Scope and limitations of the solution and solid phase synthesis of homoallylic amines via *N*-acyliminium ion reactions

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This paper is dedicated to Prof. Binne Zwanenburg on the occasion of his 70th birthday
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Abstract
The full scope and limitations of solution and solid phase one-pot three component *N*-acyliminium ion reactions are detailed. After studying the scope in solution with respect to the carbamate, nucleophile and aldehyde component, a 'translation' was made to the solid phase. The solid phase reactions were eventually carried out using the so-called SEC linker system, which was previously developed in our group. In order to maximize the scope of the nucleophile component, additional studies were successfully conducted using two-step processes involving stable *N*-acyliminium ion precursors.

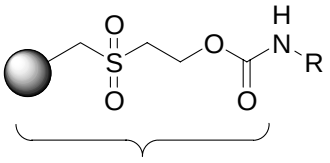
Keywords: *N*-Acyliminium ion, multicomponent reaction, solid phase chemistry, homoallylic amines, combinatorial chemistry

Introduction

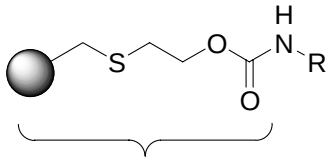
In the past decade, numerous types of reactions have been 'translated' from the solution to the solid phase, so that solid phase combinatorial chemistry may currently enable the synthesis of various compound libraries of any size.[1] However, solid phase reactions should not simply deliver as many compounds as possible, but rather as 'diverse' compounds as possible. Therefore, in the process of 'translating' solution phase reactions to the solid phase, one should

consider that establishing the scope and limitations on the solid phase in terms of variety in functionality, steric and electronic properties must be an integral aspect of this process.

In a series of publications, it was shown by our group[2,3,4,5] and by others[6] that *N*-acyliminium ion chemistry can be efficiently carried out on a solid phase, provided that an appropriate linker system is used. With the development of the novel polystyrene-based SEC and TEC linker systems,[3-5] an adequate immobilization approach was found in our group. By using these linkers, extensive and more systematic investigations in the scope and limitations of solid phase *N*-acyliminium ion chemistry can be performed. In conjunction with a preliminary publication on one-pot three component *N*-acyliminium ion reaction for the synthesis of homoallylic amines,[2] this paper will detail a full account of the scope and limitations of this reaction.

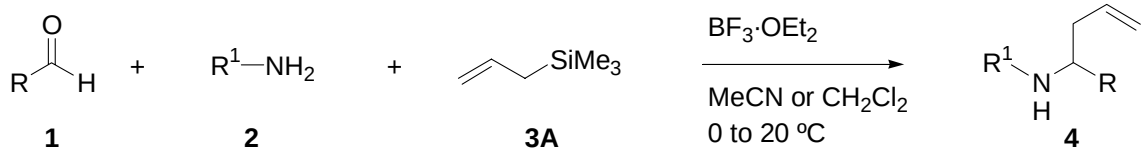


sulfonylethoxycarbonyl (SEC) linker



thioethoxycarbonyl (TEC) linker

In the solution phase one-pot three component synthesis of protected homoallylic amines introduced by Panek[7] and Veenstra,[8] studies on the scope of this *N*-acyliminium ion reaction with respect to the amide and aldehyde components were reported (Scheme 1). These studies showed that a wide variety of aromatic and aliphatic aldehydes could be used in combination with some carbamates and sulfonamides. Electron rich and poor aromatic aldehydes reacted equally well and steric bulk in the aldehyde component did not seem to play a significant role.



1 **2** **3A** **4**

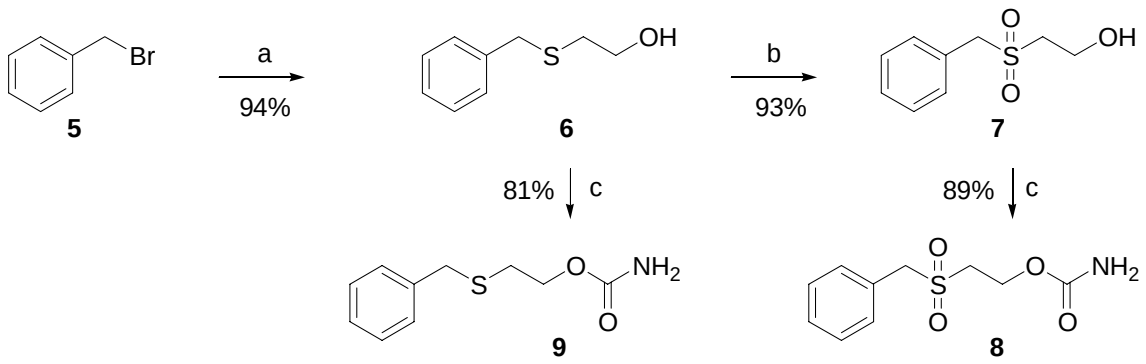
Scheme 1

In this contribution, studies to reach a broader scope of the corresponding solid phase three component *N*-acyliminium ion reaction will be presented to give the corresponding homoallylic amines.[9,] For a better understanding of the solid phase reaction, these investigations started with a more detailed scope determination using solution phase model systems. A significant part of the research focused on the use of reactive species (generated *in situ* or isolated) that subsequently could be used as *N*-acyliminium ion precursors. During the course of our work, the group of Mioskowski reported a similar type of approach,[10] in which *via* a three-component reaction from amides, aldehydes and trimethyl orthoformate a stable *N,O*-acetal was isolated and used as an *N*-acyliminium ion precursor in a subsequent step. This concept may lead to a 'two-

step' rather than a one-pot process, but which eventually might improve the diversity of the resulting products of the *N*-acyliminium ion reaction.

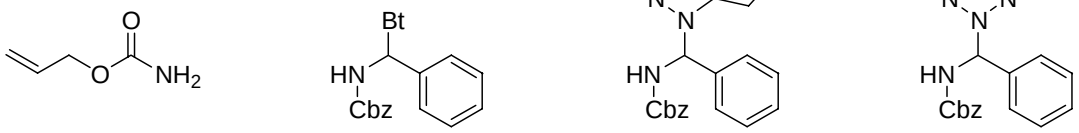
Results and Discussion

In order to synthesize the solution phase model systems, 2-(benzylsulfonyl)ethyl carbamate **8** and the corresponding 2-(benzylthio)ethyl carbamate **9** were obtained using the technology described for the synthesis of the SEC and TEC linker systems.[3,4] To facilitate the purification of the products, the reagents were used in slight excess or in equimolar amounts to provide both carbamates **8** and **9** in good overall yields (78% and 76% over three and two steps, respectively).



Scheme 2. *Reagents and conditions:* (a) Cs_2CO_3 (1.05 equiv), mercaptoethanol (1.05 equiv), DMF, 60 ºC, 4 h, rt, 18 h; (b) *m*CPBA (2.3 equiv), CH_2Cl_2, 0 ºC → rt, 18 h; (c) (1) *p*-nitrophenyl chloroformate (1.0 equiv), *N*-methylmorpholine (1.0 equiv), CH_2Cl_2, 0 ºC → rt, 18 h; (2) NH_3, MeOH/DMF, rt, 18 h.

Allyl carbamate **10** and benzotriazole (Bt) derivative **11** were also prepared as model systems for solution phase *N*-acyliminium ion reactions. The two compounds were prepared according to known literature procedures. Allyl carbamate **10** was obtained in one step from allyl chloroformate using the procedure of Roos *et al.*,[11] while Bt-derivative **11** was obtained in one step from benzyl carbamate using Katritzky technology.[12] Bt-compounds usually exist as a mixture of 1-yl and 2-yl isomers (*viz.* structures 1-yl-**11** and 2-yl-**11**), both of which display a comparable leaving group ability.[13] However, Bt-derivative **11** was mainly isolated as the pure 1-yl-**11** isomer.[12]

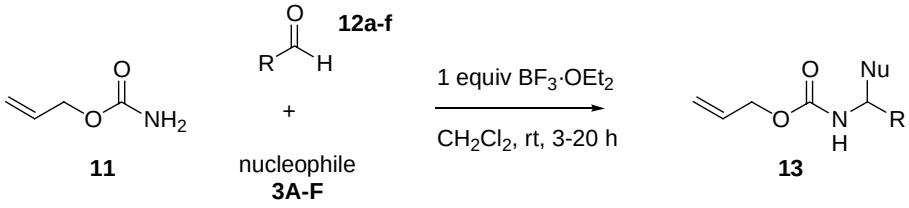


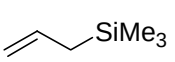
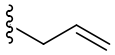
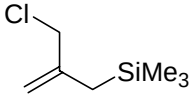
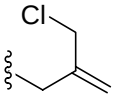
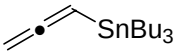
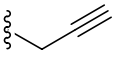
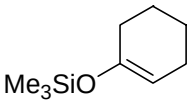
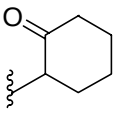
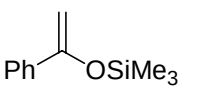
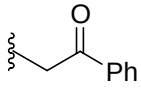
10 **11** 1-yl-**11** 2-yl-**11**

Evidently, allyl carbamate **10** was used as a model system for the allyl carbamate linker, while carbamates **8** and **9** were used as models for the corresponding SEC and TEC linker systems. Benzyl carbamate was used as a simple and readily available model system for a generally immobilized carbamate. To explore the two-step variant of the three component *N*-acyliminium ion reaction, Bt-derivative **11** was used.

First, the scope of the three component *N*-acyliminium ion reaction with allyl carbamate **11** was investigated. This carbamate was reacted with 1 equiv of aldehydes **12a-f**, nucleophile **3A-F** and $BF_3{\cdot}OEt_2$ in CH_2Cl_2 at rt. The reactions were quenched upon disappearance of the starting material or after a maximum reaction time of 20 h. Several aromatic and aliphatic aldehydes were used in combination with allyltrimethylsilane (**3A**). Furthermore, benzaldehyde (**12a**) was used in combination with several nucleophiles (Table 1).

Table 1

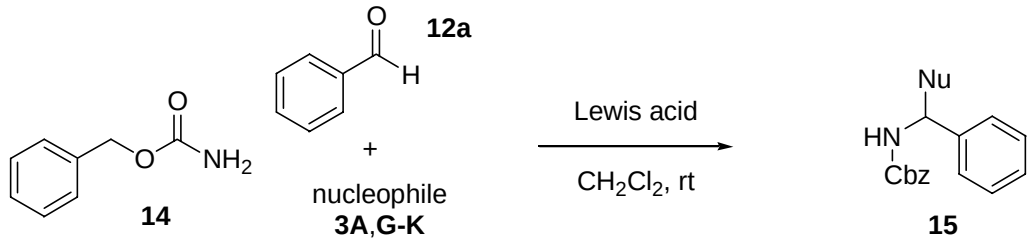


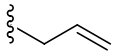
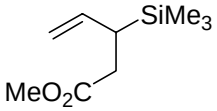
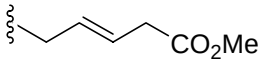
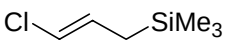
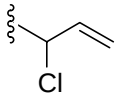
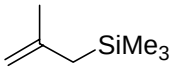
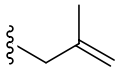
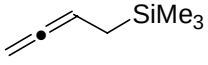
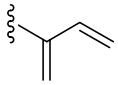
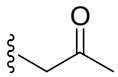
Entry	R	Nucleophile **3**	Time (h)	Nu	Product (yield)
1	Ph (**12a**)	 (**3A**)	3		**13aA** (82%)
2	*p*-$MeOC_6H_4$ (**12b**)	**3A**	3		**13bA** (80%)
3	*p*-NCC_6H_4 (**12c**)	**3A**	20		**13cA** (45%)
4	*p*-$O_2NC_6H_4$ (**12d**)	**3A**	20		**13dA** (40%)
5	*i*-Pr (**12e**)	**3A**	20		**13eA** (44%)
6	Bn (**12f**)[a]	**3A**	20		**13fA** (75%)
7	Ph (**12a**)	 (**3B**)	20		**13aB** (80%)
8	Ph (**12a**)	 (**3C**)	20		**13aC** (10%)
9	Ph (**12a**)	$Me_3Si{-}CN$ (**3D**)	20		**13aD** (5%)
10	Ph (**12a**)	 (**3E**)	20		**13aE** (10%)
11	Ph (**12a**)	 (**3F**)	20		**13aF** (6%)

[a] The corresponding diethyl acetal was used.

As shown in the Table, electron rich aromatic aldehydes (entries 1-2) gave the best results, while the electron poor aromatic aldehydes (entries 3-4) resulted in the formation of the desired homoallylic carbamate in moderate yields and longer reaction times. The same was true for the aliphatic substituents (entries 5-6). With respect to the nucleophile, the scope proved to be significantly narrower. Although the use of the substituted allylsilane **3B** (entry 7) resulted in a high yield of the desired product (80%), the reaction was much slower than with allyltrimethylsilane (**3A**, entry 1). 1,2-Propadienyltributylstannane (**3C**) has been successfully used previously as a nucleophile in *N*-acyliminium ion chemistry.[14] However, in this case, the use of the stannane (entry 8) only resulted in the formation of the desired homopropargylic carbamate **13aC** in a yield of 10%. The use of Me_3SiCN (entry 9) and silyl enol ethers (entries 10-11) gave traces of the desired products, although these nucleophiles have previously shown their viability in *N*-acyliminium ion chemistry.[15,16] The low yields achieved with the nucleophiles **3C-F** might be explained by the rather low stability of these compounds under the conditions needed for the formation of the *N*-acyliminium ion ($BF_3{\cdot}OEt_2$, rt).

Table 2

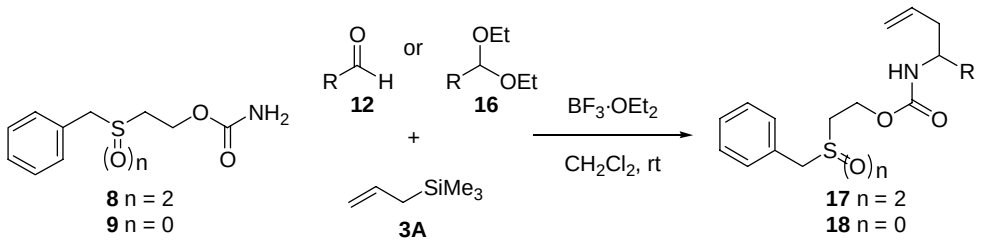


Entry	Nucleophile **3**	Lewis Acid	Time (h)	Nu	Product (yield)
1	**3A**	$BF_3{\cdot}OEt_2$	3		**15aA** (92%)
2	 (**3G**)	$BF_3{\cdot}OEt_2$	4		**15aG** (71%)
3	 (**3H**)	$BF_3{\cdot}OEt_2$	20		-
4	 (**3I**)	$BF_3{\cdot}OEt_2$	20		-
5	 (**3J**)	$BF_3{\cdot}OEt_2$	4		**15aJ** (62%)
6	 (**3K**)	$BF_3{\cdot}OEt_2$	20		-
7	(**3K**)	$Sc(OTf)_3$[a]	18		**15aK** (28%)

[a] A catalytic amount of the Lewis acid (0.1 equiv) was used.

The scope of the solution phase one-pot three component *N*-acyliminium ion reaction with respect to the nucleophile was further investigated using benzyl carbamate (**14**) as a model system (Table 2). The 1-substituted allylsilane **3G** (entry 2) reacted smoothly and resulted in a 71% yield of homoallylic carbamate **15aG**. The geometry of the newly formed double bond was assigned by ^{1}H NMR experiments and proved to be exclusively (*E*). Suprisingly, 2- and 3-substituted allylsilanes **3H** and **3I** (entries 3-4) did not lead to any product formation at all. The steric hindrance of the chloride and methyl substituent on the reactive double bond of the allylsilane might explain the poor reactivity of these nucleophiles in this specific *N*-acyliminium ion reaction. Although the use of 2,3-butadienylsilane **3J** in Sakurai-type additions to aldehydes and acetals has been reported by the groups of Hatakeyama and Takano,[17] the use of this nucleophile in *N*-acyliminium ion reactions has received only recent attention.[18] The application of allenylsilane **3J** in the one-pot three component *N*-acyliminium reaction with benzyl carbamate (**14**) and benzaldehyde (**12a**) resulted in the formation of diene **15aJ** in a yield of 62%. Analogous to the unsuccessful use of silyl enol ethers (Table 1), at this point the more stable vinyl acetate **3K** was used as a nucleophile (entries 6-7). However, under the conditions that were previously used for the formation of the transient cation (1 equiv $BF_3{\cdot}OEt_2$, entry 6), no product was formed either. Recently, new developments to generate iminium and *N*-acyliminium ion intermediates by using catalytic amounts of metal triflates ($Sc(OTf)_3$, $Yb(OTf)_3$, $Sn(OTf)_2$, $Hf(OTf)_4$, *etc*.) have been reported by Kobayashi *et al*.[19] When the Lewis acid was changed to catalytic $Sc(OTf)_3$ (entry 7), the desired ketone **15aK** was obtained, albeit in a low yield of 28%. To gain a better understanding of the 'translation' of the *N*-acyliminium ion reaction to the SEC and TEC linkers that we eventually would like to apply, the model reactions were extended to carbamates having the sulfonylethyl and thioethyl functionalities already present in the molecule. Thus, carbamates **8** and **9** were used for the one-pot three component reactions (Table 3).

Table 3

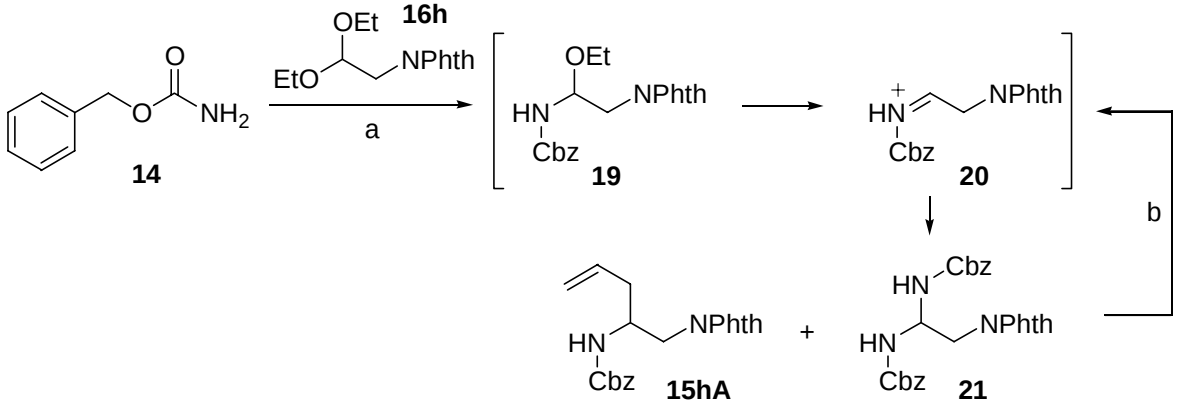


Entry	Carbamate	R (Aldehyde/Acetal)	Time (h)	Product (yield)
1	**8**	Ph (**12a**)	4	**17aA** (89%)
2	**8**	Bn (**16f**)	6[a]	**17fA** (82%)
3	**9**	Ph (**12a**)	5	**18aA** (65%)
4	**9**	*n*-hexyl (**12g**)	18	**18gA** (45%)
5	**9**	*n*-hexyl (**16g**)	18	**18gA** (66%)

[a] Reaction at 50 ºC.

The yield of sulfonylethyl carbamate **17aA** (89%, entry 1) was comparable with the yield earlier obtained in combination with allyl carbamate **11** (82%, Table 1, entry 1). However, the same components in combination with thioethyl carbamate **9** afforded product **18aA** in a somewhat lower yield (65%, entry 3). This finding was comparable to solid phase results obtained with other *N*-acyliminium ion reactions on the SEC and TEC linker systems.[4] The lower yields with thioethyl carbamate **9** and the corresponding TEC resin might be explained by the presence of the nucleophilic sulfur functionality, which could interfere with the reaction conditions that are required for the *N*-acyliminium ion reaction. A benzylic substituent was introduced using the diethyl acetal **16f** (entry 2), which was used because of the poor stability of the corresponding aldehyde. Logically, this diethyl acetal functionality also generated a more reactive precursor for the *N*-acyliminium ion formation (an *N,O*-acetal rather than an *N,O*-hemiacetal) and thus resulted in the smooth formation of product **17fA** in a yield of 82%. The same positive effect of the diethyl acetal functionality was found with the introduction of an *n*-hexyl substituent (entries 4-5). While *n*-heptanal (**12g**) produced the product **18gA** in a yield of only 45%, the use of the corresponding diethyl acetal **16g** improved the yield of **18gA** to 66%.

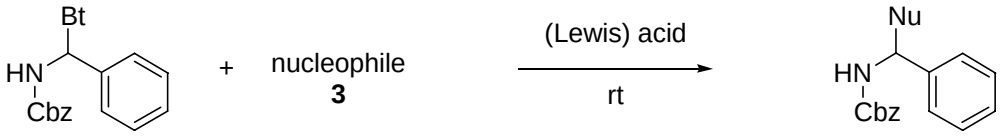
To further investigate the scope with respect to the aliphatic diethyl acetal component, benzyl carbamate (**14**) and allyltrimethylsilane (**3A**) were used in combination with the functionalized aliphatic diethyl acetal **16h** (Scheme 3). After a reaction time of 18 h, a 75% conversion of benzyl carbamate (**14**) was observed and during the reaction a white precipitate was formed, which after isolation was identified as bis-carbamate **21**. The formation of similar bis-carbamates in this type of reaction was also reported by Veenstra.[8] However, the bis-carbamate precipitate was by them observed at the beginning of the reaction and was thereafter completely transformed into the desired product. In our hands, the bis-carbamate **21** and the desired protected diamine **15hA** were obtained as a 1:1 mixture, which could be easily separated using column chromatography. Subsequently, bis-carbamate **21** itself was used as an *N*-acyliminium ion precursor, which after a reaction of 18 h resulted in a 6:4 mixture of compounds **21** and **15hA**.



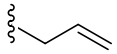
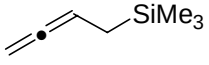
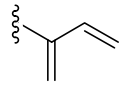
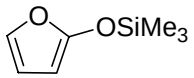
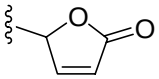
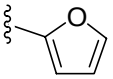
Scheme 3. *Reagents and conditions:* (a) **3A** (1 equiv), $BF_3{\cdot}OEt_2$ (1 equiv), CH_2Cl_2, rt, 18 h (75% conversion, 1:1 mixture of **21** and **15hA**); (b) **3A** (1 equiv), $BF_3{\cdot}OEt_2$ (1 equiv), MeCN, rt, 18 h (6:4 mixture of **21** and **15hA**).

Clearly, the scope of the three component *N*-acyliminium ion reaction in particular with respect to the nucleophile is still rather limited. Encouraged by the results of using more activated intermediates for the *N*-acyliminium ion formation, it was decided to further investigate the 'two-step' approach. In contrast to Mioskowski's results with aromatic amides,[10] in our hands the addition of aldehydes to benzyl carbamate in the presence of TFA and $HC(OMe)_3$ did not lead to the desired *N,O*-acetal, but resulted in the exclusive formation of the corresponding bis-carbamates.[20] Therefore, in addition to *N,O*-acetals, the Bt-derivative **11** was used as a readily available and versatile *N*-acyliminium ion precursor (Table 5).

Table 5

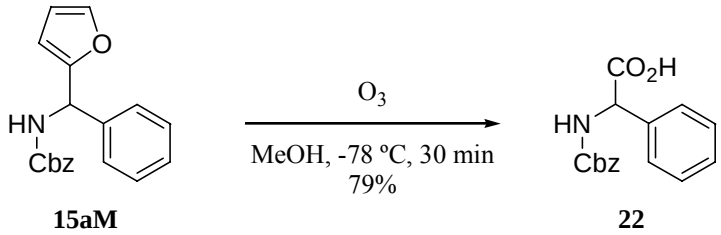


11 **15**

Entry	Nucleophile **3**		Lewis Acid	Solvent	Nu	Product (yield)
1	**3A**		$BF_3{\cdot}OEt_2$	CH_2Cl_2		**15aA** (80%)
2		(**3J**)	$BF_3{\cdot}OEt_2$	CH_2Cl_2		**15aJ** (53%)
3		(**3L**)	$Sc(OTf)_3$	CH_2Cl_2		-
4	**3L**		$BF_3{\cdot}OEt_2$	CH_2Cl_2		**15aL** (51%)
5		(**3M**)	CSA	Neat		**15aM** (55%)

By using allyltrimethylsilane (**3A**) as the nucleophile, homoallylic carbamate **15aA** was obtained in a good yield (80%, entry 1), thus proving the viability and efficiency of this Bt-derivative in *N*-acyliminium ion chemistry. 2,3-Butadienylsilane **3J** (entry 2) was reacted with Bt-derivative **11** to provide diene **15aJ**, the preparation of which was described earlier in Table 2 (entry 5). In the current case, diene **15aJ** was obtained in a slightly lower yield than in the previous example (53% and 62%, respectively). The application of a vinylogous silyl enol ether as a nucleophile was demonstrated by the use of furan **3L** (entries 3-4).[21,22] $Sc(OTf)_3$ proved to be unsuitable for *N*-acyliminium ion formation with Bt-derivative **11**, since it led to no product formation at all. However, with the use of $BF_3{\cdot}OEt_2$, the desired α,β-unsaturated lactone **15aL** was obtained in a moderate yield of 51%. The use of furan as an aromatic nucleophile in *N*-acyliminium ion chemistry has been shown before,[23] in which the best results were obtained using moderately strong protic acids in combination with furan as the solvent. Thus, Bt-derivative **11** was reacted with CSA in furan (16 M) to afford compound **15aM** in a yield of 55%

(entry 5). The introduction of the furan functionality may allow further functionalization by oxidation to the corresponding carboxylic acid functionality. Although a heterogeneous $RuO_2/NaIO_4$ system is usually used for the oxidation of α-furyl carbamates,[24] some examples of homogeneous oxidations with ozone are also known.[25] Hence, furan **15aM** was ozonolyzed to afford the *N*-protected phenylglycine derivative **26** in a yield of 79% (Scheme 4). Consequently, with this reaction sequence,the scope of products was extended to Cbz-protected α-amino acids.

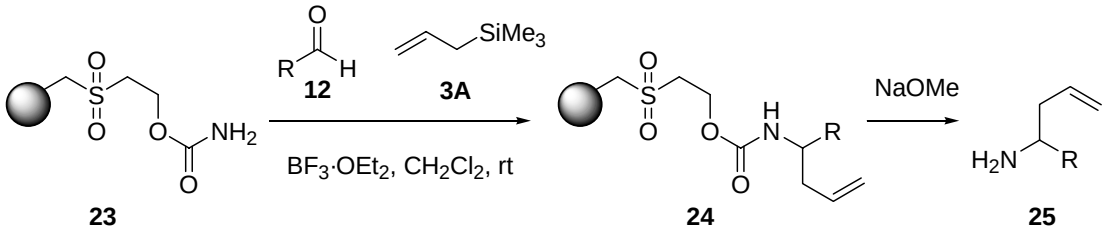


15aM **22**

Scheme 4

Next, with the results of the solution phase *N*-acyliminium ion reactions in mind, the scope and limitations of the same reactions on a solid phase were determined. For this purpose, the earlier developed SEC linker system **23** was used. The introduction of aromatic side chains is presented in Table 6.

Table 6



23 **24** **25**

Entry	R	Product (yield)[a]
1	Ph (**12a**)	**25aA** (80%)
2	*p*-$MeOC_6H_4$ (**12b**)	**25bA** (79%)
3	*p*-NCC_6H_4 (**12c**)	**25cA** (39%)
4	*p*-$O_2NC_6H_4$ (**12d**)	**25dA** (<3%)
5	3-Thienyl (**12i**)	**25iA** (60%)

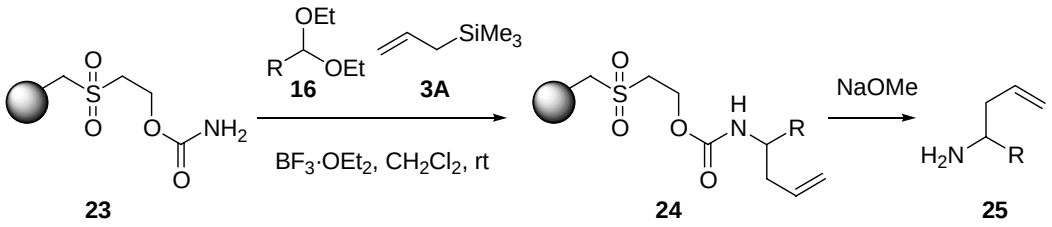
[a] Yields were determined over two steps, starting from resin **23**.

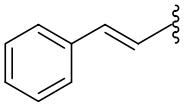
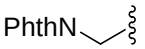
In these cases, the yields of the homoallylic amines **25** were determined after cleavage from the resin using a NaOMe solution. Again, the same trend in reactivity of the aromatic aldehydes was observed: electron rich aldehydes afforded the desired products **25** in high yields (entries 1-2, 5), whereas electron poor ones produced a lower yield (entry 3), or no product at all (entry 4).

Furthermore, the yields of these products were around 20% higher than those of the same products produced on the acid labile Wang linker system.[2] This observation again substantiated the viability of the SEC linker for application to *N*-acyliminium ion chemistry.

Earlier, the introduction of aliphatic side chains in the solid phase one-pot three component *N*-acyliminium ion reaction on the Wang resin proved to be troublesome.[2] On the other hand, the introduction of aliphatic substituents in the solution phase reaction using acetals **16** did result in the efficient formation of the desired products. Therefore, the use of diethyl acetals in combination with SEC resin **23** was investigated (Table 7).

Table 7



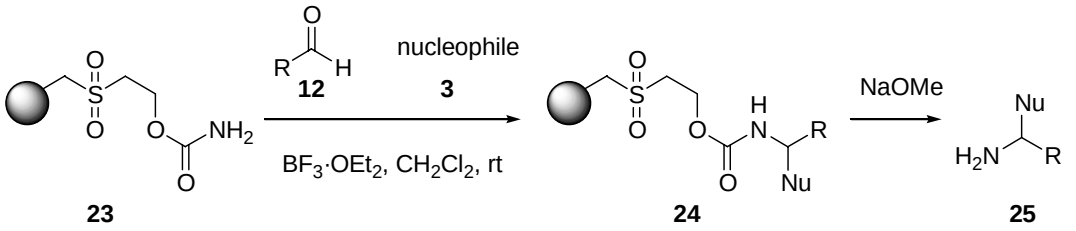
Entry	R	Product (yield)[a]
1	Bn (**16f**)	**25fA** (39%)
2	*n*-hexyl (**16g**)	**25gA** (58%)
3	cyclohexyl (**16j**)	**25jA** (35%)
4	 (**16k**)	**25kA** (46%)
5	 (**16h**)	-
6	*p*-$O_2NC_6H_4$ (**16d**)	**25dA** (7%)

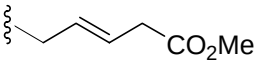
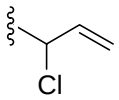
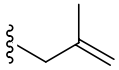
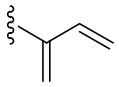
[a] Yields were determined over two steps, starting from resin **23**.

By using the aliphatic diethyl acetals **16f-g**, **j-k** (entries 1-4), the corresponding products could indeed be obtained, albeit in moderate yields. Surprisingly, with acetal **16h** in the solid phase reaction (entry 5) no product was obtained at all, whereas in solution phase (Scheme 3) the desired product was formed together with a substantial amount of the corresponding bis-carbamate. Nevertheless, the successful introduction of aliphatic substituents (entries 1-4) significantly extended the scope of the process. Encouraged by these results, the application of the corresponding diethyl acetal functionality in the introduction of an electron poor aromatic substituent was also tested (entry 6). Unfortunately, the desired homoallylic amine **25dA** was only formed in a low yield of 7%.

In addition, the application of the different silyl nucleophiles **3G-J** in combination with some aromatic aldehydes in the three component *N*-acyliminium ion reaction was investigated (Table 8).

Table 8



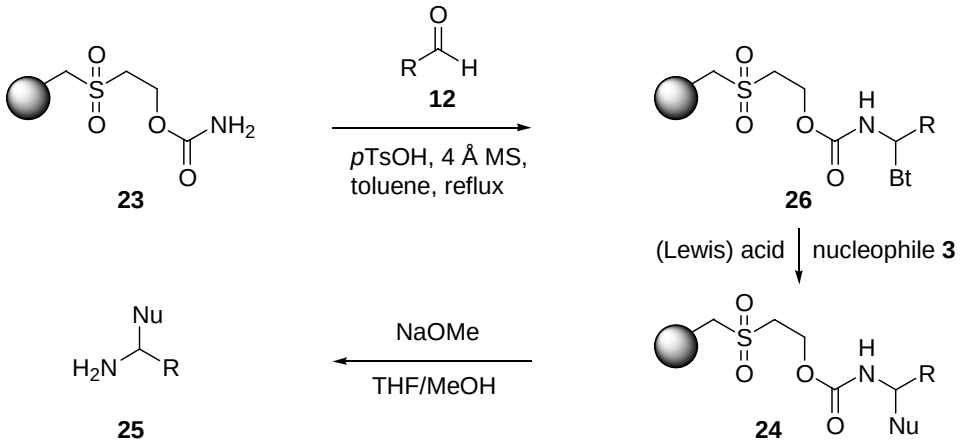
Entry	R	Nucleophile **3**	Nu	Product (yield)[a]
1	Ph (**12a)**	**3G**		**25aG** (42%)
2	Ph (**12a)**	**3H**		-
3	Ph (**12a)**	**3I**		-
4	Ph (**12a)**	**3J**		**25aJ** (30%)
5	*p*-MeOC$_6$H$_4$ (**12b**)	**3G**		**25bG** (37%)
6	*p*-MeOC$_6$H$_4$ (**12b**)	**3J**		**25bJ** (48%)
7	3-Thienyl (**12i**)	**3G**		**25iG** (36%)
8	3-Thienyl (**12i**)	**3J**		**25iJ** (42%)

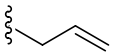
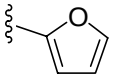
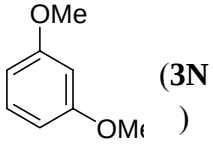
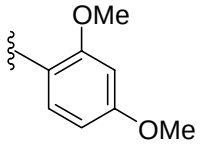
[a] Yields were determined over two steps, starting from resin **23**.

By using the substituted allylsilanes **3G-I**(entries 1-3), the 1-substituted silane **3G** again afforded the corresponding product (42%), while the 2- and 3-substituted allylsilanes **3H-I** were not reactive at all. A diene functionality could be introduced by making use of allenylsilane **3J** (entry 4). Furthermore, silanes **3G** and **3J** were successfully used in combination with the aromatic aldehydes **12b** and **12i** (entries 5-8) to afford the corresponding homoallylic amines **25** in reasonable yields.

Finally, to extend the scope of the *N*-acyliminium ion reaction even more, the 'two-step' approach, involving the immobilized Bt-derivative **26** was applied (Table 9). The results show that the scope with respect to the nucleophile indeed could be extended in case of aromatic aldehydes (entries 2-3). Analogous to the solution phase reaction, CSA was used to generate the *N*-acyliminium ion intermediate, while the aromatic nucleophile was used as the solvent. Moreover, the application of the Bt-derivative improved the yield of product **25dA** to 36% over three steps (entry 4). Thus, the 'two-step' approach also extended the scope of the reaction with respect to electron poor aromatic aldehydes.

Table 9



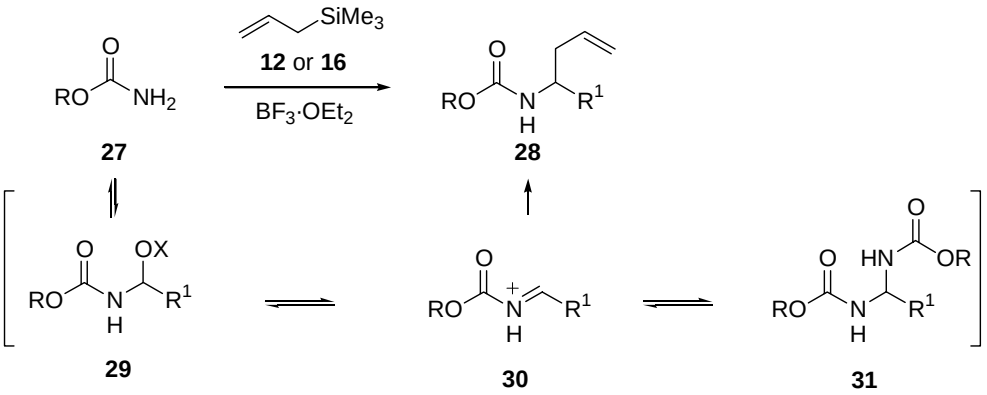
Entry	R	Nucleophile **3**	Lewis Acid	Nu	Product (yield)[a]
1	Ph (**12a**)	**3A**	$BF_3{\cdot}OEt_2$		**25aA** (71%)
2	Ph (**12a**)	**3M**	CSA		**25aM** (50%)
3	Ph (**12a**)	 (**3N**)	CSA		**25aN** (20%)
5	*p*-$O_2NC_6H_4$ (**12a**)	**3A**	$BF_3{\cdot}OEt_2$		**25dA** (36%)

[a] Yields were determined over three steps, starting from resin **23**.

If one compares the results of the solution phase *N*-acyliminium ion reactions with those of the solid phase, a few interesting features appear. In general, the yields of the solid phase reactions are somewhat lower than the solution phase ones. For example, whereas the use of *p*-nitrobenzaldehyde (**12d**) in solution phase afforded the desired product in a reasonable yield, the same aldehyde on solid phase only produced a trace of the desired homoallylic amine. Although in the solution phase a similar trend in reactivity was observed, the low reactivity of aliphatic and electron poor aromatic substituents in the solid phase reactions was much more pronounced. This difference might be explained by the polarity of the environment in which the reactions take place: in solution phase, the cationic intermediates can be to some degree stabilized by the relatively polar solvent, while on solid phase the extent of stabilization is reduced as a result of the more apolar environment of the polymer support.

Furthermore, the use of diethyl acetal **16h** in solution phase led to a considerable amount of the undesired bis-carbamate (*cf*. **31** in Scheme 5), while on the solid phase no such product was formed at all. Veenstra presumed the aforementioned bis-carbamate to be the intermediate, which was transformed into the key electrophile that then would undergo the nucleophilic attack

(**30** → **28**). However, formation of such an intermediate in the solid phase reaction (**31** in which R is attached to the polymeric backbone) would be unlikely if not impossible due to site-site isolation on the polymer. Therefore, most probably bis-carbamate **31** is formed as one of the intermediate species, but is not necessarily required for the formation of product **28**.



Scheme 5

In conclusion, the scope and limitations of the one-pot three component *N*-acyliminium ion reaction have been explored. In both the solution and solid phase reactions a similar trend can be observed. With respect to the aldehyde component, the best yields were obtained with electron rich aromatic ones. Whereas aliphatic side chains could be introduced in satisfactory yields by using the corresponding diethyl acetals, electron poor aromatic substituents could not efficiently be introduced by using the three component *N*-acyliminium ion reaction. However, a 'two-step' approach involving a Bt-derivative has led to an extension of the scope to also include electron poor aromatic groups. With respect to the nucleophile, the scope was mainly restricted to simple substituted allylsilanes. A useful addition of potential nucleophiles was found in the application of 2,3-butadienylsilane. Furthermore, aromatic nucleophiles were used in the 'two-step' approach. Overall, it can be concluded that a diverse range of products was made, although the introduction of different structural classes required its own optimization, which has led to a range of optimal reaction conditions.

Experimental Section

General Procedures. All reactions with air or moisture sensitive reagents were carried out under an inert atmosphere of dry nitrogen. Standard syringe techniques were applied for the transfer of air or moisture sensitive reagents and dry solvents. The solid phase reactions were gently stirred with a magnetic stirring bar. The resins were washed according to the indicated sequence and dried *in vacuo* (50 ºC) prior to use. The resin was allowed to swell/shrink for at least 1 minute before each filtration. Infrared (IR) spectra were obtained from KBr pellets or neat, using a Bruker IFS 28FT-spectrometer with wavelengths (ν) reported in cm^{-1}. IR spectra of resins were

measured in KBr using a DRIFT module. Proton nuclear magnetic resonance (^{1}H NMR) spectra were determined in the indicated solvent using a Bruker AC 200 (200 MHz), Bruker ARX 400 (400 MHz), or a Varian Inova (500 MHz) spectrometer. The machines were also used for carbon nuclear magnetic resonance (^{13}C NMR, APT) spectra (50 MHz, 100 MHz and 125 MHz respectively). Chemical shifts (δ) are given in ppm downfield from tetramethylsilane. Mass spectra and accurate mass measurements were carried out using a JEOL JMS-SX/SX 102A Tandem Mass spectrometer. Elemental analysis were performed by Dornis u. Kolbe Mikroanalytisches Laboratorium, Mülheim a. d. Ruhr, Germany. R_f values were obtained by using thin layer chromatography (TLC) on silica gel-coated plastic sheets (Merck silica gel 60 F_{254}) with the indicated solvent (mixture). UV light or I_2 were used as visualizing agents, while $KMnO_4$ solution and heat or anisaldehyde solution and heat were used as developing agents. Chromatographic purification refers to flash column chromatography using the indicated solvent (mixture) and Acros Organics Silica gel (0.035-0.070 nm). Melting points are uncorrected and were determined on a Büchi melting point B-545 apparatus. Dry THF and Et_2O were freshly distilled from sodium benzophenone ketyl. Dry DMF, CH_2Cl_2, EtOAc and MeCN were distilled from CaH_2 and stored over 4Å MS under a dry nitrogen atmosphere. PE (60-80) was distilled prior to use. Merrifield resin (200-400 mesh, 1% DVB, 1.7 mmol Cl/g) and Wang resin (200-400 mesh, 1% DVB, 0.71 mmol OH/g) were obtained from Fluka. All commercially available reagents were used as received, unless indicated otherwise.

2-Benzylthioethanol (6).[26] Benzyl bromide (7.21 mL, 42.7 mmol), and Cs_2CO_3 (14.6 g, 44.9 mmol) were suspended in dry DMF (150 mL), mercaptoethanol (25.0 mL, 44.9 mmol) was added dropwise and the reaction mixture was stirred for 4 h at 60 ºC and then for 20 h at rt. Then, saturated aqueous NH_4Cl (100 ml) was added and the layers were separated. The aqueous layer was extracted with CH_3CCl_3 (2 × 75 mL), the combined organic layers were washed with aqueous saturated NaCl (75 mL), dried ($MgSO_4$) and concentrated *in vacuo* to obtain **6** (7.23 g, 40.2 mmol, 94%) as a colorless oil, which was used without any further purification. ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.34-7.27 (m, 5H, Ar-H), 3.72 (s, 2H, ArC*H*$_2$), 3.64 (t, *J* = 6.1 Hz, 2H, OC*H*$_2$), 2.62 (t, *J* = 6.0 Hz, 2H, SC*H*$_2$). ^{13}C NMR (50 MHz, $CDCl_3$) δ 137.9, 128.6, 128.4, 126.9 (Ar-C), 60.1 (O*C*H$_2$), 35.6, 34.1 (Ar*C*H$_2$ and S*C*H$_2$). IR *v*, cm^{-1} 3490, 3030, 2920, 1410, 1335, 1070.

2-Benzylsulfonylethanol (7). To a solution of thioether **6** (7.69 g, 42.7 mmol) in CH_2Cl_2 (100 mL), *m*CPBA (77%, 22.1 g, 98.2 mmol) was added in portions at 0 °C. When addition was complete the mixture was stirred for 18 h at rt. Then, saturated aqueous $NaHCO_3$ (100 mL) was added and the layers were separated. The aqueous layer was extracted with CH_2Cl_2 (2 × 50 mL), the combined organic layers were washed with aqueous saturated NaCl (50 mL), dried ($MgSO_4$) and concentrated *in vacuo.* The crude product was purified using column chromatography (EtOAc/PE 1:1) to afford **7** (8.41 g, 0.40 mmol, 93%) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45-7.33 (m, 5H, Ar-H), 4.35 (s, 2H, ArC*H*$_2$), 4.06 (d, *J* = 5.3 Hz, 2H, OC*H*$_2$), 3.08 (d, *J* = 5.3 Hz, 2H, SO_2C*H*$_2$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 130.9, 129.1, 129.0, 127.8 (Ar-C),

61.1 (Ar*C*H_2), 56.3 (O*C*H_2), 53.0 (SO_2*C*H_2). IR *v*, cm^{-1} 3488, 3033, 2978, 1495, 1393, 1287, 1117, 1070, 843. HRMS (EI+) calculated for $C_9H_{12}O_3S$ (M^+) 200.0507, found 200.0514.

2-(Benzylsulfonyl)ethyl carbamate (8). Alcohol **7** (7.00 g, 33.0 mmol) was dissolved in CH_2Cl_2 (70 mL) and cooled to 0 °C, 4-nitrophenyl chloroformate (6.66 g, 33.0 mmol) and *N*-methylmorpholine (3.63 mL, 33.0 mmol) were added, the reaction mixture was allowed to warm up to rt and was stirred for 18 h at this temperature. Then, saturated aqueous NH_4Cl (50 mL) was added and the layers were separated. The aqueous layer was extracted with CH_2Cl_2 (2 × 50 mL), the combined organic layers were washed with aqueous saturated NaCl (50 mL), dried ($MgSO_4$) and concentrated *in vacuo*. The crude carbonate was dissolved in DMF (60 mL), a saturated NH_3/MeOH solution (30 ml) was added and the reaction mixture turned yellow immediately. The reaction mixture was stirred for 18 h at rt and concentrated *in vacuo.* The crude product was purified using column chromatography (EtOAc/PE 1:1) to afford **8** (7.14 g, 29.4 mmol, 89%) as a white solid. Mp 173-175 ºC. R_f 0.15 (EtOAc/PE 1:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.37-7.34 (m, 5H, Ar-H), 5.36 (br s, 2H, NH_2), 4.43 (t, *J* = 5.8 Hz, 2H, OCH_2), 4.26 (s, 2H, ArCH_2), 3.15 (t, *J* = 5.8 Hz, 2H, SO_2CH_2). ^{13}C NMR (100 MHz, $CDCl_3$) δ 156.3 (O*C*ON), 130.7, 129.0, 128.9, 127.4 (Ar-C), 60.6 (O*C*H_2), 57.8 (Ar*C*H_2), 50.6 (SO_2*C*H_2). IR *v*, cm^{-1} 3421, 3033, 2984, 1680, 1427, 1365, 1282, 1119, 1025, 995.

2-(Benzylthio)ethyl carbamate (9). Alcohol **6** (4.61 g, 25.6 mmol) was dissolved in CH_2Cl_2 (40 mL) and cooled to 0 °C, 4-nitrophenyl chloroformate (5.16 g, 25.6 mmol) and *N*-methylmorpholine (2.81 mL, 25.6 mmol) were added, the reaction mixture was allowed to warm up to rt and was stirred for 18 h at this temperature. Then, saturated aqueous NH_4Cl (30 mL) was added and the layers were separated. The aqueous layer was extracted with CH_2Cl_2 (2 × 30 mL), the combined organic layers were washed with aqueous saturated NaCl (30 mL), dried ($MgSO_4$) and concentrated *in vacuo*. The crude carbonate was dissolved in DMF (40 mL), a saturated NH_3/MeOH solution (20 mL) was added and the reaction mixture turned yellow immediately. The reaction mixture was stirred for 18 h at rt and concentrated *in vacuo.* The crude product was purified using column chromatography (EtOAc/PE 1:1) to afford **9** (4.38 g, 20.7 mmol, 81%) as a white solid. R_f 0.19 (EtOAc/PE 1:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.36-7.23 (m, 5H, Ar-H), 4.77 (br s, 2H, NH_2), 4.17 (t, *J* = 6.8 Hz, 2H, OCH_2), 3.75 (s, 2H, ArCH_2), 2.64 (t, *J* = 6.8 Hz, 2H, SCH_2). ^{13}C NMR (100 MHz, $CDCl_3$) δ 156.5 (O*C*ON), 137.9, 128.8, 128.1, 127.0 (Ar-C), 63.6 (O*C*H_2), 36.2 (Ar*C*H_2), 29.9 (S*C*H_2). IR *v*, cm^{-1} 3497, 3353, 3028, 2919, 1744, 1601, 1454, 1404, 1337, 1072.

General procedure A for the three component reaction with carbamates 8-10 and 14

The carbamate, aldehyde (1 equiv) and nucleophile (1 equiv) were dissolved in CH_2Cl_2. The Lewis acid (1 equiv) was added and the reaction mixture was stirred for the indicated time at rt. Then, saturated aqueous $NaHCO_3$ was added and the layers were separated. The aqueous layer was extracted with CH_2Cl_2 (2 ×), the combined organic layers were washed with aqueous saturated NaCl, dried ($MgSO_4$) and concentrated *in vacuo*. The crude product was purified using column chromatography (EtOAc/PE).

(1-Phenylbut-3-enyl)carbamic acid allyl ester (13aA). Allyl carbamate **11** (100 mg, 0.99 mmol), benzaldehyde (101 μL, 0.99 mmol) allyltrimethylsilane (157 μL, 0.99 mmol) and $BF_3{\cdot}OEt_2$ (125 μL, 0.99 mmol) in CH_2Cl_2 (2 mL) were reacted for 3 h according to general procedure A to afford **13aA** (188 mg, 0.82 mmol, 82%) as a colorless oil. R_f 0.59 (EtOAc/PE 1:2). ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.45-7.10 (m, 5H, Ar-H), 6.05-5.55 (m, 2H, 2 × C*H*=CH_2), 5.40-4.95 (m, 4H, 2 × CH=C*H*$_2$), 4.90-4.70 (m, 1H, NHC*H*), 4.55 (dd, *J* = 1.1, 5.6 Hz, 2H, OC*H*$_2$), 2.56-2.53 (m, 2H, C*H*$_2$CH=CH_2). ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.3 (O*C*ON), 141.9 (Ar-C), 133.7, 132.8 (2 × *C*H=CH_2), 128.4, 127.4, 126.1 (Ar-C), 118.2, 117.6 (2 × CH=*C*H$_2$), 65.5 (O*C*H$_2$), 54.4 (NH*C*H), 40.9 (*C*H$_2$CH=CH_2). IR *v*, cm^{-1} 3326, 3069, 3029, 2979, 2937, 1713, 1537, 1252, 1041, 1041, 994, 919. HRMS (FAB+) calculated for $C_{14}H_{18}NO_2$ (M^+ + H) 232.1338, found 232.1339.

[1-(4-Methoxyphenyl)but-3-enyl]carbamic acid allyl ester (13bA). Allyl carbamate **11** (100 mg, 0.99 mmol), 4-methoxybenzaldehyde (120 μL, 0.99 mmol) allyltrimethylsilane (157 μL, 0.99 mmol) and $BF_3{\cdot}OEt_2$ (125 μL, 0.99 mmol) in CH_2Cl_2 (2 mL) were reacted for 3 h according to general procedure A to afford **13bA** (207 mg, 0.79 mmol, 80%) as a colorless oil. R_f 0.48 (EtOAc/PE 1:2). ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.25-7.10 (m, 2H, Ar-H), 7.00-6.80 (m, 2H, Ar-H), 6.05-5.55 (m, 2H, 2 × C*H*=CH_2), 5.40-4.85 (m, 4H, 2 × CH=C*H*$_2$), 4.82-4.65 (m, 1H, NHC*H*), 4.55 (dd, *J* = 1.1, 4.6 Hz, 2H, OC*H*$_2$), 3.80 (s, 3H, OMe), 2.56-2.52 (m, 2H, C*H*$_2$CH=CH_2). ^{13}C NMR (100 MHz, $CDCl_3$) δ 156.7 (Ar-C), 155.4 (O*C*ON), 134.0, 133.9 (2 × *C*H=CH_2), 127.3 (Ar-C), 118.0, 117.5 (2 × CH=*C*H$_2$), 113.8 (Ar-C), 65.4 (O*C*H$_2$), 55.2, 53.9 (NH*C*H and OMe), 40.9, 40.4 (2 × *C*H$_2$CH=CH_2). IR *v*, cm^{-1} 3306, 3076, 2999, 2937, 1712, 1513, 1246, 1179, 1037, 995, 920. HRMS (FAB+) calculated for $C_{15}H_{20}NO_3$ (M^+ + H) 262.1443, found 262.1439.

[1-(4-Cyanophenyl)but-3-enyl]carbamic acid allyl ester (13cA). Allyl carbamate **11** (100 mg, 0.99 mmol), 4-cyanobenzaldehyde (112 mg, 0.99 mmol) allyltrimethylsilane (157 μL, 0.99 mmol) and $BF_3{\cdot}OEt_2$ (125 μL, 0.99 mmol) in CH_2Cl_2 (2 mL) were reacted for 20 h according to general procedure A to afford **13cA** (114 mg, 0.45 mmol, 45%) as a colorless oil. R_f 0.44 (EtOAc/PE 1:2). ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.63 (d, *J* = 8.3 Hz, 2H, Ar-H), 7.38 (d, *J* = 8.2 Hz, 2H, Ar-H), 6.00-5.50 (m, 2H, 2 × C*H*=CH_2), 5.40-5.00 (m, 4H, 2 × CH=C*H*$_2$), 4.80 (dd, *J* = 6.6, 13.2 Hz, 1H, NHC*H*), 4.53 (d, *J* = 5.6 Hz, 2H, OC*H*$_2$), 2.65-2.30 (m, 2H, C*H*$_2$CH=CH_2). ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.2 (O*C*ON), 147.5, 132.3, 132.2, 126.9, 126.7 (Ar-C and 2 × *C*H=CH_2), 119.3, 118.5, 117.8, 111.0 (Ar-C, *C*N and 2 × CH=*C*H$_2$), 65.7 (O*C*H$_2$), 54.0 (NH*C*H), 40.5 (*C*H$_2$CH=CH_2). IR *v*, cm^{-1} 3336, 3077, 2983, 2229, 1704, 1530, 1251, 1041, 923. HRMS (FAB+) calculated for $C_{15}H_{17}N_2O_2$ (M^+ + H) 257.1290, found 257.1276.

[1-(4-Nitrophenyl)but-3-enyl]carbamic acid allyl ester (13dA). Allyl carbamate **11** (100 mg, 0.99 mmol), 4-nitrobenzaldehyde (132 mg, 0.99 mmol) allyltrimethylsilane (157 μL, 0.99 mmol) and $BF_3{\cdot}OEt_2$ (125 μL, 0.99 mmol) in CH_2Cl_2 (2 mL) were reacted for 20 h according to general procedure A to afford **13dA** (109 mg, 0.40 mmol, 40%) as a colorless oil. R_f 0.48 (EtOAc/PE 1:2). ^{1}H NMR (200 MHz, $CDCl_3$) δ 8.21 (d, *J* = 7.2 Hz, 2H, Ar-H), 7.45 (d, *J* = 7.0 Hz, 2H, Ar-H), 6.00-5.50 (m, 2H, 2 × C*H*=CH_2), 5.40-5.05 (m, 4H, 2 × CH=C*H*$_2$), 4.86 (t, *J* 6.6 Hz, 1H,

NHC*H*), 4.53 (d, *J* = 5.6 Hz, 2H, OC*H*$_2$), 2.65-2.45 (m, 2H, C*H*$_2$CH=CH$_2$). ^{13}C NMR (100 MHz, $CDCl_3$) 155.4 (O*C*ON), 147.0, 132.6, 132.4, 127.0, 126.3, 123.7 (Ar-C), 119.3, 117.8 (2 × CH=*C*H$_2$), 65.7 (O*C*H$_2$), 54.1 (NH*C*H), 40.5 (*C*H$_2$CH=CH$_2$). IR *v*, cm^{-1} 3543, 3332, 3015, 2975, 1721, 1608, 1558, 1442, 1265, 1112, 1046, 931. HRMS (FAB+) calculated for $C_{14}H_{17}N_2O_4$ (M^+ + H) 277.1188, found 277.1190.

(1-Isopropylbut-3-enyl)carbamic acid allyl ester (13eA). Allyl carbamate **11** (100 mg, 0.99 mmol), isobutyraldehyde (90 μL, 0.99 mmol) allyltrimethylsilane (157 μL, 0.99 mmol) and $BF_3{\cdot}OEt_2$ (125 μL, 0.99 mmol) in CH_2Cl_2 (2 mL) were reacted for 20 h according to general procedure A to afford **13eA** (89 mg, 0.44 mmol, 44%) as a colorless oil. R_f 0.64 (EtOAc/PE 1:2). ^{1}H NMR (200 MHz, $CDCl_3$) δ 6.05-5.60 (m, 2H, 2 × C*H*=CH$_2$), 5.40-4.95 (m, 4H, 2 × CH=C*H*$_2$), 4.60-4.45 (d, *J* = 5.2 Hz, 2H, OC*H*$_2$), 3.65-3.45 (m, 1H, NHC*H*), 2.40-2.00 (m, 2H, C*H*$_2$CH=CH$_2$), 1.85-1.60 (m, 1H, C*H*(CH$_3$)$_2$), 1.00-0.70 (m, 6H, CH(C*H*$_3$)$_2$). ^{13}C NMR (125 MHz, $CDCl_3$) δ 153.6 (O*C*ON), 134.7, 133.0 (2 × *C*H=CH$_2$), 122.0, 117.3 (2 × CH=*C*H$_2$), 67.0 (O*C*H$_2$), 55.6 (NH*C*H), 36.8 (*C*H$_2$CH=CH$_2$), 31.4 (*C*H(CH$_3$)$_2$), 19.2 (CH(*C*H$_3$)$_2$). IR *v*, cm^{-1} 3323, 3076, 2960, 1720, 1647, 1536, 1250, 993. HRMS (FAB+) calculated for $C_{11}H_{20}NO_2$ (M^+ + H) 198.1494, found 298.1492.

(1-Benzylbut-3-enyl)carbamic acid allyl ester (13fA). Allyl carbamate **11** (100 mg, 0.99 mmol), phenylacetaldehyde diethyl acetal (163 μL, 0.99 mmol) allyltrimethylsilane (157 μL, 0.99 mmol) and $BF_3{\cdot}OEt_2$ (125 μL, 0.99 mmol) in CH_2Cl_2 (2 mL) were reacted for 20 h according to general procedure A to afford **13fA** (182 mg, 0.74 mmol, 75%) as a colorless oil. R_f 0.58 (EtOAc/PE 1:2). ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.40-7.10 (m, 5H, Ar-H), 6.00-5.70 (m, 2H, 2 × C*H*=CH$_2$), 5.40-5.00 (m, 4 H, 2 × CH=C*H*$_2$), 4.65-4.45 (m, 2H, OC*H*$_2$), 3.97 (dd, *J* = 6.9, 13.7 Hz, 1H, NHC*H*), 2.90-2.70 (m, 2H, ArC*H*$_2$), 2.40-2.05 (m, 2H, C*H*$_2$CH=CH$_2$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 137.8 (Ar-C), 134.1, 132.9 (2 × *C*H=CH$_2$), 139.3, 128.3, 126.3 (Ar-C), 118.0, 117.3 (2 × CH=*C*H$_2$), 65.3 (O*C*H$_2$), 53.2 (NH*C*H), 40.3, 38.0 (Ar*C*H$_2$ and *C*H$_2$CH=CH$_2$). IR *v*, cm^{-1} 3334, 3027, 2925, 1718, 1531, 1256, 1121, 1043, 994, 918. HRMS (FAB+) calculated for $C_{15}H_{20}NO_2$ (M^+ + H) 246.1494, found 246.1483.

(1-Benzylbut-3-enyl)carbamic acid allyl ester (13aB). Allyl carbamate **11** (100 mg, 0.99 mmol), benzaldehyde (101 μL, 0.99 mmol) 2-(chloromethyl)allyltrimethylsilane (179 μL, 0.99 mmol) and $BF_3{\cdot}OEt_2$ (125 μL, 0.99 mmol) in CH_2Cl_2 (2 mL) were reacted for 20 h according to general procedure A to afford **13aB** (221 mg, 0.79 mmol, 80%) as a colorless oil. R_f 0.54 (EtOAc/PE 1:2). ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.50-7.15 (m, 5H, Ar-H), 6.00-5.70 (m, 1H, C*H*=CH$_2$), 5.40-5.10 (m, 4H, CH=C*H*$_2$ and C=C*H*$_2$), 4.90 (dd, *J* = 6.0, 8.1 Hz, 1H, NHC*H*), 4.54 (dd, *J* = 1.0, 5.6 Hz, 2H, OC*H*$_2$), 4.20-3.90 (m, 2H, C*H*$_2$Cl), 2.85-2.50 (m, 2H, C*H*$_2$C=CH$_2$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.5 (O*C*ON), 141.8, 141.2 (Ar-C and *C*=CH$_2$), 132.6 (*C*H=CH$_2$), 128.6, 127.5, 126.0 (Ar-C), 117.8, 117.6 (C=*C*H$_2$ and CH=*C*H$_2$), 65.6 (O*C*H$_2$), 53.2 (NH*C*H), 47.7 (*C*H$_2$Cl), 40.3 (*C*H$_2$C=CH$_2$). IR *v*, cm^{-1} 3331, 3089, 3035, 2956, 1703, 1514, 1439, 1247, 1032, 994, 916. HRMS (FAB+) calculated for $C_{15}H_{19}NO_2Cl$ (M^+ + H) 280.1104, found 280.1115.

(1-Phenylbut-3-ynyl)carbamic acid allyl ester (13aC). Allyl carbamate **11** (100 mg, 0.99 mmol), benzaldehyde (101 μL, 0.99 mmol) allenyltributyltin (294 μL, 0.99 mmol) and

$BF_3{\cdot}OEt_2$ (125 μL, 0.99 mmol) in CH_2Cl_2 (2 mL) were reacted for 20 h according to general procedure A to afford **13aC** (23 mg, 0.01 mmol, 10%) as a colorless oil. R_f 0.54 (EtOAc/PE 1:2). ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.60-7.10 (m, 5H, Ar-H), 6.00-5.70 (m, 1H, C*H*=CH_2), 5.05-4.45 (m, 2H, CH=CH_2), 4.90 (t, *J* = 6.4 Hz, 1H, NHC*H*), 4.55 (td, *J* = 1.3, 5.5 Hz, 2H, OCH_2), 2.65 (dd, *J* = 2.6, 6.3 Hz, 2H, CH_2C≡CH), 2.10 (t, *J* = 2.6 Hz, 1H, C≡C*H*). ^{13}C NMR (50 MHz, $CDCl_3$) δ 154.0 (O*C*ON), 142.2 (Ar-C), 132.5 (*C*H=CH_2), 130.5, 128.2, 127.7, 125.5 (Ar-C), 117.4 (CH=*C*H_2), 80.4 (*C*≡CH), 72.1 (C≡*C*H), 65.4 (O*C*H_2), 51.7 (NH*C*H), 29.2 (*C*H_2C≡CH). IR *v*, cm^{-1} 3294, 3033, 2924, 2854, 1709, 1608, 1497, 1453, 1252, 1049.

(1-Cyanobenzyl)carbamic acid allyl ester (13aD). Allyl carbamate **11** (100 mg, 0.99 mmol), benzaldehyde (101 μL, 0.99 mmol) trimethylsilyl cyanide (132 μL, 0.99 mmol) and $BF_3{\cdot}OEt_2$ (125 μL, 0.99 mmol) in CH_2Cl_2 (2 mL) were reacted for 20 h according to general procedure A to afford **13aD** (11 mg, 0.05 mmol, 5%) as a colorless oil. R_f 0.61 (EtOAc/PE 1:2). ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.60-7.30 (m, 5H, Ar-H), 6.00-5.70 (m, 1H, C*H*=CH_2), 5.40-5.10 (m, 2H, CH=CH_2), 4.85-4.76 (m, 1H, NHC*H*), 4.66 (d, *J* = 6.0 Hz, 2H, OCH_2).

[1-(2-Oxocyclohexyl)benzyl]carbamic acid allyl ester (13aE). Allyl carbamate **11** (100 mg, 0.99 mmol), benzaldehyde (101 μL, 0.99 mmol) 1-cyclohexenyloxytrimethylsilane (193 μL, 0.99 mmol) and $BF_3{\cdot}OEt_2$ (125 μL, 0.99 mmol) in CH_2Cl_2 (2 mL) were reacted for 20 h according to general procedure A to afford **13aE** (26 mg, 0.09 mmol, 10%) as a colorless oil. R_f 0.57 (EtOAc/PE 1:2). ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.50-7.00 (m, 5H, Ar-H), 6.10-5.80 (m, 1H, C*H*=CH_2), 5.35-5.10 (m, 2H, CH=CH_2), 5.10-4.90 (m, 1H, NHC*H*), 4.48 (d, *J* = 5.4 Hz, 2H, OCH_2), 3.07 (dd, *J* = 4.7, 12.5 Hz, 1H, COC*H*), 2.90-2.75 (m, 2H, CH_2), 2.56 (t, *J* = 6.7 Hz, CH_2), 2.40-2.15 (m, 4H, 2 × CH_2). ^{13}C NMR (100 MHz, $CDCl_3$) δ 201.7 (CH_2*C*O), 154.5 (O*C*ON), 140.4 (Ar-C), 135.4 (*C*H=CH_2), 130.2, 128.1, 126.2 (Ar-C), 116.8 (CH=*C*H_2), 63.6 (O*C*H_2), 56.6 (CO*C*H), 49.4 (NH*C*H), 38.4, 33.2, 26.4, 22.3 (4 × *C*H_2). IR *v*, cm^{-1} 3364, 3029, 2936, 2861, 1752, 1709, 1650, 1506, 1448, 1378, 1242, 1088, 922.

[1-(2-Oxo-2-phenylethyl)benzyl]carbamic acid allyl ester (13aF). Allyl carbamate **11** (100 mg, 0.99 mmol), benzaldehyde (101 μL, 0.99 mmol) 1-phenyl-1-(trimethylsilyloxy)ethylene (203 μL, 0.99 mmol) and $BF_3{\cdot}OEt_2$ (125 μL, 0.99 mmol) in CH_2Cl_2 (2 mL) were reacted for 20 h according to general procedure A to afford **13aF** (18 mg, 0.06 mmol, 6%) as a colorless oil. R_f 0.45 (EtOAc/PE 1:2). ^{1}H NMR (200 MHz, $CDCl_3$) δ 7.60-7.00 (m, 10H, Ar-H), 6.05-5.70 (m, 1H, C*H*=CH_2), 5.40-5.10 (m, 3H, NHC*H* and CH=CH_2), 4.55 (dd, *J* = 1.3, 5.6 Hz, 2H, OCH_2), 3.70 (dd, *J* = 5.2, 16.9 Hz, 1H, COCH_2), 3.46 (dd, *J* = 6.0, 16.8 Hz, 1H, COCH_2). ^{13}C NMR 155.3 (O*C*ON), 141.1, 136.3, 134.3, 132.5, 128.9, 128.5, 127.2, 127.0, 121.7 (Ar-C and *C*H=CH_2), 117.5 (CH=*C*H_2), 65.5 (O*C*H_2), 51.4 (NH*C*H), 29.6 (CO*C*H_2). IR *v*, cm^{-1} 3337, 3084, 2926, 1740, 1694, 1539, 1450, 1253, 1045, 931. HRMS (FAB+) calculated for $C_{19}H_{20}NO_3$ (M^+ + H) 310.1443, found 310.1447.

(1-Phenylbut-3-enyl)carbamic acid benzyl ester (15aA).[8] Benzyl carbamate (1.20 g, 7.94 mmol), benzaldehyde (807 μL, 7.94 mmol), allyltrimethylsilane (1.27 μL, 7.94 mmol) and $BF_3{\cdot}OEt_2$ (976 μL, 7.94 mmol) in CH_2Cl_2 (10 mL) were reacted for 3 h at rt according to general procedure A to afford **15aA** (2.05 g, 7.30 mmol, 92%) as a white solid. Mp 56 ºC. R_f 0.40

(EtOAc/PE 1:2). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.38-7.25 (m, 10H, Ar-H), 5.76-5.65 (m, 1H, C*H*=CH_2), 5.28 (br s, 1H, NH), 5.15-5.07 (m, 4H, OCH_2 and CH=CH_2), 4.87-4.80 (m, 1H, NHC*H*), 2.56 (br s, 2H, CH_2CH=CH_2). ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.6 (O*C*ON), 136.3, 133.6, 129.9, 128.5, 128.3, 128.1, 127.1, 126.2, 126.0 (Ar-C and *C*H=CH_2), 118.2 (CH=*C*H_2), 66.7 (O*C*H_2), 54.4 (NH*C*H), 40.9 (*C*H_2CH=CH_2). IR *v*, cm^{-1} 3319, 3064, 1709, 1531, 1454, 1340, 1252, 1028, 917.

6-Benzyloxycarbonylamino-6-phenylhex-3-enoic acid methyl ester (15aG). Benzyl carbamate (100 mg, 0.66 mmol), benzaldehyde (67 μL, 0.66 mmol), methyl 3-(trimethylsilyl)-4-pentenoate (137 μL, 0.66 mmol) and BF_3·OEt_2 (81 μL, 0.66 mmol) in CH_2Cl_2 (2 mL) were reacted for 4 h at rt according to general procedure A to afford **15aG** (165 mg, 0.47 mmol, 71%) as a colorless oil. R_f 0.35 (EtOAc/PE 1:2). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.90-7.24 (m, 10H, Ar-H), 5.67-5.59 (m, 1H, MeO_2CCH_2C*H*=CH), 5.46-5.41 (m, 1H, MeO_2CCH_2CH=C*H*), 5.21 (br s, 1H, NH), 5.12-5.03 (m, 2H, ArCH_2), 4.81 (br s, 1H, NHC*H*), 3.65 (s, 3H, CO_2Me), 3.00 (d, *J* = 6.8 Hz, 2H, CH_2CO_2Me), 2.55-2.53 (m, 2H, CHCH_2). Only one double bond isomer was found, the configuration of the double bond was established by a ^{1}H NMR homo decoupling experiment. Upon irradiation at 3.00 ppm a ^3J of 15.5 Hz between the two double bond signals was observed, which can be assigned to the (*E*)-isomer. ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.9 (*C*O_2Me), 155.7 (O*C*ON), 141.8, 136.5, 129.6, 128.9, 128.5, 128.0, 127.2, 126.2, 125.6, 123.9 (Ar-C and *C*H=*C*H), 66.6 (Ar*C*H_2), 54.5 (CO_2Me), 51.7 (NH*C*H), 37.6 (*C*H_2CO_2Me), 32.7 (CH*C*H_2). IR *v*, cm^{-1} 3329, 3031, 2950, 1745, 1702, 1524, 1330, 1243, 1026, 970, 843. HRMS (FAB+) calculated for $C_{21}H_{24}NO_4$ (M^+ + H) 354.1705, found 354.1716.

(2-Methylene-1-phenylbut-3-enyl)carbamic acid benzyl ester (15aJ). Benzyl carbamate (100 mg, 0.66 mmol), benzaldehyde (67 μL, 0.66 mmol), (allenylmethyl)trimethylsilane (158 μL, 0.99 mmol) and BF_3·OEt_2 (81 μL, 0.66 mmol) in CH_2Cl_2 (2 mL) were reacted for 4 h at rt according to general procedure A to afford **15aJ** (120 mg, 0.41 mmol, 62%) as a colorless oil. R_f 0.80 (EtOAc/PE 1:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.35-7.27 (s, 10H, Ar-H), 6.33 (dd, *J* = 11.2, 17.8 Hz, 1H, C*H*=CH_2), 5.66 (br d, *J* = 7.8 Hz, 1H, NH), 5.19-5.07 (m, 7H, NHC*H*, ArCH_2, C=CH_2 and CH=CH_2). ^{13}C NMR (50 MHz, $CDCl_3$) δ 155.2 (O*C*ON), 145.6, 139.9, 136.2, 135.9, 128.4, 128.3, 127.9, 127.4, 126.9 (Ar-C, *C*=CH_2 and *C*H=CH_2), 116.6, 115.5 (C=*C*H_2 and CH=*C*H_2), 66.7 (Ar*C*H_2), 55.9 (NH*C*H). IR *v*, cm^{-1} 3320, 3089, 1697, 1497, 1237, 1026, 910. HRMS (FAB+) calculated for $C_{19}H_{20}NO_2$ (M^+ + H) 294.1494, found 294.1495.

(3-Oxo-1-phenylbutyl)carbamic acid benzyl ester (15aK). Benzyl carbamate (100 mg, 0.66 mmol), benzaldehyde (67 μL, 0.66 mmol), isopropenyl acetate (73 μL, 0.66 mmol) and $Sc(OTf)_3$ (33 mg, 0.07 mmol) in CH_2Cl_2 (2 mL) were reacted for 18 h at rt according to general procedure A to afford **15aK** (56 mg, 0.15 mmol, 28%) as a colorless oil. R_f 0.35 (EtOAc/PE 1:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.37-7.23 (m, 5H, Ar-H), 5.80 (br d, *J* = 7.3 Hz, 1H, NH), 5.18-5.05 (m, 3H, ArCH_2 and NHC*H*), 3.08-3.04 (m, 2H, MeCOCH_2), 2.91 (dd, *J* = 5.3, 16.3 Hz, 1H, MeCOCH_2), 2.07 (s, 3H, MeCO). ^{13}C NMR (50 MHz, $CDCl_3$) δ 206.4 (Me*C*O), 155.4 (O*C*ON), 141.0, 136.2, 128.5, 128.3, 128.0, 127.9, 127.3, 126.0 (Ar-C), 66.5 (Ar*C*H_2), 51.3

(NH*C*H), 48.7 (MeCO*C*H_2), 30.4 (*Me*CO). IR *v*, cm^{-1} 3302, 3026, 2932, 1718, 1702, 1524, 1340, 1251. HRMS (EI+) calculated for $C_{18}H_{19}NO_3$ (M^+) 297.1365, found 297.1362.

(1-Phenylbut-3-enyl)carbamic acid 2-benzylsulfonylethyl ester (17aA). Carbamate **8** (500 mg, 1.96 mmol), benzaldehyde (200 μL, 1.96 mmol), allyltrimethylsilane (312 μL, 1.96 mmol) and $BF_3{\cdot}OEt_2$ (241 μL, 1.96 mmol) in CH_2Cl_2 (10 mL) were reacted for 4 h at rt according to general procedure A to afford **17aA** (672 mg, 1.75 mmol, 89%) as a white solid. R_f 0.38 (EtOAc/PE 1:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41-7.27 (m, 10H, Ar-H), 5.71-5.63 (m, 1H, C*H*=CH_2), 5.19-5.08 (m, 3H, NH and CH=CH_2), 4.78 (d, *J* = 6.7 Hz, 1H, NHC*H*), 4.46 (t, *J* = 6.0 Hz, 2H, OCH_2), 4.24 (s, 2H, ArCH_2), 3.15 (br s, 2H, SO_2CH_2), 2.57-2.53 (m, 2H, CH_2CH=CH_2). ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.5 (O*C*ON), 133.5, 130.6, 129.0, 128.9, 128.6, 127.4, 126.1 (Ar-C and *C*H=CH_2), 118.5 (CH=*C*H_2), 60.6, 57.8 (O*C*H_2 and Ar*C*H_2), 54.6 (NH*C*H), 50.7 (SO_2*C*H_2), 40.8 (*C*H_2CH=CH_2). IR *v*, cm^{-1} 3345, 3033, 2956, 1714, 1537, 1305, 1253, 1118, 920.

(1-Benzylbut-3-enyl)carbamic acid 2-benzylsulfonylethyl ester (17fA). Carbamate **8** (500 mg, 2.06 mmol), phenylacetaldehyde diethyl acetal (340 μL, 2.06 mmol), allyltrimethylsilane (328 μL, 2.06 mmol) and $BF_3{\cdot}OEt_2$ (253 μL, 2.06 mmol) in MeCN (10 mL) were reacted for 6 h at 50 ºC according to general procedure A to afford **17fA** (652 mg, 1.68 mmol, 82%) as a white solid. R_f 0.47 (EtOAc/PE 1:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39-7.16 (m, 10H, Ar-H), 5.82-5.74 (m, 1H, C*H*=CH_2), 5.12-5.08 (m, 2H, CH=CH_2), 4.67 (br d, *J* = 7.7 Hz, 1H, NH), 4.43 (br s, 2H, OCH_2), 4.20 (s, 2H, ArCH_2SO_2), 4.00-3.95 (m, 1H, NHC*H*), 3.13 (t, *J* = 5.6 Hz, 2H, SO_2CH_2), 2.80 (d, *J* = 6.6 Hz, 2H, ArCH_2CH), 2.34-2.13 (m, 2H, CH_2CH=CH_2). IR *v*, cm^{-1} 3348, 3029, 2978, 1715, 1530, 1284, 1245, 1123.

(1-Phenylbut-3-enyl)carbamic acid 2-benzylsulfanylethyl ester (18aA). Carbamate **9** (500 mg, 2.37 mmol), benzaldehyde (241 μL, 2.37 mmol), allyltrimethylsilane (378 μL, 2.37 mmol) and $BF_3{\cdot}OEt_2$ (291 μL, 2.37 mmol) in MeCN (15 mL) were reacted for 4 h at rt according to general procedure A to afford **18aA** (526 mg, 1.54 mmol, 65%) as a white solid. R_f 0.29 (EtOAc/PE 1:2). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39-7.22 (m, 10H, Ar-H), 5.74-5.64 (m, 1H, C*H*=CH_2), 5.15-5.05 (m, 3H, NH and CH=CH_2), 4.79 (d, *J* = 5.6 Hz, 1H, NHC*H*), 4.16 (t, *J* = 6.7 Hz, 2H, OCH_2), 3.73 (d, *J* = 2.8 Hz, 2H, ArCH_2), 2.67-2.53 (m, 4H, SCH_2 and CH_2CH=CH_2). ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.3 (O*C*ON), 141.8, 133.6, 128.8, 128.5, 128.4, 128.0, 127.2, 127.0, 126.1 (Ar-C and *C*H=CH_2), 118.3 (CH=*C*H_2), 63.8 (O*C*H_2), 54.3 (NH*C*H), 43.1, 36.2, 30.0 (Ar*C*H_2, S*C*H_2 and *C*H_2CH=CH_2). IR *v*, cm^{-1} 3326, 3029, 2919, 1707, 1524, 1453, 1250, 1010.

(1-Hexylbut-3-enyl)carbamic acid 2-benzylsulfanylethyl ester (18gA). Carbamate **9** (50 mg, 0.24 mmol), *n*-heptanal diethyl acetal (49 mg, 0.26 mmol), allyltrimethylsilane (38 μL, 0.24 mmol) and $BF_3{\cdot}OEt_2$ (29 μL, 0.24 mmol) in CH_2Cl_2 (1.5 mL) were reacted for 18 h at rt according to general procedure A to afford **18gA** (54 mg, 0.15 mmol, 66%) as a colorless oil. R_f 0.49 (EtOAc/PE 1:3). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.35-7.22 (m, 5H, Ar-H), 5.79-5.73 (m, 1H, C*H*=CH_2), 5.09-5.05 (m, 2H, CH=CH_2), 4.45 (br d, *J* = 8.4 Hz, 1H, NH), 4.16 (d, *J* = 6.6 Hz,

2H, OCH_2), 3.75 (s, 2H, ArCH_2), 3.69-3.66 (m, 1H, NHC*H*), 2.63 (d, *J* = 6.7 Hz, 2H, SCH_2), 2.28-2.16 (m, 2H, CH_2CH=CH_2), 1.51-1.26 (m, 10H, *n*-Hex), 0.87 (t, *J* = 6.5 Hz, 3H, *n*-Hex).

Preparation of bis-carbamate 21 and homoallylic carbamate 15hA. Benzyl carbamate (100 mg, 0.66 mmol) was dissolved in CH_2Cl_2 (2 mL), phthalimidoacetaldehyde diethyl acetal (174 mg, 0.66 mmol), allyltrimethylsilane (106 μL, 0.66 mmol) and $BF_3{\cdot}OEt_2$ (81 μl, 0.66 mmol) were subsequently added, after 5 min a white precipitate was formed and the resulting suspension was stirred for 18 h at rt. Then, saturated aqueous $NaHCO_3$ (3 mL) was added and the layers were separated. The aqueous layer was extracted with CH_2Cl_2 (2 × 2 mL), the combined organic layers were washed with aqueous saturated NaCl (5 mL), dried ($MgSO_4$) and concentrated *in vacuo*. The resulting solid material was triturated with EtOAc/PE (1:1, 2 mL) and filtrated. The white, solid residue was washed with EtOAc/PE (1:1, 2 × 2 mL), the combined filtrates were concentrated *in vacuo* and purified using column chromatography resulting in 25 mg (0.17 mmol, 25%) of benzyl carbamate and 57 mg (0.16 mmol, 24%) of homoallylic carbamate **15hA**. The solid residue was dried *in vacuo* to afford 78 mg (0.17 mmol, 25%) of bis-carbamate **21** as a white solid.

[1-Benzyloxycarbonylamino-2-(1,3-dioxo-1,3-dihydroisoindol-2-yl)ethyl]carbamic acid benzyl ester (21). R_f 0.05 (EtOAc/PE 1:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85-7.82 (m, 2H, Ar-H), 7.73-7.71 (m, 2H, Ar-H), 7.31-7.26 (m, 10H, Ar-H), 5.87 (br d, *J* = 6.5 Hz, 2H, 2 × NH), 5.29 (br s, 1H, NHC*H*NH), 5.07 (s, 4H, 2 × ArCH_2), 4.16-4.11 (m, 2H, NCH_2). ^{13}C NMR (50 MHz, $CDCl_3$) δ 167.9 (*C*ON*C*O), 155.1 (2 × O*C*ON), 135.5, 134.0, 131.5, 128.2, 127.9, 127.8, 123.4 (Ar-C), 66.8 (2 × Ar*C*H$_2$), 59.0 (NH*C*HNH), 40.0 (N*C*H$_2$). IR *ν*, cm^{-1} 3306, 1709, 1509, 1398, 1236, 1031. HRMS (FAB+) calculated for $C_{26}H_{24}N_3O_6$ (M^+ + H) 474.1665, found 474.1649. Bis-carbamate **21** (70 mg, 0.15 mmol) was dissolved in MeCN (2 mL), allyltrimethylsilane (24 μL, 0.15 mmol) and $BF_3{\cdot}OEt_2$ (18 μL, 0.15 mmol) were added and the reaction mixture was stirred for 18 h at rt. Then, saturated aqueous $NaHCO_3$ (3 mL) was added and the layers were separated. The aqueous layer was extracted with CH_2Cl_2 (2 × 2 mL), the combined organic layers were washed with aqueous saturated NaCl (5 mL), dried ($MgSO_4$) and concentrated *in vacuo*. The crude product was purified using column chromatography (EtOAc/PE 1:1) to afford a second portion of **15hA** (20 mg, 0.06 mmol, 37%) as a colorless oil.

[1-(1,3-Dioxo-1,3-dihydroisoindol-2-ylmethyl)but-3-enyl]carbamic acid benzyl ester (15hA). R_f 0.45 (EtOAc/PE 1:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.83-7.81 (m, 2H, Ar-H), 7.72-7.69 (m, 2H, Ar-H), 7.30-7.22 (m, 5H, Ar-H), 5.89-5.78 (m 1H, C*H*=CH$_2$), 5.16-4.91 (m, 5H, CH=CH_2, NH and ArCH_2), 4.12-4.10 (m, 1H, NHC*H*), 3.81-3.70 (m, 2H, NCH_2), 2.40-2.27 (m, 2H, CH_2CH=CH$_2$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 168.4 (*C*ON*C*O), 155.6 (O*C*ON), 136.4, 133.9, 133.0, 131.8, 128.2, 127.8, 127.7, 123.3 (Ar-C and *C*H=CH$_2$), 118.6 (CH=*C*H$_2$), 66.4 (Ar*C*H$_2$), 50.0 (NH*C*H), 41.2 (N*C*H$_2$), 37.2 (*C*H$_2$CH=CH$_2$). IR *ν*, cm^{-1} 3360, 3068, 2912, 1773, 1723, 1526, 1397, 1253, 1009. HRMS (FAB+) calculated for $C_{21}H_{21}N_2O_4$ (M^+ + H) 365.1501, found 365.1497.

General procedure B for the *N*-acyliminium ion reaction with carbamate 11

Carbamate **11**[8] and the nucleophile were dissolved in CH_2Cl_2. $BF_3{\cdot}OEt_2$ was added and the reaction mixture was stirred for the indicated time at rt. Then, aqueous Na_2CO_3 (10%) was added and the layers were separated. The aqueous layer was extracted with CH_2Cl_2 (2 ×), the combined organic layers were washed with aqueous saturated NaCl, dried ($MgSO_4$) and concentrated *in vacuo*. The crude product was purified using column chromatography (EtOAc/PE).

(1-Phenylbut-3-enyl)carbamic acid benzyl ester (15aA) from 11. Carbamate **11** (100 mg, 0.28 mmol), allyltrimethylsilane (89 μL, 0.56 mmol) and $BF_3{\cdot}OEt_2$ (71 μL, 0.56 mmol) in CH_2Cl_2 (2 mL), were reacted for 18 h according to general procedure B to afford **15aA** (62 mg, 0.22 mmol, 80%) as a colorless oil which was identical to the compound obtained from benzyl carbamate (**14**).

(2-Methylene-1-phenylbut-3-enyl)carbamic acid benzyl ester (15aJ) from 11. Carbamate **11** (100 mg, 0.28 mmol), (allenylmethyl)trimethylsilane (45 μL, 0.56 mmol) and $BF_3{\cdot}OEt_2$ (71 μL, 0.56 mmol) in CH_2Cl_2 (2 mL), were reacted for 18 h according to general procedure B to afford **15aJ** (44 mg, 0.15 mmol, 53%) as a colorless oil which was identical to the compound obtained from benzyl carbamate (**14**).

[1-(5-Oxo-2,5-dihydrofuran-2-yl)benzyl]carbamic acid benzyl ester (15aL)[27] **from 11.** Carbamate **11** (100 mg, 0.28 mmol), 2-timethylsilyloxy-furan (70 μL, 0.42 mmol) and $BF_3{\cdot}OEt_2$ (34 μL, 0.28 mmol) in CH_2Cl_2 (1.5 mL), were reacted for 1 h at at -78 °C, the mixture was allowed to warm up to rt and reacted for 18 h at this temperature according to general procedure B to afford **15aL** (46 mg, 0.14 mmol, 51%) as a white solid. R_f 0.74 (EtOAc/PE 1:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.47 (m, 11H, Ar-H and COCH=C*H*), 6.09 (dd, *J* = 2.0, 5.7 Hz, 1H, COC*H*=CH), 5.34 (br s, 1H, NH), 5.14-5.03 (m, 4H, ArCH_2, NHC*H* and CH=CHC*H*). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.2 (O*C*O), 153.9 (O*C*ON), 137.4, 135.8, 128.9, 128.7, 128.4, 128.2, 128.0, 127.0 (Ar-C), 122.6 (COCH=*C*H), 110.5 (CO*C*H=CH), 84.7 (CH=CH*C*H), 67.1 (Ar*C*H_2), 55.7 (NH*C*H). IR *v*, cm^{-1} 3312, 3034, 1760, 1702, 1533, 1247, 1160, 1052, 819. HRMS (FAB+) calculated for $C_{19}H_{18}NO_4$ (M^+ + H) 324.1236, found 324.1240.

(1-(Furan-2-ylbenzyl)carbamic acid benzyl ester (15aM) from 11. Carbamate **11** (100 mg, 0.28 mmol) was dissolved in furan (1.5 mL), camphorsulfonic acid monohydrate (65 mg, 0.28 mmol) was added and the reaction mixture was stirred for 18 h at rt. Then, 10% aqueous Na_2CO_3 (3 mL) was added and the layers were separated. The aqueous layer was extracted with CH_2Cl_2 (2 × 2 mL), the combined organic layers were washed with aqueous saturated NaCl (5 mL), dried ($MgSO_4$) and concentrated *in vacuo*. The crude product was purified using column chromatography (EtOAc/PE 1:2) to afford **15aM** (47 mg, 0.15 mmol, 55%) as a white solid. R_f 0.56 (EtOAc/PE 1:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39-7.28 (m, 11H, Ar-H) 6.31 (dd, *J* = 1.9, 3.1 Hz, 1H, furan), 6.15 (br s, 1H, furan), 6.02 (br d, *J* = 7.6 Hz, 1H, NH), 5.52 (br s, 1H, NHC*H*), 516-5.09 (m, 2H, ArCH_2). ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.4 (O*C*ON), 153.5, 139.4, 136.1, 128.5, 128.4, 128.0, 127.8, 126.8 (Ar-C), 110.2, 107.4 (furan), 67.0 (Ar*C*H_2), 53.1 (NH*C*H). IR *v*, cm^{-1} 3307, 1689, 1539, 1248. HRMS (FAB+) calculated for $C_{19}H_{18}NO_3$ (M^+ + H) 308.1287, found 308.1280.

Benzyloxycarbonylaminophenylacetic acid (22).[28] Furan **15aM** (37 mg, 0.12 mmol) was dissolved in MeOH (2.5 mL) and cooled to -78 ºC. O_3 was bubbled through the cold solution until the reaction mixture turned blue, then some O_2 was bubbled through until the reaction mixture turned colorless again. The solution was allowed to warm up to rt, concentrated *in vacuo* and purified using column chromatography (EtOAc/PE, 1:1, 10% AcOH) to afford **22** (26 mg, 0.10 mmol, 79%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.88 (br s, 1H, CO_2H), 7.54-7.34 (m, 10H, Ar-H), 5.87 (br d, *J* = 6.9 Hz, 1H, NH), 5.39 (d, *J* = 7.1 Hz, 1H, NHC*H*), 5.10 (s, 2H, ArCH_2). ^{13}C NMR (100 MHz, $CDCl_3$) δ 174.3 (CO_2H), 155.4 (O*C*ON), 137.1, 135.8, 130.1, 128.5, 128.4, 128.2, 128.1, 127.1 (Ar-C), 67.2 (ArCH_2), 57.7 (NH*C*H). IR *ν*, cm^{-1} 3340, 3032, 1718, 1498, 1410, 1345, 1215, 1051. HRMS (EI+) calculated for $C_{16}H_{15}NO_4$ (M^+) 285.1001, found 285.1007.

General procedure C for the three component reaction with resin 23

SEC resin **23** was suspended in CH_2Cl_2. The aldehyde or acetal (3 equiv), nucleophile (3 equiv) and Lewis acid (1.5 equiv) were added. The reaction mixture was stirred at rt for the indicated time, filtered off, washed with CH_2Cl_2, EtOH (these steps were repeated four times) and Et_2O (2 ×) and dried *in vacuo*. Then, the resin was suspended in THF/MeOH (2:1), NaOMe (3 equiv) was added and the suspension was stirred for 3 h at rt. The reaction mixture was filtered off, the resin was washed with THF (2 ×), neutralized with HCl and diluted with saturated aqueous NaCl solution. The layers were separated, the aqueous phase was extracted with EtOAc (4 ×), and the collected organic phases were concentrated *in vacuo*. The product was purified using SPE chromatography (Isolute, silica, solvent system: 0→10% MeOH in CH_2Cl_2).

1-Phenylbut-3-enylamine (25aA).[29] Resin **23** (150 mg, 0.17 mmol), benzaldehyde (52 μL, 0.51 mmol), allyltrimethylsilane (82 μL, 0.51 mmol) and $BF_3{\cdot}OEt_2$ (32 μL, 0.26 mmol) were reacted for 3 h according to general procedure C to afford resin **24aA**. IR ν 3655, 3360, 1724. After subsequent cleavage and purification, **25aA** (20 mg, 0.14 mmol, 80%) was obtained as a colorless oil. R_f 0.20 (CH_2Cl_2/MeOH 9:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.34-7.22 (m, 5H, Ar-H), 5.81-5.70 (m, 1H, C*H*=CH_2), 5.15-5.07 (m, 2H, CH=CH_2), 3.99 (dd, *J* = 8.0, 5.4 Hz, 1H, NH_2C*H*), 2.51-2.33 (m, 2H, CH_2CH=CH_2), 1.66 (br s, 2H, NH_2). ^{13}C NMR (100 MHz, $CDCl_3$) δ 148.6 (Ar-H), 133.6 (*C*H=CH_2), 128.6, 127.4, 126.6 (Ar-C), 118.6 (CH=*C*H_2), 55.4 (NH_2*C*H), 41.7 (*C*H_2CH=CH_2). IR ν 3385, 1642. HRMS (EI) calculated for $C_{10}H_{13}N$ (M^+) 147.1048 found, 147.1037.

1-(4-Methoxyphenyl)but-3-enylamine (25bA).[30] Resin **23** (150 mg, 0.17 mmol), *p*-anisaldehyde (62 μL, 0.51 mmol), allyltrimethylsilane (82 μL, 0.51 mmol) and $BF_3{\cdot}OEt_2$ (32 μL, 0.26 mmol) were reacted for 3 h according to general procedure C to afford resin **24bA**. IR ν 3634, 3491, 1724. After subsequent cleavage and purification **25bA** (24 mg, 0.14 mmol, 79%) was obtained as a colorless oil. R_f 0.13 (CH_2Cl_2/MeOH 9:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.27 (d, *J* = 8.7 Hz, 2H, Ar-H), 6.85 (d, *J* = 8.5 Hz, 2H, Ar-H), 5.71-5.60 (m, 1H, C*H*=CH_2), 5.11-5.03 (m, 2H, CH=CH_2), 4.61 (br s, 2H, NH_2), 3.99 (dd, *J* = 14.2, 6.8 Hz, 1H, NH_2C*H*), 3.78 (s, 3H, OCH_3), 2.51 (t, *J* = 7.0 Hz, 2H, CH_2CH=CH_2). MS (ESI) calculated for $C_{11}H_{16}NO$ (M^+ + H) 178, found 178.

1-(4-Cyanophenyl)but-3-enylamine (25cA). Resin **23** (150 mg, 0.17 mmol), 4-cyanobenzaldehyde (67 mg, 0.51 mmol), allyltrimethylsilane (82 μL, 0.51 mmol) and $BF_3{\cdot}OEt_2$ (32 μL, 0.26 mmol) were reacted for 3 h according to general procedure C to afford resin **24cA**. IR ν 3637, 3501, 2229, 1723. After subsequent cleavage and purification **25cA** (12 mg, 0.07 mmol, 39%) was obtained as a colorless oil. R_f 0.24 (CH_2Cl_2/MeOH 9:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.61 (d, J = 8.3 Hz, 2H, Ar-H), 7.46 (d, J = 8.2 Hz, 2H, Ar-H), 5.76-5.65 (m, 1H, C*H*=CH_2), 5.13-5.01 (m, 2H, CH=C*H*$_2$), 4.07 (dd, J = 7.6, 5.6 Hz, 1H, NH_2C*H*), 2.47-2.29 (m, 2H, C*H*$_2$CH=CH_2), 1.60 (br s, 2H, N*H*$_2$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 143.9 (Ar-C) 132.2 (*C*H=CH_2), 127.6, 127.1 (Ar-C), 119.1, 118.5 (*C*N, CH=*C*H_2) 111.2 (Ar-C), 55.6 (NH_2*C*H), 42.1 (*C*H_2CH=CH_2). IR ν, cm^{-1} 3339, 2228, 1641. HRMS (EI+) calculated for $C_{11}H_{10}N$ (M^+ – NH_3) 156.0813 found, 156.0821.

1-(4-Nitrophenyl)but-3-enylamine (25dA). Resin **23** (150 mg, 0.17 mmol), 4-nitrobenzaldehyde (78 mg, 0.51 mmol), allyltrimethylsilane (82 μL, 0.51 mmol) and $BF_3{\cdot}OEt_2$ (32 μL, 0.26 mmol) were reacted for 3 h according to general procedure C to afford resin **24dA**. IR ν 3625, 3505, 1726, 1523, 1352. After subsequent cleavage and purification **25dA** (1 mg, 0.01 mmol, <3%) was obtained as a colorless oil. R_f 0.17 (CH_2Cl_2/MeOH 9:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.19 (d, J = 8.8 Hz, 2H, Ar-H), 7.52 (d, J = 8.7 Hz, 2H, Ar-H), 5.75-5.67 (m, 1H, C*H*=CH_2), 5.30-5.06 (m, 2H, CH=C*H*$_2$), 4.14 (dd, J = 5.3, 7.8 Hz, 1H, NH_2C*H*), 2.48-2.32 (m, 2H, C*H*$_2$CH=CH_2), 1.75 (br s, 2H, N*H*$_2$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 151.7, 146.2 (Ar-C), 134.0 (*C*H=CH_2), 127.2, 123.6 (Ar-C), 118.6 (CH=*C*H_2), 54.7 (NH_2*C*H), 43.6 (*C*H_2CH=CH_2). IR ν, cm^{-1} 3356, 1598, 1520, 1345. HRMS (EI+) calculated for $C_{10}H_{13}N_2O_2$ (M^+ – NH_3) 193.0977 found, 193.0974.

1-(Thiophen-3-yl)but-3-enylamine (25iA). Resin **23** (150 mg, 0.19 mmol), 3-thiophene carboxaldehyde (49 μL, 0.56 mmol), allyltrimethylsilane (89 μL, 0.56 mmol) and $BF_3{\cdot}OEt_2$ (36 μL, 0.28 mmol) were reacted according to general procedure C to afford **25iA** (17 mg, 0.11 mmol, 60%) as a pale yellow oil. R_f 0.15 (CH_2Cl_2/MeOH 9:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.43 (dd, J = 1.1, 2.8 Hz, 1H, Ar-H), 7.31-7.21 (m, 2H, Ar-H), 5.67-5.56 (m, 1H, C*H*=CH_2), 5.16-5.09 (m, 2H, CH=C*H*$_2$), 4.40-4.37 (m, 1H, NH_2C*H*), 2.85-2.68 (m, 2H, C*H*$_2$CH=CH_2). ^{13}C NMR (50 MHz, $CDCl_3$) δ 136.6, 131.2, 126.7, 126.1, 124.2 (Ar-C and *C*H=CH_2), 120.1 (CH=*C*H_2), 51.0 (NH_2*C*H), 38.3 (*C*H_2CH=CH_2). IR ν, cm^{-1} 2908, 1598, 1509, 1422, 1087, 994, 924. HRMS (EI+) calculated for $C_{18}H_{11}NS$ (M^+) 153.0612, found 153.0608.

1-Benzylbut-3-enylamine (25fA).[31] Resin **23** (200 mg, 0.28 mmol), phenylacetaldehyde diethyl acetal (158 μL, 1.12 mmol), allyltrimethylsilane (179 μL, 1.12 mmol) and $BF_3{\cdot}OEt_2$ (69 μL, 0.56 mmol) were reacted according to general procedure C to afford **25fA** (18 mg, 0.11 mmol, 39%) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.33-7.23 (m, 5H, Ar-H), 5.89-5.79 (m, 1H, C*H*=CH_2), 5.29-5.51 (m, 2H, CH=C*H*$_2$), 3.53-3.46 (m, 1H, NH_2C*H*), 3.23 (dd, J = 5.4, 13.7 Hz, 1H, ArC*H*$_2$), 2.93 (dd, J = 9.0, 13.6 Hz, 1H, ArC*H*$_2$), 2.47-2.43 (t, J = 6.5 Hz, 2H, C*H*$_2$CH=CH_2). ^{13}C NMR (100 MHz, $CDCl_3$) δ 135.5, 131.3, 129.3, 128.2, 127.2 (Ar-C and *C*H=CH_2), 120.9 (CH=*C*H_2), 53.2 (NH_2*C*H), 38.2, 35.7 (Ar*C*H_2 and *C*H_2CH=CH_2). IR ν, cm^{-1}

3027, 2904, 1598, 1496, 1076, 996, 920. HRMS (EI+) calculated for $C_{11}H_{15}N$ (M^+) 161.1204, found 161.1208.

1-Hexylbut-3-enylamine (25gA).[32] Resin **23** (200 mg, 0.28 mmol), heptanal diethyl acetal (156 mg, 0.83 mmol), allyltrimethylsilane (132 μL, 0.83 mmol) and $BF_3{\cdot}OEt_2$ (51 μL, 0.41 mmol) were reacted according to general procedure C to afford **25gA** (25 mg, 0.16 mmol, 58%) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.87-5.77 (m, 1H, C*H*=CH_2), 5.26-5.21 (m, 2H, CH=C*H*$_2$), 3.24-3.18 (m, 1H, NH_2C*H*), 2.53-2.45 (m, 2H, C*H*$_2$CH=CH_2), 1.79-1.63 (m, 2H, CHC*H*$_2$), 1.48-1.22 (m, 8H, (C*H*$_2$)$_4$), 0.88-0.85 (m, 3H, C*H*$_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 132.3 (*C*H=CH_2), 120.2 (CH=*C*H$_2$), 51.8 (NH_2*C*H), 45.8, 36.7, 32.1, 28.8, 25.1, 22.4 (*C*H$_2$CH=CH_2, (*C*H$_2$)$_5$), 8.48 (*C*H$_3$). IR *ν*, cm^{-1} 2952, 2899, 1605, 1516, 995. HRMS (FAB+) calculated for $C_{13}H_{30}NO_2S$ (M^+ + H + thioglycerol) 264.1997, found 264.1993.

1-Cyclohexylbut-3-enylamine (25jA).[33] Resin **23** (200 mg, 0.28 mmol), cyclohexane carboxaldehyde diethyl acetal (**16j**, 208 mg, 1.12 mmol), allyltrimethylsilane (179 μL, 1.12 mmol) and $BF_3{\cdot}OEt_2$ (69 μL, 0.56 mmol) were reacted according to general procedure C to afford **25jA** (15 mg, 0.10 mmol, 35%) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.89-5.78 (m, 1H, C*H*=CH_2), 5.28-5.19 (m, 2H, CH=C*H*$_2$), 3.09-3.04 (m, 1H, NH_2C*H*), 2.52-2.48 (m, 2H, C*H*$_2$CH=CH_2), 1.84-1.64 (m, 6H, *c*-He), 1.35-1.10 (m, 5H, *c*-Hex). ^{13}C NMR (100 MHz, $CDCl_3$) δ 132.1 (*C*H=CH_2), 119.8 (CH=*C*H$_2$), 56.7 (NH_2*C*H), 39.0 (*c*-Hex), 34.2, 28.8, 27.8, 25.8, 25.7 (*C*H$_2$CH=CH_2 and *c*-Hex). IR *ν*, cm^{-1} 2928, 2854, 1602, 1515, 1447, 993.

1-Styrylbut-3-enylamine (25kA).[30] Resin **23** (200 mg, 0.28 mmol), (*E*)-cinnamaldehyde diethyl acetal (171 mg, 0.83 mmol), allyltrimethylsilane (132 μL, 0.83 mmol) and $BF_3{\cdot}OEt_2$ (51 μL, 0.41 mmol) were reacted according to general procedure C to afford **25kA** (22 mg, 0.13 mmol, 46%) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.37-7.21 (m, 5H, Ar-H), 6.69 (d, *J* = 16.0 Hz, 1H, PhC*H*=CH), 6.20 (dd, *J* = 8.0, 16.0 Hz, 1H, PhCH=C*H*), 5.74-5.63 (m, 1H, C*H*=CH_2), 5.17-5.10 (m, 2H, CH=C*H*$_2$), 3.91-3.67 (m, 1H, NH_2C*H*), 2.73-2.54 (m, 2H, C*H*$_2$CH=CH_2). ^{13}C NMR (125 MHz, $CDCl_3$) δ 135.8, 135.5, 131.4, 128.6, 128.4, 126.9, 123.8 (Ar-C, PhC*H*=C*H* and C*H*=CH_2) 120.3 (CH=*C*H$_2$), 53.8 (NH_2*C*H), 37.8 (*C*H$_2$CH=CH_2). IR *ν*, cm^{-1} 3383, 2980, 2884, 1601, 1495, 1073, 968, 922.

1-(4-Nitrophenyl)but-3-enylamine (25dA). Resin **23** (200 mg, 0.28 mmol), 4-nitrobenzaldehyde diethyl acetal (189 mg, 0.83 mmol), allyltrimethylsilane (132 μL, 0.83 mmol) and $BF_3{\cdot}OEt_2$ (51 μL, 0.41 mmol) were reacted according to general procedure C to afford **25dA** (4 mg, 0.02 mmol, 7%) as a colorless oil which was identical to the product obtained with 4-nitrobenzaldehyde (**12d**).

6-Amino-6-phenylhex-3-enoic acid methyl ester (25aG). Resin **23** (150 mg, 0.19 mmol), benzaldehyde (57 μL, 0.56 mmol), methyl 3-(trimethylsilyl)-4-pentenoate (116 μL, 0.56 mmol) and $BF_3{\cdot}OEt_2$ (36 μL, 0.28 mmol) were reacted according to general procedure C to afford **25aG** (17 mg, 0.08 mmol, 42%) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.44-7.27 (m, 5H, Ar-H), 5.69-5.62 (m, 1H, MeO_2CCH_2C*H*=CH), 5.42-5.30 (m, 1H, MeO_2CCH_2CH=C*H*), 4.14-4.09 (m, 1H, NH_2C*H*), 3.62 (s, 3H, CO_2Me), 3.00 (d, *J* = 6.8 Hz, 2H, MeO_2CC*H*$_2$), 2.69-2.60 (m, 2H, CHC*H*$_2$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.1 (*C*O_2Me), 128.9, 128.7, 127.5, 127.1, 126.7

(Ar-C and 2 × *C*H=CH), 55.6 (CO_2Me), 51.7 (NH_2CH), 39.2, 37.5 (MeO_2CCH_2 and $CHCH_2$). IR *v*, cm^{-1} 3250, 2946, 1722, 1602, 1509, 1437, 1256, 1198, 1167. HRMS (FAB+) calculated for $C_{13}H_{18}NO_2$ (M^++ H) 200.1338, found 200.1346.

2-Methylene-1-phenylbut-3-enylamine (25aJ). Resin **23** (150 mg, 0.19 mmol), benzaldehyde (57 μL, 0.56 mmol), (allenylmethyl)trimethylsilane (90 μL, 0.56 mmol) and $BF_3{\cdot}OEt_2$ (36 μL, 0.28 mmol) were reacted according to general procedure C to afford **25aJ** (18 mg, 0.06 mmol, 30%) as a colorless oil. R_f 0.23 (CH_2Cl_2/MeOH 9:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.43-7.31 (m, 5H, Ar-H), 6.84 (dd, *J* = 11.7, 22.5 Hz, 1H, CH_2=C*H*), 5.39 (d, *J* = 18.4 Hz, 2H, =CH_2), 5.04-4.98 (m, 3H, =CH_2 and NH_2CH). ^{13}C NMR (100 MHz, $CDCl_3$) δ 141.2, 135.0 (Ar-C and CH_2=*C*), 135.3 (CH_2=*C*H), 129.0, 128.9, 128.1 (Ar-C), 117.4, 116.2 (=*C*H_2), 55.7 (NH_2CH). IR *v*, cm^{-1} 2894, 2709, 1599, 1519, 1073, 1029, 908.

6-Amino-6-(4-methoxyphenyl)hex-3-enoic acid methyl ester (25bG). Resin **23** (150 mg, 0.19 mmol), 4-methoxybenzaldehyde (68 μL, 0.56 mmol), methyl 3-(trimethylsilyl)-4-pentenoate (116 μL, 0.56 mmol) and $BF_3{\cdot}OEt_2$ (36 μL, 0.28 mmol) were reacted according to general procedure C to afford **25bG** (17 mg, 0.07 mmol, 37%) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45 (d, *J* = 8.7 Hz, 2H, Ar-H), 6.88 (d, *J* = 8.8 Hz, 2H, Ar-H), 5.72-5.64 (m, 1H, MeO_2CCH_2C*H*=CH), 5.34-5.26 (m, 1H, MeO_2CCH_2CH=C*H*), 4.15 (br s, 1H, NH_2CH), 3.77, 3.66 (CO_2Me and OMe), 2.98 (d, *J* = 7.0 Hz, 2H, MeO_2CCH_2), 2.44-2.21 (m, 2H, $CHCH_2$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.6 (*C*O_2Me), 159.8, 129.4, 128.7, 127.8, 126.0, 114.2 (Ar-C and 2 × *C*H=CH), 55.2, 55.1, 52.0 (CO_2Me, NH_2CH and OMe), 37.5, 36.1 (MeO_2CCH_2 and $CHCH_2$). IR *v*, cm^{-1} 3384, 2958, 1734, 1614, 1518, 1253, 1182, 1031. HRMS (FAB+) calculated for $C_{12}H_{17}NO$ ($M^{+\cdot}$ $C_2H_2O_2$) 190.1310, found 190.1218.

1-(4-Methoxyphenyl)-2-methylenebut-3-enylamine (25bJ). Resin **23** (150 mg, 0.19 mmol), 4-methoxybenzaldehyde (68 μL, 0.56 mmol), (allenylmethyl)trimethylsilane (90 μL, 0.56 mmol) and $BF_3{\cdot}OEt_2$ (36 μL, 0.28 mmol) were reacted according to general procedure C to afford **25bJ** (17 mg, 0.09 mmol, 48%) as a colorless oil. R_f 0.18 (CH_2Cl_2/MeOH 9:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.35 (d, *J* = 7.9 Hz, 2H, Ar-H), 6.83 (d, *J* = 7.9 Hz, 2H, Ar-H), 6.19 (dd *J* = 11.2, 17.6 Hz, 1H, C*H*=CH_2), 5.31 (d, *J* = 33.7 Hz, 2H, =CH_2), 5.03-4.96 (m, 3H, NH_2CH_2 and =CH_2), 3.77 (s, 3H, OMe). ^{13}C NMR (50 MHz, $CDCl_3$) δ 159.9 (Ar-C), 140.7 (*C*=CH_2), 135.2 (*C*H=CH_2), 129.6, 126.3 (Ar-C), 117.3, 116.0 (2 × =*C*H_2), 114.1 (Ar-C), 55.1, 55.0 (NH_2CH, OMe). IR *v*, cm^{-1} 3220, 3031, 1616, 1519, 1466, 1257, 1182, 1035, 908, 835. HRMS (EI+) calculated for $C_{12}H_{15}NO$ (M^+) 189.1154, found 189.1154.

6-Amino-6-thiophen-3-ylhex-3-enoic acid methyl ester (25iG). Resin **23** (150 mg, 0.19 mmol), 3-thiophene carboxaldehyde (49 μL, 0.56 mmol), methyl 3-(trimethylsilyl)-4-pentenoate (116 μL, 0.56 mmol) and $BF_3{\cdot}OEt_2$ (36 μL, 0.28 mmol) were reacted according to general procedure C to afford **25iG** (15 mg, 0.07 mmol, 36%) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45 (d, *J* = 2.6 Hz, 1H, Ar-H), 7.31 (dd, *J* = 2.8, 4.9 Hz, 1H, Ar-H), 7.23 (d, *J* = 5.3 Hz, 1H, Ar-H), 5.74-5.68 (m, 1H, MeO_2CCH_2C*H*=CH), 5.43-5.35 (m, 1H, MeO_2CCH_2CH=C*H*), 4.41 (br s, 1H, NH_2CH), 3.63 (s, 3H, CO_2Me), 3.03 (d, *J* = 6.8 Hz, MeO_2CCH_2), 2.86-2.69 (m, 2H, $CHCH_2$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.2 (*C*O_2Me), 136.5,

127.8, 127.1, 126.0, 124.3, 122.2 (Ar-C and *C*H=CH), 52.3, 50.8 (NH_2CH and CO_2Me), 37.5, 37.2 (MeO_2CCH_2 and $CHCH_2$). IR *v*, cm^{-1} 3232, 2984, 1718, 1637, 1509, 1438, 1284, 1206, 974. HRMS (FAB+) calculated for $C_{11}H_{16}NO_2S$ ($M^+ + H$) 226.0902, found 226.0907.

2-Methylene-1-thiophen-3-ylbut-3-enylamine (25iJ). Resin **23** (150 mg, 0.19 mmol), 3-thiophene carboxaldehyde (49 μL, 0.56 mmol), (allenylmethyl)trimethylsilane (90 μL, 0.56 mmol) and $BF_3{\cdot}OEt_2$ (36 μL, 0.28 mmol) were reacted according to general procedure C to afford **25iJ** (18 mg, 0.08 mmol, 36%) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.44 (s, 1H, Ar-H), 7.27 (d, *J* = 5.0 Hz, 1H, Ar-H), 7.16 (d, *J* = 4.9 Hz, 1H, Ar-H), 6.28 (dd, *J* = 11.2, 17.7 Hz, 1H, C*H*=CH_2), 5.51-5.08 (m, 5H, CH=CH_2, C=CH_2 and NH_2CH). ^{13}C NMR (50 MHz, $CDCl_3$) δ 141.3 (*C*=CH_2), 135.5 (Ar-C), 134.9 (*C*H=CH_2), 126.8, 126.5, 125.4 (Ar-C), 117.3, 116.2 (C=*C*H_2 and CH=*C*H_2), 50.5 (NH_2CH). IR *v*, cm^{-1} 3032, 2884, 1599, 1515, 1419, 1235, 1082, 996, 907. HRMS (EI+) calculated for $C_9H_{11}NS$ (M^+) 165.0612, found 165.0617.

(1-Benzotriazolylphenylmethyl)carbamic acid 2-sulfonylethyl ester resin (26a). Resin **23** (1.00 g, 1.38 mmol) was suspended in toluene (10 mL), benzaldehyde (421 μL, 4.14 mmol), 1-H-benzotriazole (493 mg, 4.14 mmol) and *p*TsOH (39 mg, 0.21 mmol) were added and heated to reflux temperature. The reflux condensor was placed on top of a pressure-equalizing dropping funnel filled with 4Å MS and the mixture was refluxed for 18 h. The suspension was filtered, the resin was washed with CH_2Cl_2 (10 mL), EtOH (2 mL, the last two steps were repeated four times) and Et_2O (2 × 10 mL). After drying *in vacuo* (50 ºC) resin **26a** was obtained. IR ν 3560, 3023, 2919, 2852, 1728, 1601, 1492, 1310, 1118.

1-Phenylbut-3-enylamine (25aA) from resin 26a. Resin **26a** (150 mg, 0.16 mmol), allyltrimethylsilane (51 μL, 0.32 mmol) and $BF_3{\cdot}OEt_2$ (39 μL, 0.32 mmol) were reacted according to general procedure C to afford **25aA** (17 mg, 0.11 mmol, 71% from resin **23**) as a colorless oil which was identical to the product obtained directly from resin **23**.

1-(Furan-2-yl)benzylamine (25aM)[30] from resin 26a. Resin **26a** (150 mg, 0.16 mmol) and camphersulfonic acid monohydrate (76 mg, 0.32 mmol) were suspended in furan (1.5 mL) and were reacted according to general procedure C to afford **25aM** (14 mg, 0.08 mmol, 50% from resin **23**) as a colorless oil. R_f 0.41 (CH_2Cl_2/MeOH 9:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46-7.27 (m, 6H, Ar-H), 6.30 (dd, *J* = 1.8, 3.1 Hz, 1H, furan), 6.10 (d, *J* = 3.2 Hz, 1H, furan), 5.18 (s, 1H, NH_2CH). ^{13}C NMR (100 MHz, $CDCl_3$) δ 148.9, 134.1, 129.1, 128.9, 128.1, (Ar-C and furan), 110.6, 109.7 (furan), 53.0 (NH_2CH). IR *v*, cm^{-1} 3169, 2933, 2819, 1743, 1619, 1526, 1187, 1042. HRMS (EI+) calculated for $C_{11}H_{11}NO$ (M^+) 173.0841, found 173.0838.

2-(2,4-Dimethoxyphenyl)benzylamine (25aN) from resin 26a. Resin **26a** (100 mg, 0.11 mmol) and camphorsulfonic acid monohydrate (51 mg, 0.22 mmol) were suspended in 1,3-dimethoxybenzene (1.0 mL) and were reacted according to general procedure C to afford **25aN** (5 mg, 0.02 mmol, 20% from resin **23**) as a colorless oil. R_f 0.15 (CH_2Cl_2/MeOH 9:1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41-7.11 (m, 6H, Ar-H), 6.44-6.41 (m, 2H, Ar-H), 5.45 (s, 1H, NH_2CH), 3.78 (2, 3H, OMe), 3.77 (s, 3H, OMe). ^{13}C NMR (100 MHz, $CDCl_3$), 160.0, 157.6, 130.0, 129.4, 128.9, 127.7, 127.6, 125.7, 104.0, 98.7 (Ar-C), 55.3, 55.2 (OMe), 53.6 (NH_2CH). IR *v*, cm^{-1}

3361, 3007, 2935, 1612, 1587, 1454, 1293, 1209, 1034. HRMS (FAB+) calculated for $C_{14}H_{21}N_2O_5$ (M^+ + H) 297.1450, found 297.1459.

1-(4-Nitrophenyl)but-3-enylamine (25dA) *via* Bt-derivative 26d. Resin **23** (1.00 g, 1.38 mmol) was suspended in toluene (10 mL), 4-nitrobenzaldehyde (421 μL, 4.14 mmol), 1-H-benzotriazole (493 mg, 4.14 mmol) and *p*TsOH (39 mg, 0.21 mmol) were added and heated to reflux temperature. The reflux condensor was placed on top of a pressure-equalizing dropping funnel filled with 4Å MS and the mixture was refluxed for 18 h. The suspension was filtered, the resin was washed with CH_2Cl_2 (10 mL), EtOH (2 mL, the last two steps were repeated four times) and Et_2O (2 × 10 mL). After drying *in vacuo* (50 ºC) resin **26d** was obtained. IR ν 3545, 3018, 2957, 1726, 1524, 1353. Resin **26d** (150 mg, 0.16 mmol), allyltrimethylsilane (51 μL, 0.32 mmol) and $BF_3{\cdot}OEt_2$ (40 μL, 0.32 mmol) were reacted according to general procedure C to afford **25dA** (15 mg, 0.78 mmol, 49% from resin **23**) as a colorless oil which was identical to the product obtained directly from resin **23**.

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