;
(b) H.M. Walborsky, L. Barash, T.C. Davis, Tetrahedron 19 (1963) 2333.
[10] (a) T.R. Kelly, R.L. Lebedev, J. Org. Chem. 67 (2002) 2197;
(b) S. König, S. Lohberger, I. Ugi, Synthesis (1993) 1223.

[11] (a) H. Miyabe, M. Ueda, A. Nishimura, T. Naito, Tetrahedron 60 (2004) 4227;
(b) F. Lo Galbo, E.G. Occhiato, A. Guarna, C. Faggi, J. Org. Chem. 68 (2003) 6360.
[12] W.D. Emmons, T.E. Stevens, Eur. Pat. Appl. EP 63,018, 1983.
[13] J. Cabral, P. Laszlo, M.T. Montaufier, S.L. Randriamanhefa, Tetrahedron Lett. 31 (1990) 1705.
[14] C.W. Roberts, N.F. Nuenke, J. Org. Chem. 24 (1959) 1907.
[15] S. Kohmoto, Y. Miyaji, T. Yoshiyuki, M. Tsuruoka, K. Kishikawa, M. Yamamoto, K. Yamada, J . Chem. Soc., Perkin Trans 1 (2004) 2082.
[16] S. Puertas, R. Brieva, F. Rebolledo, V. Gotor, Tetrahedron 49 (1993) 4007.
[17] N.S. Barta, A. Brode, J.R. Stille, J. Am. Chem. Soc. 116 (1994) 6201.
[18] R. Grigg, M. Monteith, V. Sridharan, C. Terrier, Tetrahedron 54 (1998) 3885.
[19] H. Plaut, J.J. Ritter, J. Am. Chem. Soc. 73 (1951) 4076.
[20] M.T.W. Hearn, A.D. Ward, Aust. J. Chem. 30 (1977) 2031.
[21] N.B. Mehta, A.P. Phillips, F.F. Lui, R.E. Brooks, J. Org. Chem. 25 (1960) 1012.
[22] K. Harada, K. Matsumoto, J. Org. Chem. 31 (1966) 2985.