Solid-phase synthesis of *N*-(buta-2,3-dien-1-yl)amides by the Crabbé reaction

Tuomo Leikoski, Pauli Wrigstedt, Jorma Matikainen, Jussi Sipilä, and Jari Yli-Kauhaluoma

Abstract: The Crabbé homologation of polymer-supported propargylamine with paraformaldehyde, CuI, and dicyclohexylamine in 1,4-dioxane at 100 °C, followed by cleavage with dilute trifluoroacetic acid, furnishes *N*-(buta-2,3-dien-1-yl)amides as isolable products. The *N*-acyltriazene linker on Merrifield resin serves simultaneously as a protecting group for the nucleophilic primary amine. The product diversity is achieved by altering the acyl chloride in the acylation of the triazene linker. In addition to being a new route to nitrogen-containing allenes, our solid-phase method enables immobilization of these reactive cumulated dienes for further synthetic operations.

Key words: allene, solid phase, Crabbé, homologation, propargylamine.

Résumé : La réaction d'homologation de Crabbé de la propargylamine fixée à un polymère, par du paraformaldéhyde, en présence de CuI et de dicyclohexylamine, dans le 1,4-dioxane, à 100 °C, suivie par un clivage à l'aide d'acide trifluoroacétique dilué, conduit à la formation de *N*-(buta-2,3-dién-1-yl)amides comme produits isolables. Le *N*-acyltriazène utilisé comme coupleur sur la résine de Merrifield agit simultanément comme groupe protecteur pour l'amine primaire nucléophile. La diversion des produits est obtenue en modifiant la nature du chlorure d'acyle utilisé dans l'acylation du coupleur triazène. En plus d'être une nouvelle voie vers des allènes contenant de l'azote, notre méthode en phase solide permet d'immobiliser ces dienes cumulés réactifs en vue d'opérations de synthèse ultérieures.

Mots-clés : allène, phase solide, Crabbé, homologation, propargylamine.

[Traduit par la Rédaction]

Introduction

Allenes as cumulated dienes are useful and versatile synthetic intermediates in numerous synthetic applications, e.g., in gold-catalyzed intramolecular hydroamination reactions[1] and in photoinduced [2 + 2] cycloadditions with olefins.[2] Moreover, nitrogen-containing, such as amidomethyl-substituted, allenes are useful building blocks in organic synthesis.[3] Certain aminoallenes, such as 1-amino-2,3-butadiene, have been associated with monoamine oxidase B inhibition.[4] Our continuing interest in immobilizing amines onto solid support and modifying them by carbon–carbon bond-forming reactions[5] was the starting point for the study of the one-carbon homologation of solid-supported propargylamine. Keeping in mind the easy nucleophilic attack of primary amines at the central carbon atom of allenes, to give enamines,[6] the general reactivity and potent lability of cumulated carbon–carbon double bonds make the synthesis and use of allenes sometimes challenging.

To the best of our knowledge, there are no reports about the solid-phase synthesis of allenes. Rafai Far and Tidwell[7] prepared allenecarboxylic esters for β-ketoester equivalents by the Wittig reaction, starting from α-haloacetates, which were attached on soluble poly(ethylene glycol). On the other hand, Ma et al.[8,9] used 1,2-allenyl carboxylic acids in solution in a palladium(0)-catalyzed cyclization reaction with polymer-bound aryl iodides to give butenolides. The α-allenyl amine derivatives of our interest have previously been synthesized in solution, e.g., Casara et al.[10] prepared a series of α-allenyl amines from *N-tert*-butoxycarbonyl-protected propargylamines by the Crabbé reaction for inhibition studies of pyridoxal-phosphate-dependent enzymes. There are, however, no examples of the synthesis of simple *N*-(buta-2,3-dien-1-yl) amides in the literature.

Owing to the sensitivity of these nitrogen-containing allenes, the linker on the polymer must be stable enough during the preparation and storage to serve simultaneously as the crucial protective group. In addition, the cleavage step should be

Received 29 June 2012. Accepted 27 September 2012. Published at www.nrcresearchpress.com/cjc on 19 December 2012.

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This article is part of a Special Issue dedicated to Professor Derrick Clive.

performed fast and simply, under as mild conditions as possible. The drawbacks of many cleavage procedures of amines are long reaction times under relatively harsh conditions, such as 60% trifluoroacetic acid (TFA) in dichloromethane[11] or oxidation with 2,3-dichloro-5,6-dicyano-1,4-benzoquinone (DDQ).[12] These procedures would not be among the first desirable options to choose. It would also be preferable if the allenes could be cleaved as some less reactive derivatives of amines.

We decided to test the triazene linkage[13] for immobilization of propargylamine to fit the requirements mentioned previously. This linker is prepared from Merrifield resin-bound 3-aminophenol by diazotization and adding a primary amine to the polymer-bound diazonium salt. The triazene moiety can be acylated with acyl chlorides and it is cleavable as an amide, with 5% TFA in CH_2Cl_2 at room temperature, within a few minutes. These immobilized triazenes are remarkably stable at room temperature under dry conditions and they are safe to handle when compared with triazenes in solution, which are potent carcinogens.[14]

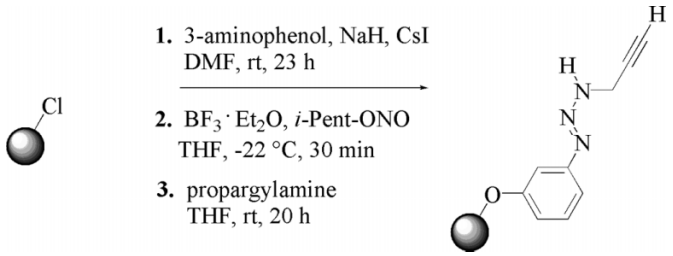
For the allene formation we used the Crabbé reaction,[15] which is a powerful method for homologation of terminal alkynes. In the updated procedure, alkyne is heated with paraformaldehyde, dicyclohexylamine, and copper(I) iodide in 1,4-dioxane at 100 °C.[16] Since the reaction involves a Mannich base derived from acetylene, formaldehyde, and amine as an intermediate, which turns to the allene via the copper-mediated 1,5-hydride transfer, the use of a secondary amine is necessary.[15,17] Anhydrous conditions are essential. In comparison, in a study by Bieber and da Silva,[18] a series of terminal alkynes was subjected to the related Mannich conditions in aqueous dimethyl sulfoxide at 30 °C to give tertiary propargylamines as products instead of allenes.

Results and discussion

We immobilized propargylamine on Merrifield resin (Scheme 1) according to the known literature procedure for primary amines,[13] with minor modifications. In the attachment of 3-aminophenol to the Merrifield resin, 5 mol % of cesium iodide was added to increase the rate of the substitution reaction. For the formation of diazonium salt from polymer-bound 3-aminophenol, isopentyl nitrite was used instead of *tert*-butyl nitrite. This three-step transformation was a reliable method and easy to reproduce. The intermediate orange (deep carmine-red with solvent) polymer-bound diazonium salt is relatively stable to air and safe to handle. The air-stable brown-orange (deep orange-red with solvent) propargyltriazene resin is formed by the addition of propargylamine to the polymer-bound diazonium salt in dry tetrahydrofuran (THF) at room temperature.

To broaden the product diversity and to improve the stability, the NH group of the triazene moiety was acylated with various acyl chlorides[13] prior to the Crabbé reaction and cleavage (Scheme 2). At this stage, the order of introduction of the reagents into the reaction medium is particularly important. Triethylamine must be added before the acyl chloride to maintain a basic solution phase throughout the reaction. Acyl chlorides alone cleave the extremely acid-labile triazene,[19] liberating propargylamine as an amide into the solution. In fact, we observed that the triazene linker is cleaved by far more dilute TFA concentrations than 5% in CH_2Cl_2, so acidic contamination must be excluded in all operations.

Scheme 1. Loading of propargylamine to polystyrene through a triazene linker. rt, room temperature.



In our studies with seven various polymer-bound acyltriazenes, the yield of allene from propargyl triazene resin varied between 10% and 63%, depending on the N substituent (Table 1). It is very likely that the allene formation is strongly controlled by steric factors, because the best yields were obtained with simple small-sized aliphatic N substituents, acetyl, and pivaloyl groups. Otherwise, a yield significantly higher than 11% of the electronically very similar *N*-octanoyl-substituted product would have been expected. However, although sterically crowded, the pivaloyl group is apparently too short to reach the vicinity of the terminal acetylene unit to interfere with the reaction. On the other hand, the reactivity of the acryloyl group apparently suppresses the yield, despite its small size.

It must be pointed out that the yield of the isolated product does not necessarily solely illustrate the success of the Crabbé reaction on resin. Decomposition after the cleavage cannot be excluded, despite the fast procedure (2 × 15 min) and the immediate neutralization of additional TFA using $NaHCO_3$, after filtering the resin off. This was very evident with the *N*-2-phenylacetyl-substituted triazene resin, which gave, according to ^{1}H NMR, an approximate 1:1 mixture of the desired allene and phenylacetic acid as the cleavage product. Decomposition, although in this particular case probably independent of the allene moiety, is understandable considering the easy acidolysis of 2-phenylacetamide to phenylacetic acid.[20] According to thin-layer chromatography, this allene product also decomposes on silica gel.

We studied the stability of the isolated and purified *N*-4-nitrobenzoyl-substituted allene by dissolving a sample to 5% TFA in $CDCl_3$ and monitoring the content by ^{1}H NMR for 24 h (27 °C, 8 h; and 21 °C, 16 h). A little surprisingly, the product was totally intact despite this prolonged acidic treatment, demonstrating its stability in mild acidic conditions. Thus, we assume that the cleavage with 5% TFA in CH_2Cl_2 is not the origin of decomposition or suppression of the yields, except with the previously mentioned *N*-2-phenylacetyl derivative.

The *N*-(buta-2,3-dien-1-yl)amides generally appeared to be fairly stable when stored below –18 °C under argon and protected from light. The compounds could be characterized unambiguously with very distinct allenic traces at 1950–1960 cm^{-1} by FT-IR, and 4.7–4.9 ppm (td) and 5.1–5.4 ppm (quint) by ^{1}H NMR. The CH_2, CH, and central carbon atom signals were also distinct at 78, 87–88, and 208 ppm, respectively, by ^{13}C NMR. However, a small amount of aliphatic polymers appeared in most products, according to signals in the ^{1}H and ^{13}C NMR, at around 0.8–2.2 and 20–30 ppm, respectively, demonstrating slow decomposition. Despite this, considering the treatment of the previously mentioned *N*-phenylacetyl derivative,

Scheme 2. *N*-Acylation and the allene formation from the propargyltriazene resin. rt, room temperature.

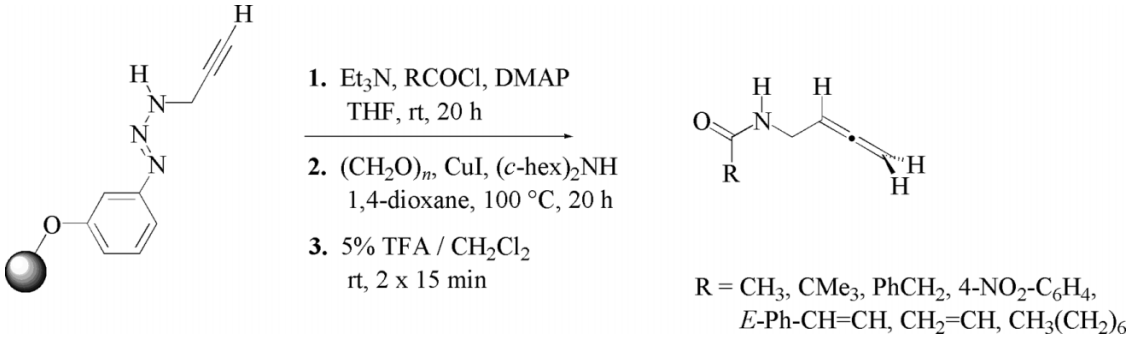


Table 1. Yields of isolated *N*-(buta-2,3-dien-1-yl)amides obtained with various acyl chlorides.

Entry	R in RCOCl	Yield (%)
1	CH_3	63
2	CMe_3	53
3	$PhCH_2$	10
4	4-NO_2–C_6H_4	13
5	(*E*)-Ph–CH=CH	20
6	CH_2=CH	18
7	$CH_3(CH_2)_6$	11

upon isolation (see the Experimental section) it is evident that these allenes can tolerate even water for short periods.

Conclusion

We have developed a solid-phase method that introduces new possibilities in the syntheses of biologically active nitrogen-containing allenes. All reagents required in our reaction sequence are inexpensive and the final products are afforded by a cleavage reaction under very mild conditions. Although the yields of the isolated products in this preliminary study are moderate, our method enables access to *N*-(buta-2,3-dien-1-yl)amides, demonstrated by seven new characterized compounds. Owing to the versatility of allenes as synthetic intermediates, the possibility of immobilizing potentially labile cumulated carbon–carbon double bonds on solid support for further reactions is even more interesting. Hence, our solid-phase method introduces interesting possibilities for new applications.

Experimental

General

Reagents were obtained from Sigma-Aldrich, Fluka, Acros, Riedel-de Haën, and Merck. Merrifield resin (loading: 0.64 mmol/g, 200–400 mesh, cross-linked with 1% divinylbenzene) was commercially available from Novabiochem. The yields are based on the actual loading of 0.59 mmol/g of the propargyltriazene resin. *N*,*N*-Dimethylformamide (DMF) was dried by distillation from anhydrous $CaSO_4$ under reduced pressure. THF and 1,4-dioxane were dried by distillation from sodium or with activated 3 Å molecular sieves. Triethylamine was dried by distillation from P_2O_5 or with activated 3 Å molecular sieves. Dicyclohexylamine was dried with activated 3 Å molecular sieves. Otherwise, commercial grade reagents and solvents were used without further purification or drying. Merck aluminium sheets coated with silica gel 60 F_{254} were used for thin-layer chromatography and they were visualized by UV light at 254 nm or by brief heating at 120 °C, after wetting with 0.4 mol/L vanilline solution in H_2SO_4/ethanol (1:100, v/v). Column chromatography was performed with Fluka silica gel 60, 230–400 mesh. ^1H and ^{13}C NMR spectra were recorded at 300 and 75 MHz, respectively, on a Varian Mercury 300 Plus spectrometer. Chemical shifts are relative to the residual solvent signal 7.26 ppm of $CDCl_3$ in the ^1H spectra and to the NMR solvent signal 77.2 ppm for $CDCl_3$ in the ^{13}C spectra. FT-IR spectra were recorded on a PerkinElmer Spectrum One FT-IR spectrometer equipped with a one reflection attenuated total reflection (ATR) unit. Melting points were obtained with an Electrothermal melting point apparatus (Cat. No. IA6301) and they are uncorrected. High-resolution (HR) electron impact (EI) mass spectrometry (MS) analyses were performed using a Jeol JMS-700 mass spectrometer at 700 eV.[21] GC–MS analyses were performed using an Agilent 6890N gas chromatograph equipped with a DB-1MS capillary column (34.0 m × 250 μm × 0.25 μm; calibrated) and Agilent 5973 Network mass-selective detector.

Loading of propargylamine to polystyrene through a triazene linker

Dry DMF (13 mL/g resin) was added to a mixture of the Merrifield resin (loading: 0.64 mmol/g), sodium hydride as a dispersion with mineral oil (~50%, 5 equiv), and cesium iodide (0.05 equiv) under argon. 3-Aminophenol (5 equiv) in dry DMF (4 mL/g) was slowly added at 0 °C and the mixture was stirred at room temperature for 23 h. The resin was filtered, washed three times (3 × 3 mL/g resin) with each of THF, MeOH, and CH_2Cl_2, and dried fast in high vacuum. Dry THF (9 mL/g resin) was added and the mixture was cooled under argon to –22 °C by means of EtOH / dry ice. After that, BF_3·Et_2O (8 equiv) was added, followed after 5 min by isopentyl nitrite (8 equiv). The mixture was stirred for 30 min in an EtOH / dry ice bath, filtered, and washed four times (4 × 3 mL/g resin) with cold THF. Dry THF (9 mL/g resin) and propargylamine (10 equiv) were added and the mixture was stirred at room temperature for 20 h under argon. After the addition of methanol/THF (1:1, v/v; 3 mL/g resin), the mixture was filtered, washed three times (3 mL/g resin) with each of THF, MeOH, and CH_2Cl_2, and dried in vacuo to constant

weight, which is in agreement with the quantitative attachment of propargylamine, with a new loading of 0.59 mmol/g. The resin was stored in a desiccator at room temperature.

General procedure for the *N*-acylation and the allene formation from the propargyltriazene resin

Propargyltriazene resin (1.0 g, 0.59 mmol/g) was swollen in 10 mL of dry THF. A catalytic amount of 4-dimethylaminopyridine (DMAP) and 1.0 mL of dry triethylamine were added, followed by 5–7 equiv of the acyl chloride under stirring. The mixture was stirred at room temperature for 21–24 h. The resin was filtered and washed twice (2 × 10 mL) with each of DMF, MeOH, THF, diethyl ether, and CH_2Cl_2, and introduced directly into the allene formation reaction. The resin, 5–6 equiv of paraformaldehyde, 0.5–0.6 equiv of CuI, and 2 equiv of dicyclohexylamine, in 5.0–10 mL of dry 1,4-dioxane, were stirred under argon at 100 °C for 20–22 h. The resin was filtered, washed twice (2 × 10 mL) with each of 1,4-dioxane, *n*-hexane, THF, diethyl ether, and CH_2Cl_2, and subjected to the cleavage step.

General procedure for the cleavage of the *N*-acylated allene product

The polymer-bound *N*-acylated allene product was double-cleaved by stirring the resin twice in 5% trifluoroacetic acid in dichloromethane (10 mL) at room temperature for 15 min. After both treatments, the resin was filtered and washed (1 × 10 mL) with each of CH_2Cl_2, diethyl ether, and CH_2Cl_2. The filtrates were immediately neutralized with solid $NaHCO_3$ (2.0 g), and the solvents were evaporated. The allene product was purified by flash chromatography if necessary or applicable and stored in a freezer, under argon and protected from light.

Syntheses of *N*-(buta-2,3-dien-1-yl)amides (1–7)

^{1}H NMR and ^{13}C NMR spectra for compounds **1–7** are available in the Supplementary data.

N-*(Buta-2,3-dien-1-yl)acetamide (1)*

Propargyltriazene resin (1.0 g, 0.59 mmol) was treated with acetyl chloride (0.30 mL, 330 mg, 4.2 mmol) for 22 h according to the general procedure (without DMAP). The allene formation was achieved by reaction with paraformaldehyde (95.0 mg, 3.16 mmol CH_2O), CuI (59.2 mg, 0.311 mmol), and dicyclohexylamine (226 mg, 1.25 mmol) for 20 h. The product was cleaved (general procedure) and dried in vacuo. Yellow-brown oil (41.0 mg, 63%). R_f = 0.07 (EtOAc–*n*-hexane, 1:1/vanilline–H_2SO_4). IR (ATR, cm^{-1}): 705, 798, 849, 1152, 1548, 1647, 1959. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 2.07 (s, 3H), 3.86 (m, 2H), 4.87 (td, J = 3.3, 6.5 Hz, 2H), 5.21 (quint, J = 6.3 Hz, 1H), 6.05 (br s, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 22.8, 38.1, 78.2, 87.3, 172.2, 208.2. GC–MS (*m*/*z*): 111, 110, 72, 70, 69, 68, 43, 32, 30, 28 (100%), 18.

N-*(Buta-2,3-dien-1-yl)pivalamide (2)*

Propargyltriazene resin (1.0 g, 0.59 mmol) was treated with pivaloyl chloride (0.50 mL, 490 mg, 4.1 mmol) for 21 h according to the general procedure. The allene formation was achieved by reaction with paraformaldehyde (99.2 mg, 3.30 mmol CH_2O), CuI (56.4 mg, 0.296 mmol), and dicyclohexylamine (221 mg, 1.22 mmol) for 20 h. The product was cleaved (general procedure) and dried in vacuo. Yellow-brown oil (48.0 mg, 53%). R_f = 0.41 (EtOAc–*n*-hexane, 1:1/vanilline–H_2SO_4). IR (ATR, cm^{-1}): 705, 845, 1166, 1201, 1525, 1641, 1959, 2963, 3342. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 1.21 (s, 9H), 3.84 (m, 2H), 4.88 (td, J = 3.5, 6.9 Hz, 2H), 5.24 (quint, J = 6.0 Hz, 1H), 6.05 (br s, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 27.6, 37.4, 38.9, 78.2, 88.2, 179.1, 207.9. HR-MS calcd for $C_9H_{15}NO$: 153.11536; found: 153.1146.

N-*(Buta-2,3-dien-1-yl)-2-phenylacetamide (3)*

Propargyltriazene resin (1.0 g, 0.59 mmol) was treated with phenylacetyl chloride (0.50 mL, 580 mg, 3.8 mmol) for 24 h according to the general procedure. The allene formation was achieved by reaction with paraformaldehyde (106 mg, 3.53 mmol CH_2O), CuI (64.3 mg, 0.338 mmol), and dicyclohexylamine (213 mg, 1.17 mmol) for 23 h. The product was cleaved (general procedure) and dried in vacuo. The oily residue was dissolved in chloroform, ~1 mL of triethylamine was added (removal of phenylacetic acid), the solution was filtered through a small plug of $NaHCO_3$, and the solvents were evaporated. The residue was dissolved in chloroform and ethyl acetate and washed twice with water. The organic phase was evaporated twice with acetone, and the product was dried in vacuo. Brown oil (11.4 mg, 10%). R_f = 0.0 (dec.; EtOAc–*n*-hexane, 1:1/UV). IR (ATR, cm^{-1}): 696, 719, 847, 1539, 1647, 1957, 2929. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 3.59 (s, 2H), 3.80 (m, 2H), 4.73 (td, J = 3.4, 6.8 Hz, 2H), 5.15 (quint, J = 6.1 Hz, 1H), 5.52 (br s, 1H), 7.22–7.39 (m, 5H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 37.4, 43.9, 78.1, 88.0, 127.6, 129.2, 129.8, 134.8, 171.1, 207.7. HR-MS calcd for $C_{12}H_{13}NO$: 187.09971; found: 187.0990.

N-*(Buta-2,3-dien-1-yl)-4-nitrobenzamide (4)*

Propargyltriazene resin (1.0 g, 0.59 mmol) was treated with 4-nitrobenzoyl chloride (659 mg, 3.55 mmol) for 24 h according to the general procedure. The allene formation was achieved by reaction with paraformaldehyde (89.5 mg, 2.98 mmol CH_2O), CuI (60.2 mg, 0.316 mmol), and dicyclohexylamine (218 mg, 1.20 mmol) for 21 h. The product was cleaved (general procedure) and dried in vacuo. Column chromatography on SiO_2 (acetone–$CHCl_3$, 1:10) gave the product. Yellow crystals (17.1 mg, 13%; $CHCl_3$), mp 119–122 °C. R_f = 0.36 (EtOAc–*n*-hexane, 1:1/UV). IR (ATR, cm^{-1}): 686, 707, 861, 1349, 1510, 1598, 1638, 1955, 3287, 3329. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 4.07 (m, 2H), 4.92 (td, J = 3.4, 6.7 Hz, 2H), 5.35 (quint, J = 6.2 Hz, 1H), 6.38 (br s, 1H), 7.93 (d, J = 8.9 Hz, 2H), 8.28 (d, J = 8.9 Hz, 2H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 38.2, 78.4, 87.8, 124.0, 128.3, 140.2, 149.8, 165.4, 208.2. HR-MS calcd for $C_{11}H_{10}N_2O_3$: 218.06914; found: 218.0704.

N-*(Buta-2,3-dien-1-yl)cinnamamide (5)*

Propargyltriazene resin (1.0 g, 0.59 mmol) was treated with cinnamoyl chloride (predominantly *E* isomer; 605 mg, 3.63 mmol) for 24 h according to the general procedure. The allene formation was achieved by reaction with paraformaldehyde (100 mg, 3.33 mmol CH_2O), CuI (67.5 mg, 0.354 mmol), and dicyclohexylamine (223 mg, 1.23 mmol) for 22 h. The product was cleaved (general procedure) and dried in vacuo. Column chromatography on SiO_2 (*n*-hexane to EtOAc–*n*-hexane, 2:3) gave the product. Pale yellow solid (23.0 mg, 20%; $CHCl_3$), mp 70–71 °C. R_f = 0.33 (EtOAc–*n*-hexane, 1:1/UV). IR (ATR, cm^{-1}): 674, 727, 853, 971, 1222, 1343,

1552, 1610, 1655, 1952, 3246. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 3.99 (m, 2H), 4.86 (td, J = 3.3, 6.5 Hz, 2H), 5.28 (quint, J = 6.3 Hz, 1H), 6.01 (br s, 1H), 6.43 (d, J = 15.6 Hz, 1H), 7.29–7.39 (m, 3H), 7.44–7.53 (m, 2H), 7.63 (d, J = 15.6 Hz, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 37.9, 77.8, 88.0, 120.6, 127.9, 128.9, 129.8, 134.9, 141.3, 165.9, 208.2. HR-MS calcd for $C_{13}H_{13}NO$: 199.09971; found: 199.0994.

N-*(Buta-2,3-dien-1-yl)acrylamide (6)*

Propargyltriazene resin (1.0 g, 0.59 mmol) was treated with acryloyl chloride (0.30 mL, 330 mg, 3.6 mmol) for 23 h according to the general procedure. The allene formation was achieved by reaction with paraformaldehyde (112 mg, 3.73 mmol CH_2O), CuI (57.8 mg, 0.303 mmol), and dicyclohexylamine (222 mg, 1.22 mmol) for 21 h. The product was cleaved (general procedure) and dried in vacuo. Column chromatography on SiO_2 (*n*-pentane to acetone–*n*-pentane, 1:4) gave the product. Pale yellow oil (13.0 mg, 18%). R_f = 0.20 (EtOAc–*n*-hexane, 1:1/vanilline–H_2SO_4). IR (ATR, cm^{-1}): 720, 730, 1240, 1463, 1660, 1739, 1958, 2849, 2917. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 3.94 (m, 2H), 4.86 (td, J = 3.4, 6.7 Hz, 2H), 5.26 (quint, J = 6.3 Hz, 1H), 5.65 (dd, J = 1.4, 10.2 Hz, 1H), 5.66 (br s, 1H), 6.09 (dd, J = 10.1, 17.1 Hz, 1H), 6.29 (dd, J = 1.4, 16.9 Hz, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 37.9, 78.1, 87.5, 127.5, 130.4, 166.4, 208.2. GC–MS (*m*/*z*): 123, 122, 94, 84, 70, 69, 55 (100%), 32, 28, 18.

N-*(Buta-2,3-dien-1-yl)octanamide (7)*

Propargyltriazene resin (1.0 g, 0.59 mmol) was treated with *n*-octanoyl chloride (0.50 mL, 480 mg, 3.0 mmol) for 17 h according to the general procedure. The allene formation was achieved by reaction with paraformaldehyde (95.0 mg, 3.16 mmol CH_2O), CuI (56.9 mg, 0.299 mmol), and dicyclohexylamine (216 mg, 1.19 mmol) for 22 h. The product was cleaved (general procedure) and dried in vacuo. Column chromatography on SiO_2 (*n*-hexane to EtOAc–*n*-hexane, 1:1) gave the product. Yellow oil (13.0 mg, 11%). R_f = 0.33 (EtOAc–*n*-hexane, 1:1/vanilline–H_2SO_4). IR (ATR, cm^{-1}): 843, 1544, 1644, 1959, 2925, 3286. ^{1}H NMR (300 MHz, $CDCl_3$) δ: 0.87 (t, J = 6.9 Hz, 3H), 1.15–1.39 (m, 8H), 1.52–1.72 (m, 2H), 2.17 (t, J = 7.6 Hz, 2H), 3.85 (m, 2H), 4.84 (td, J = 3.4, 6.7 Hz, 2H), 5.22 (quint, J = 6.3 Hz, 1H), 5.57 (br s, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 14.2, 22.7, 25.9, 29.2, 29.4, 31.8, 36.9, 37.5, 77.8, 88.3, 173.1, 208.1. HR-MS calcd for $C_{12}H_{21}NO$: 195.16231; found: 195.1628.

Supplementary data

Supplementary data (^{1}H NMR and ^{13}C NMR spectra for compounds **1**–**7**) are available with this article through the journal Web site at http://nrcresearchpress.com/doi/suppl/10.1139/cjc-2012-0255.

Acknowledgement

This research has been financially supported by TEKES (the Finnish Funding Agency for Technology and Innovation), Juvantia Pharma Ltd., Orion Corporation, Hormos Medical, the Academy of Finland, Drug Discovery and Development Technology Center (DDTC) research programme of the University of Helsinki, and the Finnish Work Environment Fund. We thank Dr. A.W.T. King for reviewing the language.

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(21) HR-MS analysis was preferred over elemental analysis for these relatively labile allenes. Our attempts to obtain HR-MS spectra of the acetyl- and acryloyl-substituted products (Table 1, entries 1 and 6) failed because of their high volatility in the prevacuum of the mass spectrometer. However, GC–MS and ^{1}H and ^{13}C NMR data are fully unambiguous with the structures shown.