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UNNATURAL AMINO ACIDS.
2*. SIMPLE METHOD OF OBTAINING ESTERS OF AZIRIDINE-2-CARBOXYLIC ACIDS BY A TRANSESTERIFICATION REACTION

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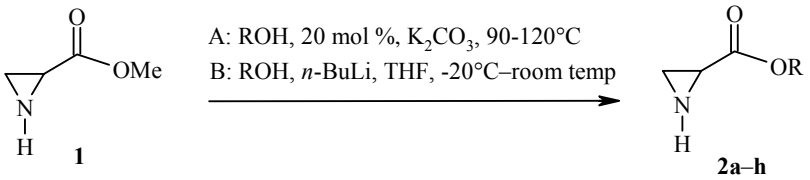
A series of N-unsubstituted esters of aziridine-2-carboxylic acid has been obtained by transesterification in basic medium using primary, secondary, and tertiary alcohols. Methods of transesterification using various bases (K_2CO_3, ROLi, t-BuOK) have been compared. Transesterification with lithium alcoholates also affords the possibility of obtaining esters of N-substituted aziridine-2-carboxylic acids. Transesterification of chiral esters proceeds with retention of the configuration of the chiral center.

Keywords: diastereomers, esters of aziridine-2-carboxylic acid, enantiomers, transesterification.

Esters of aziridine-2-carboxylic acid are a convenient source of various derivatives of α- and β-amino acids, due to the high reactivity of the aziridine ring [2,3]. In difference to esters of other amino acids, aziridine-2-carboxylates have no tendency to dimerize, consequently the direct transesterification method may be used in the aziridine-2-carboxylate series.

The transesterification of aziridine-2-carboxylates has not been described in the literature, although good results have been obtained for compounds of other classes [4] on using acid or base catalysis, catalysis by alcoholates [4-7], organotin [8] and organotitanium compounds [9], and also indium triiodide [10]. To obtain aziridine-2-carboxylates we chose the base catalysis method [4,5] since aziridines are unstable under acid conditions and in the presence of strong Lewis acids. Lithium alcoholates, used in [5], are readily obtained from the corresponding alcohols by reaction with butyllithium. As starting materials we used aziridine-2-carboxylic acid methyl ester **1**, for which a convenient method of synthesis has been developed [1], and its 1-alkyl and 1-acyl derivatives obtained by known methods used for the protection of the amino group of amino acids [11].

We have obtained a series of N-unsubstituted aziridine-2-carboxylates **2a-h**, using primary, secondary, and tertiary alcohols, and have compared two methods (A and B) of transesterification. The transesterification products were obtained in high or moderate yields (Table 1).



* For Part 1 see [1].

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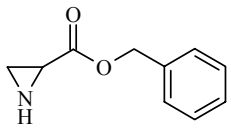
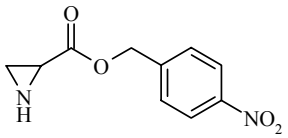
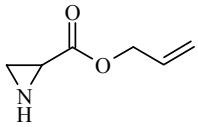
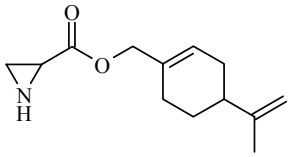
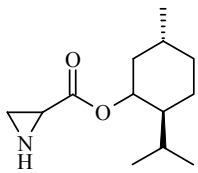
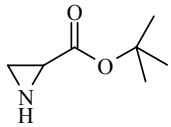
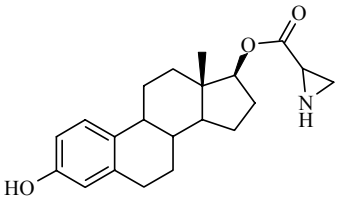
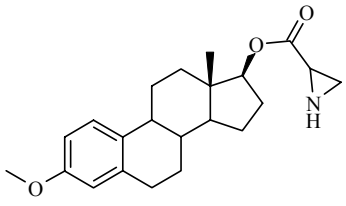
TABLE 1. Yields of Esters **2a-h** Synthesized by Methods A and B

	Ester	Method A		Method B	
		Reaction time, h	Yield, %*	Reaction time, h	Yield, %*
2a		24	41	1	30
2b		2	32	48	<1
2c		2	40	5	4
2d		24	78*	2	45
2e		240	0	1	67
2f		100	0	1	80
2g		100	0	1	39
2h		100	0	1	57

* According to data of gas chromatography.

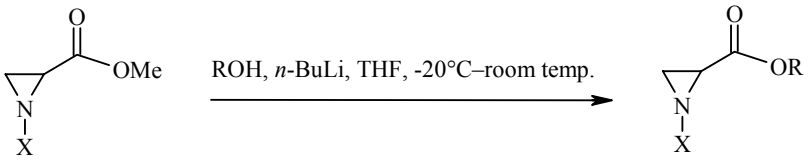
Method A is based on catalysis by K_2CO_3 base and by the shift in chemical equilibrium in the direction of forming reaction products by distilling out the more volatile alcohol MeOH. Reaction was carried out without solvent. In method B [5] the appropriate lithium alcoholate was used as reagent, generated with butyllithium *in situ* from the corresponding alcohol.

Comparison of methods A and B showed that catalysis by a weak base (K_2CO_3) gives satisfactory yields of esters only with primary alcohols of the benzyl and allyl types (esters **2a-d**). In the case of perillyl alcohol (ester **2d**) the reaction proceeds by method A (according to data of gas chromatography the yield was 78%), but the ester was not isolated successfully due to side product formation. The 4-nitrobenzyl ester **2b** was successfully obtained only by method A. This is not unexpected since the incompatibility of organolithium bases with nitro compounds is known.

In the case of the more sterically hindered alcohols (esters **2e-h**) the transesterification proceeds only by method B, since the alcoholates of secondary and tertiary alcohols are more strongly basic than K_2CO_3. This method enables acylation of alcoholic groups of complex molecules such as steroids, particularly of estradiol derivatives (esters **2g,h**). Acylation in the case of estradiol (ester **2g**) occurs regioselectively only at the alicyclic and not at the phenolic hydroxyl, although for deprotonation both alcoholic groups use 2 equivalents of BuLi.

Attempts to carry out the transesterification reaction with polyhydric alcohols (glycerol, pentaerythritol, diacetonylglucose) did not give the expected reaction products. When using these alcohols in method A a mixture of aziridine ring fission products was obtained, on using the corresponding lithium alcoholates (method B), only starting materials were obtained.

Transesterification with lithium alcoholates also enables esters of the N-substituted aziridine-2-carboxylic acids **4a-j** to be obtained from the corresponding methyl esters (Table 2).

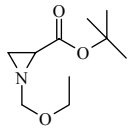
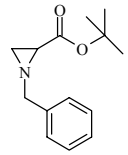
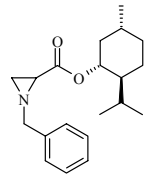
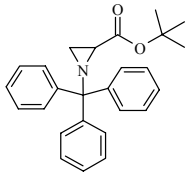
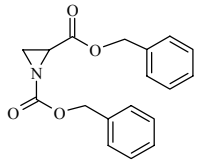
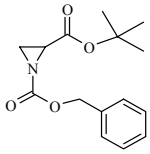
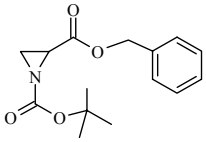
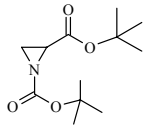
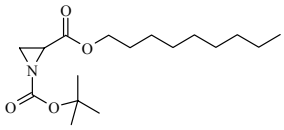
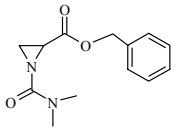


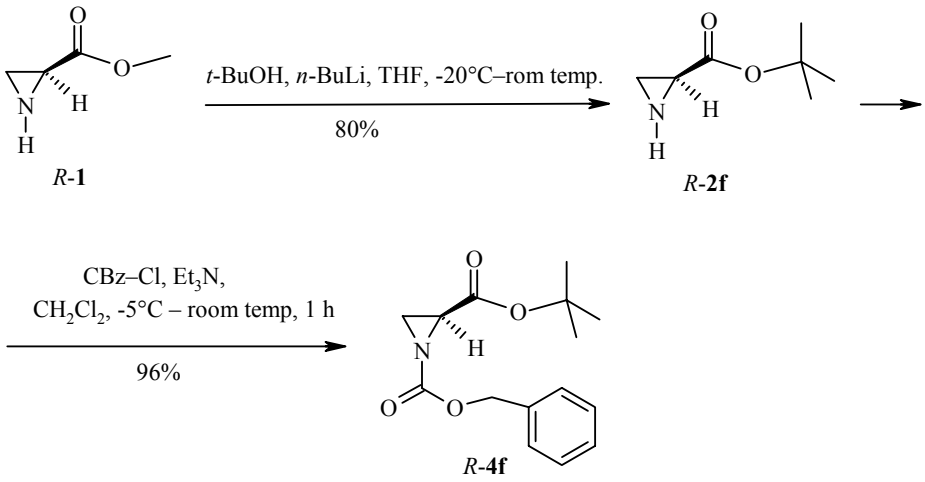
3a–i **4a–i**

The reaction of lithium alcoholates with N-alkyl derivatives of aziridine-2-carboxylic acid methyl ester **3a-d** proceeds smoothly with yields of esters **4a-d** of 41-88%. The steric effects of the substituent at the nitrogen atom proved to have no significant effect on the course of the reaction. Transesterification of methyl esters is the most convenient route to obtain esters **4c,d**, since alkylation of esters **2e,f** with benzyl and trityl chlorides proceeds slowly and with the formation of side products. The use in this reaction of the corresponding bromides is undesirable due to the higher nucleophilicity of bromide ion, which leads to fission of the aziridine ring even at room temperature.

It was shown that the diastereomers of the (-)-menthyl ester of N-benzylaziridine-2-carboxylic acid **4c** and **4'c** may be separated chromatographically. In the case of the N-unsubstituted compounds **2e** the diastereomers are not separable. It was also established that the asymmetric center $C_{(2)}$ of the aziridine ring is not racemized on transesterification. The optically pure ester *R*-**1** [1], obtained from the methyl ester of *L*-serine by the Mitsunobu reaction [12], on transesterification with lithium *tert*-butylate by method B gives ester *R*-**2f**. Comparison of the N-benzyloxycarbonyl derivative of this ester *R*-**4f**, obtained by the standard method [11], with the racemic ester *R,S*-**4f** by HPLC on a chiral column (enantiomer retention times 9.3 and 10.5 min) showed that ester *R*-**4f** (retention time 9.3 min) is enantiomerically pure.

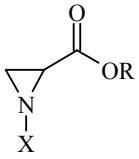
TABLE 2. Yields of Esters **4a-j**

	Ester	Reaction time, h	Yield, %
4a		1	88
4b		1	79
4c		3	48
4d		3	41
4e		1	65
4f		1	15
4g		1	21
4h		1	71
4i		2	76
4j		2	56



Transesterification of the corresponding methyl esters of N-acylaziridine-2-carboxylic acid **3e-j** also enables the preparation of the series of esters of N-acyl aziridine-2-carboxylic acid **4e-j**. Satisfactory yields were observed when the substituent at the nitrogen atom was identical to the ester group (esters **4e,h**). On transesterification of the methyl ester of N-benzyloxycarbonylaziridine-2-carboxylic acid **3f** with lithium *tert*-butylate a 1:1 mixture of esters **4f** and **4h** was formed. Ester **4h** is formed by transacylation at the nitrogen atom of the aziridine ring, consequently esters **4f** and **4g** are conveniently obtained by the N-acylation of esters **2f** and **2a** respectively. In the case of the carbamoyl derivative **4j** the transesterification reaction proceeds smoothly (56%). The *tert*-butyl carbamate group of ester **3i** is also not subject to a transacylation side reaction, and also provides a good yield of ester **4i**.

TABLE 3. ^{1}H NMR Spectra of Aziridine-2-carboxylic Acid Esters **2a-h** and **4a-n**



Com-pound	X	R	^{1}H NMR spectrum ($CDCl_3$), δ, ppm (*J*, Hz)
1	2	3	4
2a	H	Bn	1.09 (1H, br. s, NH); 1.74-1.93 (1H, m, H-3); 1.93-2.08 (1H, m, H-3); 2.47-2.63 (1H, m, H-2); 5.18 (2H, s, CH_2Ph); 7.30-7.41 (5H, m, arom.)
2b	H	4-NO_2–$C_6H_4CH_2$	1.11 (1H, br. s, NH); 1.71-2.06 (2H, m, H-3); 2.40-2.64 (1H, m, H-2); 5.22 (2H, s, CH_2Ph); 7.76 (2H, d, *J* = 9.0, *o*-H arom.); 8.22 (2H, d, *J* = 9.0, *m*-H arom.)
2c	H	Allyl	1.08 (1H, br. s, NH); 1.78-2.12 (2H, m, H-3); 2.48-2.65 (1H, m, H-2); 4.63-4.71 (2H, m, $C\underline{H}_2$–CH=CH_2); 5.24–5.43 (2H, m, CH_2–CH=$C\underline{H}_2$); 5.84-6.06 (1H, m, CH_2–$C\underline{H}$=CH_2)

TABLE 3 (continued)

1	2	3	4
2d	H	Perillyl	1.07 (1H, br. s, NH); 1.35-2.26 (9H, m, aliph.); 1.74 (3H, s, CH_3); 2.50-2.60 (1H, unresolved dd, H-2); 4.47-4.64 (2H, m, OCH_2); 4.68-4.80 (2H, m, $C=CH_2$); 5.75-5.86 (1H, m, aliph.)
2e	H	Menthyl	0.76 and 0.77 (3H, d and d, J = 7.0 and J = 7.0, menthyl CH_3); 0.79-1.16 (4H, m, aliph.); 0.91 (6H, d, J = 6.5, *i*-Pr); 1.31-2.07 (9H, m, aliph.); 4.73 (1H, ddt, ^3J = 2.2, ^3J = 4.5, ^3J = 10.8, OCH)
2f	H	*t*-Bu	0.96 (1H, br. s, NH); 1.48 (9H, s, *t*-Bu); 1.70-1.84 (1H, m, H-3); 1.86-1.98 (1H, m, H-3); 2.33-2.47 (1H, m, H-2)
2g	H	Estradiolyl	0.85 (3H, s, CH_3); 1.08-2.38 (15H, m, aliph., NH); 2.55 (1H, dd, ^2J = 3.0, ^3J = 5.4, H-2); 2.71-2.88 (3H, m, aliph.); 4.68-4.82 (1H, m, OCH); 4.53–5.52 (1H, br. s, OH); 6.55 (1H, d, J = 2.4, *o*-H arom.); 6.61 (1H, dd, J = 2.4, J = 8.3, *o*-H arom.); 7.14 (1H, d, J = 8.3, *m*-H arom.)
2h	H	3-Methoxy-estradiolyl	0.86 (3H, s, CH_3); 1.05 (1H, br. s, NH); 1.17-2.08 (12H, m, aliph.); 2.12-2.38 (3H, m, aliph.); 2.47-2.59 (1H, m, aliph.); 2.79-2.93 (2H, m, aliph.); 3.78 (3H, s, OCH_3); 4.69-4.84 (1H, m, OCH); 6.63 (1H, d, J = 2.8, *o*-H arom.); 6.71 (1H, dd, J = 2.8, J = 8.6, *o*-H arom.); 7.20 (1H, d, J = 8.6, *m*-H arom.)
4a	CH_2OMe	*t*-Bu	1.47 (9H, s, *t*-Bu); 1.81 (1H, dd, ^2J = 1.2, $^3J_{cis}$ = 6.8, *cis*-H-3); 2.07 (1H, dd, ^2J = 1.2, $^3J_{trans}$ = 3.0, *trans*-H-3); 2.27 (1H, dd, $^3J_{trans}$ = 3.0, $^3J_{cis}$ = 6.8, H-2); 3.43 (3H, s, OCH_3); 3.93 and 3.97 (1H and 1H, AB system, J = 7.9, NCH_2O)
4b	Bn	*t*-Bu	1.46 (9H, s, *t*-Bu); 1.64 (1H, unresolved dd, $^3J_{cis}$ = 6.3, *cis*-H-3); 2.07 (1H, dd, $^3J_{trans}$ = 3.2, $^3J_{cis}$ = 6.3, H-2); 2.19 (1H, dd, ^2J = 1.3, $^3J_{trans}$ = 3.2, *trans*-H-3); 3.54 and 3.57 (1H and 1H, AB system, J = 13.7, CH_2Ph); 7.19-7.38 (5H, m, arom.)
4c	Bn	Menthyl	0.60-2.27 (21H, m, aliph.); 3.37 and 3.73 (1H and 1H, AM system, J = 13.8, CH_2Ph); 4.73 (1H, dt, ^3J = 4.4, ^3J = 10.7, OCH); 7.11-7.40 (5H, m, arom.)
4'c	Bn	Menthyl	0.46-2.33 (21H, m, aliph.); 3.26 and 3.85 (1H and 1H, AM system, J = 13.7, CH_2Ph); 4.75 (1H, dt, ^3J = 4.4, ^3J = 10.9, OCH); 7.04-7.48 (5H, m, arom.)
4d	CPh_3	*t*-Bu	1.31 (1H, dd, ^2J = 1.6, $^3J_{cis}$ = 6.1, *cis*-H-3); 1.49 (9H, s, *t*-Bu); 1.77 (1H, dd, $^3J_{trans}$ = 2.6, $^3J_{cis}$ = 6.1, H-2); 2.20 (1H, dd, ^2J = 1.6, $^3J_{trans}$ = 2.6, *trans*-H-3); 7.16-7.34 (9H, m, arom.); 7.46-7.56 (6H, m, arom.)
4e	CO_2Bn	Bn	2.47 (1H, dd, ^2J = 1.2, $^3J_{cis}$ = 5.6, *cis*-H-3); 2.62 (1H, dd, ^2J = 1.2, $^3J_{trans}$ = 3.1, *trans*-H-3); 3.14 (1H, d.d, $^3J_{trans}$ = 3.1, $^3J_{cis}$ = 5.6, H-2); 5.02-5.21 (4H, m, CH_2Ph); 7.32-7.38 (10H, m, arom.)
***R*,*S*-4f**	CO_2Bn	*t*-Bu	1.45 (9H, s, *t*-Bu); 2.40 (1H, dd, ^2J = 1.3, $^3J_{cis}$ = 5.0, *cis*-H-3); 2.55 (1H, dd, ^2J = 1.3, $^3J_{trans}$ = 3.1, *trans*-H-3); 3.00 (1H, dd, $^3J_{trans}$ = 3.1, $^3J_{cis}$ = 5.0, H-2); 5.11 and 5.17 (1H and 1H, AB system, J = 12.1, CH_2Ph); 7.32-7.40 (5H, m, arom.)
***R*-4f**	CO_2Bn	*t*-Bu	1.45 (9H, s, *t*-Bu); 2.40 (1H, dd, ^2J = 1.3, $^3J_{cis}$ = 5.0, *cis*-H-3); 2.55 (1H, dd, ^2J = 1.3, $^3J_{trans}$ = 3.1, *trans*-H-3); 3.00 (1H, dd, $^3J_{trans}$ = 3.1, $^3J_{cis}$ = 5.0, H-2); 5.11 and 5.17 (1H and 1H, AB system, J = 12.1, CH_2Ph); 7.32-7.40 (5H, m, arom.)

TABLE 3 (continued)

1	2	3	4
4g	COOBu-*t*	Bn	1.43 (9H, s, *t*-Bu); 2.40 (1H, dd, ^2J = 1.4, $^3J_{cis}$ = 5.2, *cis*-H-3); 2.55 (1H, dd, ^2J = 1.2, $^3J_{trans}$ = 3.3, *trans*-H-3); 3.00 (1H, dd, $^3J_{trans}$ = 3.2, $^3J_{cis}$ = 5.1, H-2); 5.18 and 5.25 (1H and 1H, AB system, J = 12.4, CH_2Ph); 7.30-7.42 (5H, m, arom.)
4h	COOBu-*t*	*t*-Bu	1.47 (9H, s, *t*-Bu); 1.50 (9H, s, *t*-Bu); 2.32 (1H, dd, ^2J = 1.6, $^3J_{cis}$ = 5.2, *cis*-H-3); 2.47 (1H, dd, ^2J = 1.6, $^3J_{trans}$ = 3.1, *trans*-H-3); 2.93 (1H, dd, $^3J_{trans}$ = 3.1, $^3J_{cis}$ = 5.2, H-2)
4i	COOBu-*t*	Nonyl	0.86 (3H, t, J = 6.7, nonyl CH_3); 1.16-1.49 (21H, m, nonyl, *t*-Bu); 1.55-1.73 (2H, m, aliph.); 2.38 (1H, dd, ^2J = 1.5, $^3J_{cis}$ = 5.5, *cis*-H-3); 2.50 (1H, dd, ^2J = 1.5, $^3J_{trans}$ = 3.2, *trans*-H-3); 3.00 (1H, dd, $^3J_{trans}$ = 3.2, $^3J_{cis}$ = 5.5, H-2); 4.02-4.26 (2H, m, OCH_2)
4j	$CONMe_2$	Bn	2.48 (1H, dd, ^2J = 1.2, $^3J_{trans}$ = 3.2, *trans*-H-3); 2.55 (1H, dd, ^2J = 1.2, $^3J_{cis}$ = 6.3, *cis*-H-3); 2.92 (3H, s, CH_3); 3.02-3.08 (1H, unresolved dd, H-2); 3.05 (3H, s, CH_3); 5.14-5.28 (2H, m, CH_2Ph); 7.34-7.39 (5H, m, arom.)
4m	$CH(Ph)CH_2OMe$	*t*-Bu	1.42 (1H, dd, ^2J = 1.0, $^3J_{cis}$ = 6.3, *cis*-H-3); 1.50 (9H, s, *t*-Bu); 2.01 (1H, dd, ^2J = 1.0, $^3J_{trans}$ = 3.4, *trans*-H-3); 2.38 (1H, dd, $^3J_{trans}$ = 3.4, $^3J_{cis}$ = 6.3, H-2); 2.69 (1H, dd, J = 4.8, J = 7.7, NCH); 3.37 (3H, s, OCH_3); 3.61 (1H, dd, J = 4.8, J = 9.8, OCH); 3.70 (1H, dd, J = 7.7, J = 9.8, OCH); 7.25-7.45 (5H, m, arom.)
4n	$CH(Ph)CH_2OMe$	*t*-Bu	1.40 (9H, s, *t*-Bu), 1.87 (1H, dd, $^3J_{trans}$ = 3.3, $^3J_{cis}$ = 6.4, H-2); 1.98 (1H, dd, ^2J = 1.0, $^3J_{cis}$ = 6.3, *cis*-H-3); 2.39 (1H, dd, ^2J = 1.0, $^3J_{trans}$ = 3.3, *trans*-H-3); 2.75 (1H, dd, J = 4.5, J = 7.9, NCH); 3.34 (3H, s, OCH_3); 3.54 (1H, dd, J = 4.8, J = 9.8, OCH); 3.72 (1H, dd, J = 7.9, J = 9.8, OCH); 7.23-7.42 (5H, m, arom.)

We have shown by two different methods B and C (using potassium *tert*-butylate as base) that transesterification of the diastereomeric esters **4k** and **4l** proceeds with retention of the configuration of the substituent at the aziridine nitrogen atom and have obtained the corresponding diastereomeric esters **4m** and **4n**.

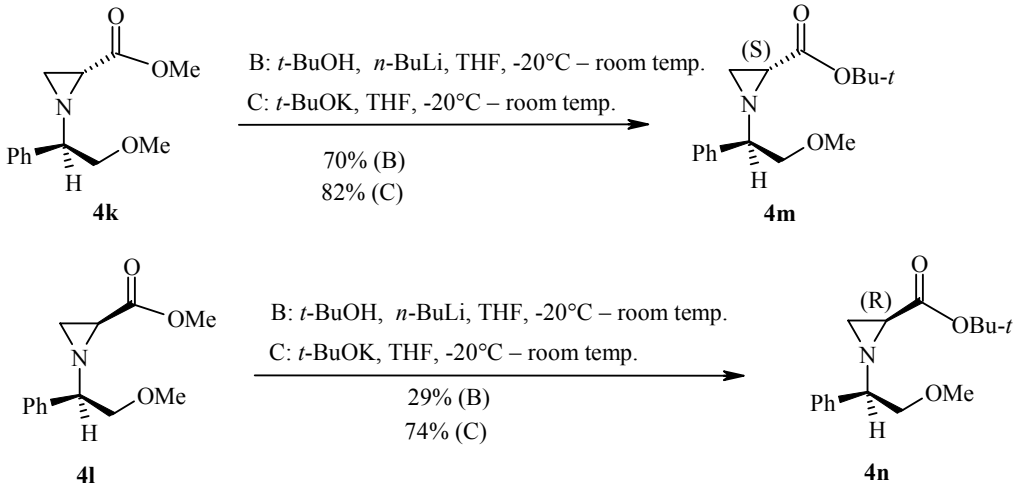


TABLE 4. Physicochemical Characteristics of Esters of Aziridine-2-carboxylic Acids **2** and **4**

Compound	Empirical formula	Found, % / Calculated, %			R_f*	mp, °C
		C	H	N		
2b	$C_{10}H_{10}N_2O_4$	52.69 / 54.06	4.64 / 4.54	12.16 / 12.61	0.13	115-117
2d	$C_{13}H_{19}NO_2$	69.30 / 70.56	8.59 / 8.65	6.28 / 6.33	0.58	
2e	$C_{13}H_{23}NO_2$	68.38 / 69.29	10.13 / 10.29	5.65 / 6.22	0.62	
2g	$C_{21}H_{27}NO_3$	73.63 / 73.87	8.24 / 7.97	3.50 / 4.10	0.26	129-130
2h	$C_{22}H_{29}NO_3$	74.14 / 74.33	8.28 / 8.22	3.92 / 3.94	0.15	135-136
4c	$C_{20}H_{29}NO_2$	75.44 / 76.15	9.60 / 9.27	3.97 / 4.44	0.63	107-109
4'c	$C_{20}H_{29}NO_2$	76.00 / 76.15	9.23 / 9.27	4.36 / 4.44	0.57	111-112
4d	$C_{26}H_{27}NO_2$	80.89 / 81.01	7.05 / 7.06	3.65 / 3.63	0.36	146-147
4f	$C_{15}H_{19}NO_4$	64.94 / 64.97	6.89 / 6.91	5.11 / 5.05	0.57	137.5-138.5
4h	$C_{12}H_{21}NO_4$	59.05 / 59.24	8.79 / 8.70	5.57 / 5.76	0.77	
4m	$C_{16}H_{23}NO_3$	69.30 / 69.29	8.40 / 8.36	4.99 / 5.05	0.59	128
4n	$C_{16}H_{23}NO_3$	69.11 / 69.29	8.51 / 8.36	5.03 / 5.05	0.46	

* Mobile phase in TLC: ethyl acetate–petroleum ether, 1:1 (compounds **2b,d,e,g, 4c, 4'c, 4m,n**), 1:3 (compounds **2h**, **4f**), 1:9 (compounds **4d,h**).

EXPERIMENTAL

The ^{1}H NMR spectra were recorded on a Varian Mercury 200 (200 MHz) spectrometer, internal standard was TMS. Elemental analyses were carried out on a Carlo Erba EA 1108 apparatus. Melting points were determined on a Gallenkamp heating stage and are not corrected. TLC was carried out on DC Alufolien plates of Kieselgel 60. Chiral HPLC of compounds **4f** and **4f-l** was carried out on a Gilson chromatographic system and a column of Chiralcel OD (Daicel), in hexane—ethanol, 95 : 5 (flow rate 1.0 ml/min and UV detector at 254 nm). Dry THF was prepared by double distillation over sodium (second time in the presence of benzoquinone).

Transesterification of Aziridine-2-carboxylic Acid Methyl Ester and Its Derivatives (General Procedure). A. Compounds 2a-h (Tables 1,3,4). Potassium carbonate (41.4 g, 300 mmol) was added with stirring to a solution of aziridine-2-carboxylic acid methyl ester [1] (10.1 g, 100 mmol) in the alcohol (100 mmol) at ~20°C. The mixture obtained was stirred and heated at 150°C in a stream of argon while distilling off the methanol. The reaction mixture was then cooled to room temperature, poured into water (50 ml), and extracted with ether (3 × 20 ml). The combined ether extracts were washed with water (2 × 20 ml), and with saturated NaCl solution (20 ml), then dried over Na_2SO_4, the solution filtered, and the solvent evaporated in vacuum. The obtained esters were purified by chromatography on silica gel with petroleum ether–ethyl acetate, or by distillation in vacuum.

B. Compounds 2a-h and 4a-j (Tables 1-4). A round-bottomed flask (100 ml) was placed in a heater for 5 h at 150°C and cooled in a stream of argon to room temperature. The alcohol (100 mmol) was placed in the flask and absolute THF (10 ml) was added. The obtained solution was cooled to -20°C in a stream of argon and BuLi (40 ml, 100 mmol) was added dropwise as a 2.5 M solution in hexane. The solution of alcoholate obtained was stirred at -20°C for 15 min, a solution of aziridine-2-carboxylic acid methyl ester (100 mmol) in absolute THF (15 ml) was added, the mixture was stirred for 1-5 h at -20°C, heated to room temperature, poured into ice water (20 ml), and extracted with ether (3 × 20 ml). The ether extracts were combined, washed with water (2 × 20 ml), and with saturated NaCl solution (20 ml), dried over Na_2SO_4, and the solvent evaporated in vacuum. The esters obtained were purified by chromatography on silica gel in the system petroleum ether–ethyl acetate, or by distillation in vacuum.

C. Compounds 4m and 4n (Tables 3, 4). A round-bottomed flask (100 ml) was placed in a heater at 150°C for 5 h and cooled in a current of argon to room temperature. Potassium *tert*-butylate (100 mmol) was placed in the flask and absolute THF (15 ml) was added. The solution obtained was cooled in a current of argon to -20°C and a solution of aziridine-2-carboxylic acid methyl ester (100 mmol) in absolute THF (15 ml) was added dropwise. The mixture was stirred at -20°C for 1.5 h, heated to room temperature, poured into ice water (25 ml), and extracted with ether (3 × 25 ml). The ether extracts were combined, washed with water (2 × 25 ml), and with saturated NaCl solution (25 ml), dried over Na_2SO_4, and evaporated. The esters obtained were purified by chromatography on silica gel in the system petroleum ether–ethyl acetate, 4:1.

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