Tetrahedron Vol. 43, No. 4, pp. 743 to 753, 1987
Printed in Great Britain.

0040-4020/87 $3.00+.00

Selective Proton Transfer of Unsaturated Esters.[1] Syntheses of A Trail-Following Pheromone for Subterranean Termites[2] and Megatomoic Acid

YOSHIHIKO IKEDA, JUNZO UKAI, NOBUO IKEDA, and HISASHI YAMAMOTO*

Department of Applied Chemistry, Faculty of Engineering
Nagoya University, Chikusa Nagoya 464, Japan

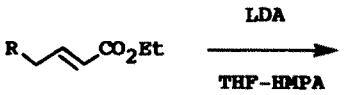
(*Received in Japan* 19 *November* 1986)

Abstract - Deconjugative protonation of dienolates from (E)-2-alkenoate using potassium disilazide as the base gives (Z)-3-alkenoate predominantly. A trail-following pheromone for subterranean termites is synthesized stereoselectively with this method. Deconjugative protonation of trienolates from (E,E)-2,4-tetradecadienoates gives (E,Z)-3,5-tetradecanoates which is hydrolyzed to give Megatomoic acid, a sex pheromone for a black carpet beetle Attagenus megatoma.

Introduction

Development of a general route to alkyl (Z)-3-alkenoates with high stereoselectivities is synthetically very important. Among several synthetic routes available, the deconjugative isomerization of (E)-2-alkenoate is especially attractive for several reasons including easy accessibility of the starting material from an aldehyde via the Wittig reaction.

Deconjugative alkylation of the enolate anion derived from ethyl crotonate was first reported independently by Rathke and Schlessinger.[3] A major experimental concern in generating crotonic enolates was the possibility that the base employed for these reactions might also act as a nucleophile. An essentially non-nucleophilic form of lithium diisopropylamide was realized by the formation of 1:1 complex with HMPA and no Michael addition to ethyl crotonate was observed with this base mixture.[3] Two recent publications[4] described that deprotonation of ethyl (E)-2-alkenoates with lithium diisopropylamide (LDA) in tetrahydrofuran (THF)-hexamethylphosphoric triamide (HMPA) yielded after protonation the double bond migrated (Z)-3-isomer as major products. In those papers, Electrophilic discharge of the lithium enolate from the ester of an (E)-2-alkenoate was reported to lead to stereospecifically the (Z)-3-alkenoate unless the C-4 carbon bore a substituent larger than CH_3, beyond which the reaction became increasingly stereorandom (eq. 1).[4] We wish to describe a simple and yet useful solution to this problem for effecting such transformation with high stereoselectivities. The success of this process also simplifies the task of stereoselective construction of terminal (Z)-homoallyl alcohol. Application of this methodology to the total synthesis of a trail-following pheromone of subterranean termites (10) having such



(eq. 1)

		Z / E	
R=	Me	89 : 11 - 95 : 5	(ref. 4a)
	Et	87 : 13	(ref. 4a)
	Me	100 : 0	(ref. 4b)
	n-Pr	86 : 14	(ref. 4b)

a structure is described. That pheromone was found to function as a trail-following substance for both the eastern subterranean termite, Retuculitermes flavipes[5] and the southern subterranean termite, R. virginicus,[6] was discovered in 1961 from woods decayed by the fungus Lenzites trabea Per. ex Fr.,[5] and was isolated[7] and fully identified.[8] The similar application of the new method to the (E,E)-2,4-tetradecadienoate gave an (E,Z)-3,5-isomer[9] which was further converted into Megatomoic acid (5), the principal component of the sex attractant of the black carpet beetle Attagenus megatoma (Fabricius).[10]

Results and Discussions

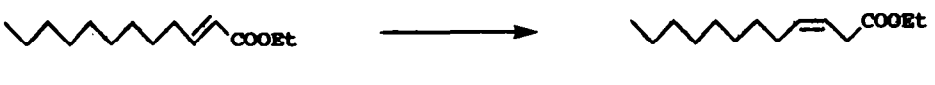
Deconjugative Protonation of Dienoate from (E)-2-Dodecenoate. Under the standard reaction conditions reported,[4] an ester of dodecenoic acid was added to a slight excess of LDA in THF-HMPA at -78°C. The enolate thus obtained was quenched after 30 min with water. After the usual workup the product was analyzed by gas chromatography (gc) by which the stereochemistry of new double bond was found to be approximately 85:15 (Z/E); relatively high ratio but not as high as the case reported with the smaller esters.[4] Using ethyl (E)-2-dodecenoate as a model, a variety of metal amides were explored, and the results are shown in Table 1.

Several trends emerged from these data. 1) Higher Z selectivety was given by the use of disilylamide as a base than by the use of dialkylamide (entry 1,2,3,4). 2) The use of HMPA as cosolvent made selectivity slightly low, though giving higher yield (entry 5,6,7). 3) The counter cation of amide affected the stereoselectivity of the product. Thus, with alkali metal as counter cation disilylamide gave good results, and with magnesium and ammonium ion none of the desired products was observed (entry 24-28). Clearly potassium disilazide in the absence of HMPA gave the most satisfactory results for the above transformations.

Subsequently, the steric effects of alkoxyl group were studied, and the results are shown in Table 2. The Z/E ratio was significantly enhanced as the size of the alcohol group increased, and in particular, the use of 2,4-dimethyl-3-pentyl (E)-2-dodecenoate (2b) gave excellent results (entry 8).

The results may be explained as follows: Potassium hexamethyldisilazide is known to have a pseudoionic monomeric structure in dioxane.[11] On the other hand, lithium and sodium hexamethyldisilazide and lithum diisopropylamide are known to associate each other, thus form relatively bulky structures: they are readily soluble in hydrocarbon solutions and exist as dimers.[12] The ionic character of potassium disilazide may play an important role in selective deprotonation of (E)-2-alkenoate to (Z)-dienoate. The use of dimeric amides gives low selectivity because of the enhanced steric hindrance of these metal amides. The role of HMPA

Table 1. Isomerization of Ethyl (E)-2-Dodecenoate (1a) to Ethyl (Z)-3-Dodecenoate (2a) Using a Variety of Metal Amides.

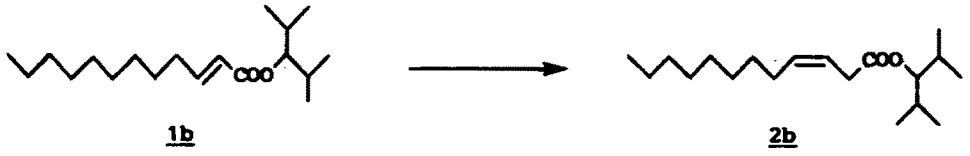


1a 2a

Entry	Base[a] (eq.)	Solvent	HMPA (eq.)	Conc. (M)	°C, h	Yield[b] (%)	Isomers Ratio[d] 1a : 2a	(Z / E[c])
1	LDA (1.2)	THF	(1.2)	0.5	-78, 0.5	50	33 : 67	(60 : 40)
2	LDA (1.5)	THF	(4.5)	0.7	-78, 2.0	85	0 :100	(84 : 16)
3	LTMP (1.2)	THF	(1.2)	0.5	-78, 0.5	50	>95 : <5	(60 : 40)
4	$LiN(SiMe_3)_2$ (1.2)	THF	(1.2)	0.5	-78, 0.5	<5	50 : 50	(95 : 5)
5	$LiN(SiMe_3)_2$ (1.5)	THF	(1.5)	0.1	-78, 0.5	78	27 : 73	(92 : 8)
6	$LiN(SiMe_3)_2$ (1.5)	THF	(3.0)	0.1	-78, 0.5	82	0 :100	(90 : 10)
7	$LiN(SiMe_3)_2$ (1.5)	THF	(6.0)	0.1	-78, 0.5	87	0 :100	(87 : 13)
8	$LiN(SiMe_3)_2$ (1.2)	Ether	(3.0)	0.5	-78, 0.5	48	100 : 0	(-------)
9	$LiN(SiMe_3)_2$ (1.2)	THF	d	0.5	-78, 0.5	89	100 : 0	(-------)
10	$LiN(SiMe_3)_2$ (3.0)	Ether	(3.0)	0.5	-78, 0.5	20	60 : 40	(92 : 8)
11	$NaN(SiMe_3)_2$ (1.5)	THF	(3.0)	0.1	-78, 0.5	90	0 :100	(90 : 10)
12[e]	$NaN(SiMe_3)_2$ (1.5)	THF	(3.0)	0.1	-78, 0.5	88	0 :100	(91 : 9)
13	$NaN(SiMe_3)_2$ (1.5)	THF	(1.5)	0.1	-78, 0.5	80	7 : 93	(92 : 8)
14	$KN(SiMe_3)_2$ (1.5)	THF	(1.5)	0.1	-78, 0.5	86	4 : 96	(89 : 11)
15[e]	$KN(SiMe_3)_2$ (1.5)	THF	(1.5)	0.1	-78, 2.0	84	0 :100	(85 : 15)
16	$KN(SiMe_3)_2$ (1.5)	THF	---	0.1	-78, 0.5	74	23 : 77	(94 : 6)
17[e]	$KN(SiMe_3)_2$ (1.5)	THF	---	0.1	-78, 0.5	63	1 : 99	(95 : 5)
18[e]	$KN(SiMe_3)_2$ (1.5)	Ether	---	0.1	-78, 0.5	76	19 : 81	(91 : 9)
19[e]	$KN(SiMe_3)_2$ (1.5)	DME	---	0.1	-78, 2.0	84	0 :100	(88 : 12)
20[e]	$KN(SiMe_3)_2$ (1.5)	Diglyme	---	0.1	-78, 2.0	49	0 :100	(93 : 7)
21	$KN(SiMe_3)_2$ (1.2)	THF	(1.2)	0.5	-78, 1.0	74	20 : 80	(91 : 9)
22	$KN(SiMe_3)_2$ (1.5)	THF	(1.5)	0.1	-100, 2.0	71	3 : 97	(91 : 9)
23	$KN(SiMe_3)_2$ (1.5)	Toluene	---	0.1	-40, 2.0	62	8 : 92	(91 : 9)
24	A[a] (1.5)	THF	---	0.1	-78, 1.0	96	100 : 0	(-------)
25	B[a] (1.5)	THF	(3.0)	0.1	-78, 0.5	<5	100 : 0	(-------)
26	C[a] (1.5)	THF	---	0.1	-78, 1.0	100	100 : 0	(-------)
27	C[a] (1.5)	THF	---	0.1	0, 1.0	100	100 : 0	(-------)
28	C[a] (1.5)	THF	---	0.1	-78, 1.0	100	100 : 0	(-------)
29	D[a] (1.5)	THF	---	0.1	-78, 1.0	83	79 : 21	(94 : 6)
30	E[a] (1.5)	THF	---	0.1	-78, 1.0	97	100 : 0	(-------)
31	F[a] (1.5)	THF	---	0.1	-78, 0.5	76	59 : 41	(95 : 5)

[a] A: $(n\text{-}Bu_4N)F$ + $(Me_3Si)_3N$; B: MeMgI + $(Me_3Si)_2NH$; C: Et_2Mg + $(Me_3Si)_2NH$; D: K-Np + $(Me_2PhSi)_2NH$; E: K-Np + $(Ph_3Si)_2NH$; F: K-Np + $(NHSiMe_2)_3$. [b] Isolated yield of the mixture of 1a and 2a. [c] Z/E ratio was determined by gc. [d] TMEDA (1.2 equiv.) was used as cosolvent. [e] To a solution of ester in indicated solvent was added in solution of base.

Table 2. Isomerization of 2,4-Dimethyl-3-pentyl (E)-2-Dodecenoate (1b) to (Z)-3-Dodecenoate (2b).

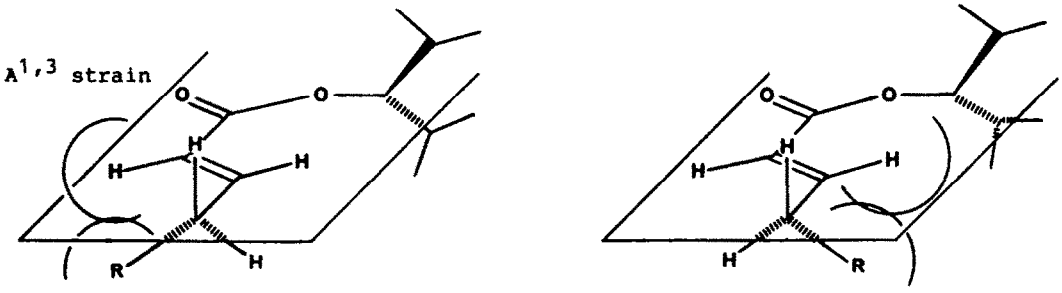


1b 2b

Entry	Reaction Conditions				Product	
	Base	HMPA	Solvent (eq.)	Temp. (°C)	Yield[a] (%)	Z / E[b]
1	LDA	3	THF	-78	85	84 : 16
2	$KN(SiMe_3)_2$	1	THF	-78	80	94 : 6
3	$KN(SiMe_3)_2$	-	THF	-78	64	97 : 3
4	$KN(SiMe_3)_2$	-	DME	-40	94	89 : 11
5	$KN(SiMe_3)_2$	-	DME	-60	79	92 : 8
6	$KN(SiMe_3)_2$	-	Diglyme	-60	81	90 : 10
7	$KN(SiMe_3)_2$	-	THF	-100	c	-------

[a]Isolated yield. [b]Z/E ratio was determined by gc. [c]Low conversion and the starting material was recovered.

Fig. 1.



A B

is still ambiguous, but may be effective enough for the partial dissociation of the associated lithium amides.

It is assumed that the s-trans structure of (E)-2-alkenoate is preferred conformation than that of the s-cis form. The $A^{1,2}$ strain of the transition state B may be enhanced by the bulky alkoxy group and thus the $A^{1,3}$ strain of A may be expected to be not significant enough (Fig. 1).[4b]

Deconjugative Protonation of Trienolate from (E,E)-2,4-Tetradecadienoate and Synthesis of Megatomoic Acid (5). The method was applied to isomerize the (E,E)-2,4-tetradecanoate to the corresponding (E,Z)-3,5-isomer using the best reaction condition for the conversion of 1 to 2.[9] Some of the results are shown in Table 3. Surprisingly, the size of alkoxy group did not makes any significant differ-

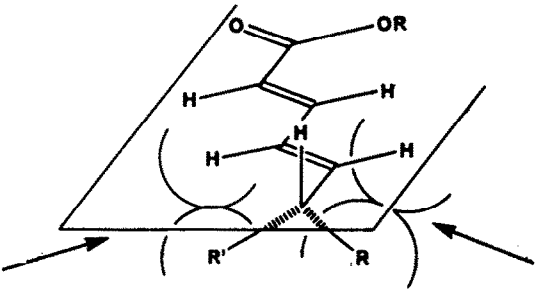
Table 3. Isomerization of (E,E)-2,4-Tetradecadienate (3) to (E,Z)-3,5-tetradecadienoate (4).

3 4

Entry	3 R-	Reaction conditions Base	HMPA (eq.)	Solvent	Temp. (°C)	Yield[a] (%)	4 E,Z/E,E[b]
1	Et	LDA	3	THF	-78	75	73 : 27
2	Et	$KN(SiMe_3)_2$	---	THF	-78	0	-------
3	Et	$KN(SiMe_3)_2$	0.1	THF	-78	62	70 : 30
4	Et	$KN(SiMe_3)_2$	1	THF	-78	93	59 : 41
5	Et	$KN(SiMe_3)_2$	---	DME	c	53	79 : 21
6	Et	$KN(SiMe_3)_2$	1	DME	c	58	80 : 20
7	Et	$KN(SiMe_3)_2$	2	DME	-42	88	69 : 31
8	Et	$KN(SiMe_3)_2$	1	Diglyme	-61	79	73 : 27
9	$CH(i\text{-}Pr)_2$	LDA	3	THF	-78	83	71 : 29
10	$CH(i\text{-}Pr)_2$	$KN(SiMe_3)_2$	---	THF	-78	0	-------
11	$CH(i\text{-}Pr)_2$	$KN(SiMe_3)_2$	0.1	THF	-78	20	73 : 27
12	$CH(i\text{-}Pr)_2$	$KN(SiMe_3)_2$	1	THF	-78	81	76 : 24
13	$CH(i\text{-}Pr)_2$	$KN(SiMe_3)_2$	1	DME	-42	82	70 : 30
14	$CH(i\text{-}Pr)_2$	$KN(SiMe_3)_2$	2	DME	-42	100	67 : 33
15	$CH(i\text{-}Pr)_2$	$KN(SiMe_3)_2$	1	Diglyme	-61	91	70 : 30
16	Me	$KN(SiMe_3)_2$	1	THF	-100	83	73 : 27
17	Me	$KN(SiMe_3)_2$	1	d	-100	42	79 : 21

[a]Isolated yield. [b]E,Z/E,E ratio was determined by gc. [c]Reaction was done at -78°C for 1.5 h and at -42°C for 2 h. [d]DME-pentane was used as solvent.

Fig. 2.



$A^{1,3}$ strain $A^{1,2}$ strain

4a 5 (eq. 2.)

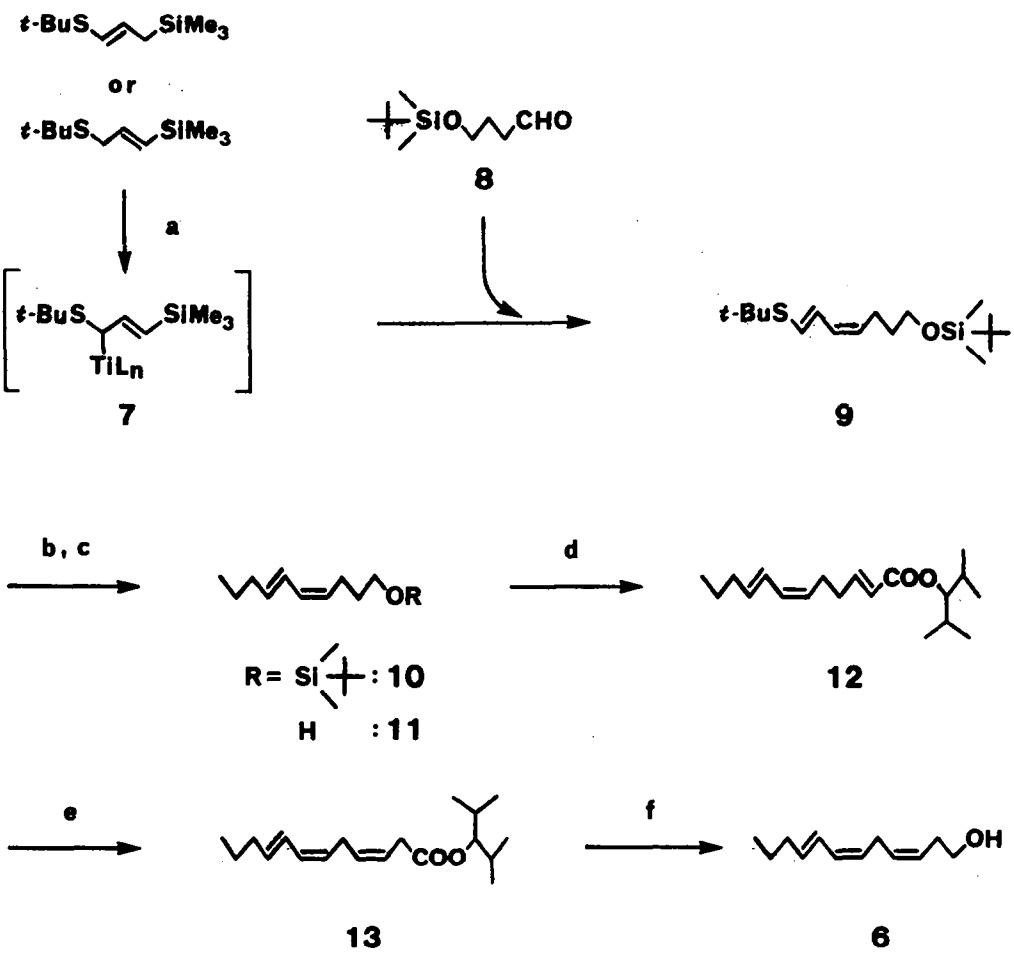
ence on the isomers ratio, but the choice of solvent is still crucial. The best result was obtained by the use of potassium hexamethyldisilazide as base in DME-HMPA solvent system and the ethyl ester 4a was trasformed to the corresponding (E,Z)-3,5-isomer predominantly (entry 6; E,Z/E,E= 80:20 in Table 3).

The relatively low selectivity of the transformation of (E,E)-2,4-alkadienoate to (E,Z)-3,5-isomer may be due to the much smaller $A^{1,2}$ strain as shown in Fig. 2.

Megatomoic acid (5)[10] is easily obtained from 4a (from entry 6) by hydrolysis with potassium hydroxide in EtOH-H_2O at 0°C for 2 h in 88% yield (eq. 2).

Total synthesis of a trail-following pheromone for subterranean termite (6). The conversion of the intermediate 9 to the trail-following pheromone 6 was accomplished by a sequence of straightforward steps shown in Scheme 1. Reaction of 1-t-butyl-3-trimethylsilyl-1-propene with an equivalent of t-butyllithium in THF-HMPA at -78°C for 10 min and at 0°C for 1 h followed by treatment with an equiva-

Scheme 1.



a) t-BuLi, $Ti(OPr^i)_4$; b) n-PrMgI, cat. $Ni(dppp)Cl_2$; c) n-Bu_4NF; d) NCS-Me_2S, Et_3N in toluene then NaH-$(EtO)_2P(O)CH_2COOCH(Pr^i)_2$ (15) in THF; e) $KN(SiMe_3)_2$ in THF; f) excess $LiAlH_4$.

lent of titanium tetraisopropoxide at -78°C for 40 min generated allyltitanium derivative **7**[2,13] which on reaction with 4-(t-butyldimethylsilyloxy)butanal (**8**)[2] afforded 7-t-butyldimethylsililoxy-1-t-butylthio-(E,Z)-1,3-heptadiene (**9**) as a key intermediate of the synthesis of **10**. The t-butylthio group of **9** was clearly replaced by propyl group with excess propylmagnesium iodide (10 equiv.) in the presence of a catalytic amount of Ni(dppp)Cl_2 at 80-90°C (bath temperature) in benzene to give 1-t-butyldimethylsilyloxy-(Z,E)-4,6-decadiene (**10**) in 71% yield,[14] which was quantitatively converted to the crude (Z,E)-4,6-decadiene-1-ol (**11**) using anhydrous tetrabutylammonium fluoride in THF.[15] Purification of **11** and the intermediary silyl ether **10** was effected by careful column chromatography on silica gel, and the product **11** so obtained was >96% isomerically pure by gc analysis and exhibited fully consistent spectral data. Oxidation of **11** with Me_2S-N-chlorosuccinimide and triethylamine[16] yielded the unstable aldehyde[17] which was transformed by reaction with the Wadsworth reagent, prepared from 2,4-dimethyl-3-pentyl diethylphosphonoacetate (**15**)[18] with sodium hydride, in THF-HMPA into 2,4-dimethyl-3-pentyl (E,Z,E)-2,6,8-dodecatrienoate (**12**) in 78% over-all yield and 95% pure by gc analysis. The stereoselective isomerization of the ester **12** to the (Z)-3-isomer **13** was carried out in 70% yield by the new method[1] in one step which involved stirring of **12** with excess potassium hexamethyldisilazide in THF to generate the corresponding enolate which was then quenched with saturated aqueous ammonium chloride. Exposure of the ester **13** to excess lithium aluminium hydride in ether resulted in formation of the desired alcohol **6** in 86% yield.

Experimental

General. The IR spectra were determined on a Hitachi 260-10 spectometer in a CCl_4 solution unless otherwise stated. The NMR spectra were recorded on a JNM-PMX 60 spectrometer, using tetramethylsilane as an internal standard. Splitting patterns are indicated as s: singlet, d: doublet, t: triplet, q: quartet, m: multiplet, and br: broad peak. The isomeric ratio of the products was determined by gas chromatography (gc) on a 25-m PEG-HT capillary column using a Hitachi Model 163 and 164 instruments equipped with a flame ionization detector using nitrogen as carrier gas. The analyses were performed at the Institute of Applied Organic Chemistry, Faculty of Engineering, Nagoya University. Tetrahydrofuran (THF) and ether were distilled from benzophenone ketyl. Benzene, hexane, and toluene were dried over sodium metal. Dichloromethane was dried over 4A molecular sieves. Hexamethylphosphric triamide (HMPA) was distilled from CaH_2 under reduced pressure. All the experiments were carried out under an argon atmosphere. For thin layer chromatography (TLC) analyses throughout this work, Merck precoated TLC plates (silica gel 60 GF_{254}, 0.25 mm) were used. Purification of the product was carried out by column chromatography on silica gel Fuji BW-820.

2,4-Dimethyl-3-pentyl (E)-2-dodecenoate (1b): To a solution of LDA (75 mmol) which was prepared from diisopropylamine (11 ml, 75 mmol) and a solution of n-butyllithium in hexane (1.6 M, 47 ml, 75 mmol) in THF (100 ml) and HMPA (13 ml) was added **15** (22 g, 75 mmol) dropwise at 0°C. The resulting solution was stirred at 0°C for 15 min. Decanal (14 ml, 75 mmol) was added dropwise at 0°C to the above solution. The reaction mixture was stirred at 0°C for 30 min, at room temperature for 30 min, and poured into brine. The product was extracted twice with ether, dried and concentrated in vacuo. The residual oil was purified by column chromatography to give **1b** (19 g, 63 mmol, E pure by gc) as a colorless oil in 84% yield: R_f= 0.46 (10:1, hexane-ether); IR (CCl_4) 2920, 1720, 1660, 1460, 1260, 1180, and 980 cm^{-1}; ^1H NMR (CCl_4) δ= 4.55 (t, J= 3Hz, 1H), 5.69 (d, J= 15Hz, 1H), 6.81 (dt, J= 3 and 15Hz, 1H); gc t_R 25.7 min (E-2-isomer) at 160°C; Anal. Found: C, 76.75; H, 12.44%. Calcd for $C_{19}H_{36}O_2$: C, 76.97; H, 12.24%.

Ethyl (E,E)-2,4-tetradecadienoate (3a): A mixture of (E)-2-dodecenal (2.2 g, 12 mmol) and ethoxycarbonylmethylidenetriphenylphosphorane (7.0 g, 20 mmol) in benzene (50 ml) was stirred at reflux for 10 h, concentrated, and filtered. The filtrate was concentrated to give an oil which was purified by column chromatography on silica gel to give **3a** (2.3 g, 9 mmol, E,E pure by gc) as a colorless oil in 77% yield: R_f= 0.33 (hexane-ether, 10:1); IR (CCl_4) 2900, 1710, 1640, 1455,

1360, 1300, 1250, 1170, 1130, 1030, 995, 870, and 720 cm^{-1}; ^1H NMR (CCl_4) δ= 1.87-2.44 (br, 2H), 5.71 (d, J= 15Hz, 1H), 5.94-6.22 (m, 2H), 6.91-7.33 (m, 1H); gc t_R 18.5 min (E,E-2,4-isomer) at 180°C; Anal. Found: C, 75.99, H, 11.33%. Calcd for $C_{16}H_{28}O_2$: C, 76.14; H, 11.18%.

2,4-Dimethyl-3-pentyl (E,E)-2,4-tetradecadienoate (3b): To a solution of LDA which was prepared from diisopropylamine (1.7 ml, 12 mmol) and a solution of n-butyllithium in in hexane (1.6 M, 7 ml, 11 mmol) in THF (20 ml) and HMPA (2 ml) was added 15 dropwise at 0°C. The resulting solution was stirred at 0°C for 15 min and (E)-2-dodecenal (2.0 g, 11 mmol) was added dropwise at 0°C. The reaction mixture was stirred at 0°C for 30 min, at room temperature for 30 min, and poured into brine. The product was extracted twice with hexane. The combined organic layers were dried and concentrated in vacuo. The residual oil was purified by column chromatography on silica gel to give 3b (3.1 g, 10 mmol, E,E pure by gc) as a colorless oil in 89% yield: R_f= 0.34 (hexane-ether, 10:1); IR (CCl_4) 2920, 1710, 1640, 1460, 1260, 1130, and 1000 cm^{-1}; ^1H NMR (CCl_4) δ= 5.72 (d, J= 15Hz, 1H), 5.93-6.25 (m, 2H), 7.15 (m, 1H); gc t_R 25.0 min (E,E-2,4-isomer) at 200°C; Anal. Found: C, 78.45; H, 11.63%. Calcd for $C_{21}H_{38}O_2$: C, 78.20; H, 11.88%.

Preparation of Potassium Hexamethyldisilazide: Potassium (0.39 g, 10 mmol) was added to a solution of naphthalene (1.28 g, 10 mmol) in THF (6 ml) at room temperature. The resulting deep-green solution was stirred at room temperature for 1 h. The solution was cooled to 0°C and treated with hexamethyldisilazane (3.2 ml, 15 mmol) to generate a dark red solution of $KN(SiMe_3)_2$ (ca. 1 M).

General Procedure of Isomerization of (E)-2-dodecenoate (1) and (E,E)-2,4-tetradecadienoate (3): To a stirred solution of 2,4-dimethyl-3-pentyl (E)-2-dodecenoate 1b (0.16 g, 0.55 mmol) in THF (4 ml) was added the above solution of $KN(SiMe_3)_2$ (ca. 1 M, 0.8 ml, 0.8 mmol) at -78°C. The resulting pale yellow solution was stirred at -78°C for 2 h. The reaction was quenched with saturated aqueous ammonium chloride at -78°C. The product was extracted twice with ether. The combined organic layers were washed with brine, dried and concentrated in vacuo to give an oil of which chromatographic purification afforded **2,4-dimethyl-3-pentyl (Z)-3-dodecenoate (2b)** as a colorless oil (0.10 g, 0.35 mmol, Z/E ratio 97:3 by gc) in 64% yield: R_f= 0.46 (10:1, hexane-ether); IR (CCl_4) 2920, 1740, 1460, 1250, 1170, and 980 cm^{-1}; ^1H NMR (CCl_4) δ= 2.99 (d, J= 5Hz, 2H), 4.52 (t, J= 6Hz, 1H), 5.50 (m, 2H); gc t_R 18.4 min (Z-3-isomer), 18.8 min (E-3-isomer) at 160°C; Anal. Found: C, 76.69; H, 12.34%. Calcd for $C_{19}H_{36}O_2$: C, 76.97; H, 12.24%.

Ethyl (Z)-3-dodecenoate (2a) was obtained from ethyl (E)-2-dodecenoate 1a by the same procedure as described above: R_f= 0.44 (10:1, hexane-ether); IR (CCl_4) 2920, 1730, 1150, and 1030 cm^{-1}; ^1H NMR (CCl_4) δ= 0.62-1.70 (16H), 2.08 (br, 2H), 2.96 (d, J= 5Hz, 2H), 4.06 (q, J= 7Hz, 2H), 5.47 (t, J= 5Hz, 2H); gc t_R 19.5 min (Z-3-isomer), 20.3 min (E-3-isomer), 26.6 min (E-2-isomer) at 130°C; Anal. Found: C, 74.24; H, 11.63%. Calcd for $C_{14}H_{26}O_2$): C, 74.29; H, 11.58%.

Ethyl (E,Z)-3,5-tetradecadienoate (4a) was obtained from 3a by the same procedure as described above: R_f= 0.33 (hexane-ether, 10:1); IR (CCl_4) 2930, 1740, 1460, 1370, 1240, 1160, 1030, 990, and 950 cm^{-1}; ^1H NMR (CCl_4) δ= 1.79-2.45 (br., m, 2H), 3.03 (d, J= 6Hz, 2H), 5.05-6.12 (m, 3H), 6.41 (dd, J= 10 and 15Hz, 1H); 5.35 (d, J= 10Hz, 1H),5.93 (dd, J= 10 and 10Hz, 1H) on irradiation to the allylic methylene proton (δ= 2.12), 5.67 (d, J= 15Hz, 1H) on irradiation to the allylic methylene proton at α-position of carbonyl group (δ= 3.03); gc t_R 13.8 min (E,Z-3,5-isomer), 15.8 min (E,E-3,5-isomer) at 180°C; Anal. Found: C,75.90; H, 11.42%. Calcd for $C_{16}H_{28}O_2$: C, 76.14; H, 11.18%.

2,4-Dimethyl-3-pentyl (E,Z)-3,5-tetradecadienoate (4b) was obtained from 3b by the same procedure described above: R_f= 0.43 (hexane-ether, 10:1); IR (CCl_4) 2920, 1735, 1460, 1245, 1170, 1130, and 980 cm^{-1}; ^1H NMR (CCl_4) δ= 2.07 (br, 2H), 3.07 (d, J= 7Hz, 2H), 4.54 (dd, J= 6 and 6Hz, 1H), 5.07-6.13 (m, 3H), 6.37 (dd, J= 10 and 15Hz, 1H); 5.28 (d, J= 10Hz, 1H), 5.87 (dd, J= 10 and 10Hz, 1H) on irradiation to the allylic methylene proton (δ= 2.07), 5.60 (d, J= 15Hz, 1H) on irradiation to the allylic proton at α-position of carbonyl group (δ= 3.07); gc t_R 17.2 min (E,Z-3,5-isomer), 20.6 min (E,E-3,5-isomer) at 200°C; Anal. Found: C, 78.24; H, 11.84%. Calcd for $C_{21}H_{38}O_2$: C, 78.20; H, 11.88%.

(E,Z)-3,5-Tetradecadienoic acid (5, Megatomoic acid): The solution of ethyl (E,Z)-3,5-tetradecadienoate, 4a (0.14 g, 0.59 mmol) and a aqueous solution of 2 N potassium hydroxide (0.6 ml) in ethanol (1.8 ml) was stirred at 0°C. Hydrolysis was completed at 0°C for 2 h by tlc analysis. The reaction mixture was poured into ice-cold 2 N aqueous hydrochloric acid. The product was extracted ten times with ethyl acetate. The combined organic layers were dried and concentrated in vacuo. The residue was purified by column chromatography on silica gel to give 5 (0.12 g, 0.52 mmol) in 88% yield: R_f= 0.16 (Hexane-AcOEt, 1:1); ^1H NMR ($CDCl_3$) δ=

2.11 (br t, J= 7Hz, 2H), 0.66-2.53 (m, 20H), 3.14 (d, J= 6Hz, E-5-isomer), 3.19 (d, J= 7Hz, Z-5-isomer), 5.20-6.74 (m, 4H), 11.29 (br s, 1H); 5.70 (d, J= 15Hz, 1H), 6.49 (dd, J= 10 and 15Hz, 1H) on irradiation to the allylic methylene proton at α-position of carbonyl group (δ= 3.19); Anal. Found: C, 74.82; H, 10.81%. Calcd for $C_{14}H_{24}O_2$: C, 74.95; H, 10.78%.

4-(t-Butyldimethylsilyloxy)butanal (8) was prepared as follows: To a solution of 1,4-butanediol (18.0 g, 200 mmol), triethylamine (6.6 g, 65 mmol), and 4-N,N-dimethylaminopyridine (0.6 g, 5 mmol) in dichloromethane (180 ml) was added a solution of t-butylchlorodimethylsilane (7.5 g, 50 mmol) in dichloromethane (100 ml) over a period of 4 h at room temperature. The reaction mixture was stirred for an additional hour and poured into brine. The product was extracted three times with dichloromethane, washed with brine. The combined organic layers were dried and concentrated. The residual oil was purified by column chromatography on silica gel to give **4-t-butyldimethylsilyloxy-1-butanol** (9.0 g, 44 mmol) as a colorless oil in 88% yield: R_f= 0.38 (3:1, hexane-AcOEt). Oxidation of this monosilylated alcohol (4.1 g, 20 mmol) with oxalyl chloride (1.9 ml, 22 mmol), dimethyl sulfoxide (3.1 ml, 44 mmol) and triethylamine (13.9 ml, 100 mmol) in dichloromethane (50 ml) afforded **8** (3.6 g, 18 mmol) as a colorless oil in 90% yield:[19] R_f= 0.38 (3:1, hexane-AcOEt); IR (neat) 3550, 2950, 1740, 1260, and 1105 cm^{-1}; ^1H NMR (CCl_4) δ= 0.00 (s, 6H), 0.83 (s, 9H), 1.62-2.03 (m, 2H), 2.25-2.63 (m, 2H), 3.58 (t, J= 6H, 2H), 9.66 (s, 1H); Analitically data was not obtained by decomposition.

(E,Z)-7-t-Butyldimethylsilyloxy-1-t-butylthio-1,3-heptadiene (9): To a solution of 3-t-butylthio-1-trimethylsilyl-(E)-1-propene (5.1 g, 25 mmol) in THF (100 ml) was added a solution of t-butyllithium in pentane (1.8 M, 14 ml, 25 mmol) dropwise at -78°C. The resulting solution was stirred at -78°C for 15 min and at 0°C for 2 h. Titanium tetraisopropoxide (7.5 ml, 15 mmol) was added to the above solution after cooled to -78°C, and the redish brown solution was stirred at -78°C for 1 h. The aldehyde **8** (3.3 g, 16 mmol) was added dropwise to the above solution of titanium reagent **7** at -78°C. The reaction mixture was stirred at -78°C for 1.5 h, at 0°C for 1 h, at room temperature for 21 h, and then poured into ice-cooled 2 N aqueous hydrochloric acid. The product was extracted twice with ether. The combined organic layers were dried and concentrated in vacuo. The residual oil was purified by column chromatography on silica gel to give **9** (2.9 g, 9 mmol) as a colorless oil in 57% yield: R_f= 0.09 (hexane); IR (neat) 2970, 2870, 1260, 1105, and 840 cm^{-1}; ^1H NMR ($CDCl_3$) δ= 0.08 (s, 6H), 0.83 (s, 9H), 1.28 (s, 9H), 1.37-2.43 (m, 4H), 3.55 (t, J= 6Hz, 2H), 5.33 (dt, J= 6 and 10Hz, 1H), 5.97 (t, J= 10Hz, 1H), 6.20 (d, J= 14Hz, 1H), 6.58 (dd, J= 10 and 14Hz, 1H); Anal. Found: C, 65.18; H, 10.61%. Calcd for $C_{17}H_{34}OSSi$: C, 64.90; H, 10.89%.

(Z,E)-1-t-Butyldimethylsilyloxy-4,6-decadiene (10): To a suspension of magnesium (2.9 g, 120 mmol) in ether (38 ml) was added 1-iodopropane (9.2 ml, 94 mmol) over 2 h at 0°C. To a solution of **9** (2.9 g, 9.4 mmol) and nickel(II) 1,3-bis(diphenylphosphino)propane chloride (0.5 g, 0.9 mmol) in benzene in another flask was added the above solution of propylmagnesium iodide in ether at 0°C. The reaction mixture was heated at reflux (85-95°C on bath temperature) for 0.5-1 h, poured into ice-cooled 2 N aqueous hydrochloric acid after cooled down to room temperature. The product was extracted twice with ether. The combined organic layers were washed with brine, dried and concentrated in vacuo. The residual oil was purified by column chromatography on silica gel to give **10** (1.8 g, 6.7 mmol, with 90% isomeric purity by gc) in 71% yield: R_f= 0.39 (10:1, hexane-dichloromethane); IR (neat) 2950, 1465, 1380, 1250, 1100, 980, 940, 830, and 770 cm^{-1}; ^1H NMR (CCl_4) δ= 0.02 (s, 6H), 0.67-1.82 (13H), 1.82-2.43 (m, 4H), 3.57 (t, J= 6Hz, 2H), 5.11 (d, J= 10Hz, 1H), 5.44 (d, J= 14Hz, 1H), 5.76 (dd, J= 10 and 10Hz, 1H), 6.18 (dd, J= 10 and 14 Hz, 1H); gc t_R 7.5 min of the major isomer at 130°C; Anal. Found: C, 71.30; H, 12,28%. Calcd for $C_{16}H_{32}OSi$: C, 71.57; H, 12.01%.

(Z,E)-4,6-decadiene-1-ol (11): A solution of tetrabutylammonium fluoride in THF (1 M, 16 ml, 16 mmol) which was dried with molecular sieve 3A (2.5 g) at room temperature for 1 h was added to **10** (1.8 g, 6.6 mmol) at room temperature. The reaction mixture was stirred at room temperature for 1.5 h and poured into water. The product was extracted three times with ether. The combined organic layers were dried and concentrated in vacuo. The residual oil was carefully purified by to column chromatography on silica gel to give **11** (0.98 g, 6.3 mmol), whose isomers ratio exhibited 96% of (Z,E)-form, by gc as an oil in 96% yield: R_f= 0.35 (1:1, hexane-ether); IR (neat) 3320, 2930, 1450, 1060, 980, and 950 cm^{-1}; ^1H NMR (CCl_4) δ= 0.67-2.47 (12H), 3.56 (t, J= 6Hz, 2H), 5.00-6.53 (m, 4H); gc t_R 12.5 min of the major isomer, 13.0 and 13.2 min unidentified minor isomers at 160°C; Anal. Found: C, 77.86; H, 11.77%. Calcd for $C_{10}H_{18}O$: C, 77.87; H, 11.76%.

2,4-dimethyl-3-pentyl (E,Z,E)-2,6,8-dodecatrienoate (12): To a suspension of N-chlorosuccinimide (1.1 g, 8.5 mmol) in 2.8 ml of toluene was added dimethyl sulfide (1 ml) at 0°C. After appearance of white precipitate, the mixture was cooled down to -23°C, and a solution of 11 (0.9 g, 5.6 mmol) in 6 ml of toluene was added dropwise over 5 min. The stirring was continued for 2 h at -23°C and then a solution of triethylamine (1.2 ml, 8.5 mmol) in toluene (1.4 ml) was added dropwise over 3 min. The cooling bath was removed, after 5 min the mixture was filtered with glass filter to remove ammonium salt. The resulting solution was introduced into a solution of the Wordsworth reagent in THF which was prepared from sodium hydride (50 wt%, 0.4 g, 8.5 mmol) washed twice with hexane and 15 (2.9 g, 10 mmol) in THF (17 ml)-HMPA (1.5 ml) at 0°C. The reaction mixture was stirred at 0°C for 30 min and poured into ice-cold 2 N aqueous hydrochloric acid. The product was extracted twice with hexane, dried and concentrated in vacuo. The residual oil was purified by column chromatography on silica gel to give 12 (1.1 g, 3.8 mmol) as a colorless oil in 68% yield: R_f= 0.27 (10:1, hexane-ether); IR (CCl_4) 2960, 1720, 1650, 1455, 1255, 1190, and 980 cm^{-1}; ^1H NMR (CCl_4) δ= 2.29 (m, 1H), 4.56 (t, J= 6Hz, 1H), 4.91-5.96 (m, 4H), 6.29 (dd, J= 10 and 14Hz, 1H), 6.85 (d, J= 16Hz, 1H); gc t_R 12.7 min of the major isomer at 180°C; Anal. Found: C, 77.88; H, 11.09%. Calcd for $C_{19}H_{32}O_2$: C, 78.03; H, 10.94%.

2,4-dimetyl-3-pentyl (Z,Z,E)-3,6,8-decatrienoate (13): To a solution of 12 (0.20 g, 0.69 mmol) in THF (5.5 ml) was added a solution of $KN(SiMe_3)_2$ in THF (ca. 1 M, 1 ml, 1 mmol) over 5 min at -78°C. The resulting yellow solution was stirred at -78°C for 2.5 h. The reaction was quenched with saturated aqueous ammonium chloride. The product was extracted twice with hexane. The combined organic layers were dried and concentrated in vacuo. The residual oil was purified by column chromatography on silica gel to give 13 (0.14 g, 0.48 mmol) as a colorless oil in 70% yield: R_f= 0.31 (20:1, hexane-ether); IR (CCl_4) 2960, 1730, 1460, 1250, 1170, 1135, and 980 cm^{-1}; ^1H NMR (CCl_4) δ= 0.69-2.39 (21H), 2.67-3.28 (4H), 4.51 (t, J= 6Hz, 1H), 5.03-6.60 (m, 6H); gc t_R 12.8 min of the major isomer at 180°C; Anal. Found: C, 78.02; H, 11.04%. Calcd for $C_{19}H_{32}O_2$: C, 78.03; H, 11.03%.

(Z,Z,E)-3,6,8-dodecatrien-1-ol (6; A trail-following pheromone for subterranean termite): To a suspension of lithium alluminium hydride (LAH: 18 mg, 0.48 mmol) in ether (0.8 ml) was added a solution of 13 (141 mg, 0.48 mmol) in ether (1.2 ml) at 0°C. The reaction mixture was stirred at 0°C for 30 min, another 30 min after further addition of LAH (18 mg, 0.48 mmol), and poured into ice-cold 2 N aqueous hydrochloric acid. The product was extracted three times with ether. The combined organic layers were washed with brine, dried, and concentrated in vacuo. The residual oil was purified by column chromatography of silica gel to give 6 (74 mg, 0.41 mmol) as a colorless oil in 86% yield: R_f= 0.32 (1:1, hexane-ether); spectral data were identical with reported values:[8] IR (CS_2) 3350, 2920, 2150, 1740, 1460, 1240, 1110, 1050, 990, and 950 cm^{-1}; ^1H NMR (CCl_4) δ= 0.92 (t, J= 5Hz, 3H), 2.54 (s, 1H, -OH), 2.90 (dd, J= 6Hz, 1H), 3.56 (t, J= 7Hz, 2H), 4.95-6.05 (m, 5H), 6.29 (dd, J= 10 and 15Hz, 1H, n-PrCH=CH-). Careful gc analysis showed, however, our product is containing with a maximum of 12% of unidentified impurities: gc t_R 15.5 min of the major isomer at 160°C.

2,4-Dimethyl-3-pentyl bromoacetate (14): To a solution of 2,4-dimethyl-3-pentanol (21 ml, 0.15 mol), pyridine (12 ml, 0.15 mol), and catalytic amount of N,N-dimethyl-4-aminopyridine (0.9 g, 7.5 mmol) in dichloromethane (300 ml) was added a solution of bromoacetylbromide (25 g, 0.13 mol) in dichloromethane (50 ml) over a period of 4 h at 0°C. The reaction mixture was stirred at room temperature for 1 h and poured into ice-cold 2 N aqueous hydrochloric acid. The product was extracted three times with ether. The combined organic layers were washed with brine, dried, and concentrated. The residue was distilled to give 14 (28 g, 0.12 mol) as a colorless oil in 94% yield: bp. 74°C (6 Torr); IR (neat) 2950, 1720, 1460, 1390, 1370, 1270, 1170, 1100, 970, 920, and 880 cm^{-1}; ^1H NMR (CCl_4) δ= 0.91 (d, J= 7Hz, 12H), 1.94 (ddd, J= 6Hz, 2H), 3.75 (s, 2H), 4.57 (dd, J= 6Hz, 1H).

2,4-Dimethyl-3-pentyl diethylphosphonoacetate (15): The mixture of 14 (21 g, 89 mmol) and triethylphosphite (15 g, 89 mmol) was heated at reflux for 2 h. The product was distilled to give 15 (23 g, 77 mmol) as a colorless oil in 87% yield:[18] bp. 147.5-148.5°C (4 Torr); IR (CCl_4) 3450, 2970, 2930, 2870, 1725, 1460, 1380, 1370, 1260, 1210, 1160, 1110, 1050, 1020, and 970 cm^{-1}; ^1H NMR (CCl_4) δ= 0.92 (d, J= 7Hz, 12H), 1.33 (t, J= 7Hz, 6H), 1.51-2.21 (m, 2H), 2.88 (d, J= 21Hz, 2H), 3.82-4.38 (m, 4H), 4.55 (dd, J= 6Hz, 1H).

References and Notes

1. Preliminary accounts of the results was published, see: Y. Ikeda and H.

Yamamoto, Tetrahedron Lett., 25, 5181 (1984).
2. Preliminary acouunts of the results was published, see: Y. Ikeda, J. Ukai, N. Ikeda, and H. Yamamoto, Tetrahedron Lett., 25, 5177 (1984).
3. (a) M. W. Rathke and D. Sullivan, Tetrahedron Lett., 4249 (1972); (b) J. L. Herrmann, G. P. Kieczykowski, and R. H. Schlessinger, ibid., 2433 (1973).
4. (a) E.-P. Krebs, Helv. Chim. Acta, 64, 1023 (1981); (b) A. S. Kende and B. H. Toder, J. Org. Chem., 47, 163 (1982).
5. G. R. Esenther, T. C. Allen, J. E. Casida, and R. D. Shenefelt, Science, 134, 50 (1961).
6. R. V. Smythe, H. C. Coppel, S. H. Lipton, and F. M. Strong, J. Econ. Entomol., 60, 228 (1967).
7. F. Matsumura, H. C. Coppel, and A. Tai, Nature, 219, 963 (1968).
8. A. Tai, F. Matsumura, and H. C. Coppel, J. Org. Chem., 34, 2180 (1969).
9. S. Tsuboi, A. Kuroda, T. Masuda, and A. Takeda, Chem. Lett., 1541 (1984).
10. R. M. Silverstein and J. O. Rodin, Science, 157, 85 (1967).
11. A. M. Domingos and G. M. Sheldrick, Acta Crystallogr., B30, 517 (1974).
12. (a) R. Gruning and J. L. Atwood, J. Organomet. Chem., 137, 101 (1977); (b) R. D. Rogers, J. L. Atwood, and R. Gruning, ibid., 157, 229 (1978) and references cited therein. As general reviews of disilyl amides, see: (c) M. F. Lappert, P. P. Power, A. R. Sanger, and R. C. Srivastava in "Metal and Metalloid Amides," Ellis Horwood-John Wiley, Chichester (1980); (d) J. L. Wardell in "Comprehensive Organometallic Chemistry," edited by G. Wilkinson, F. G. A. Stone, and E. W. Abel, Pergamon, New York (1982), Volume 1, Chapter 2; (e) H. Burger, Angew. Chem., Int. Ed. Engl., 12, 474 (1973).
13. J. Ukai, Y. Ikeda, N. Ikeda, and H. Yamamoto, Tetrahedron Lett., 25, 5173 (1984).
14. (a) H. Okamura, M. Miura and H. Takei, Tetrahedron Lett., 43 (1979); (b) E. Wenkert, T. W. Ferreira, and E. L. Michelotti, J. Chem. Soc., Chem. Commun., 637 (1979). Under standard conditions using $Ni(PPh_3)_2Cl_2$ and propyl magnesium iodide, the yield of the cross coupling product was found to be exceedingly low. Using Grignard reagents prepared from alkyl bromide, the yield of the cross coupling product was also found to be exceedingly low.
15. E. J. Corey and A. Venkaeswarlu, J. Am. Chem. Soc., 94, 6190 (1972).
16. E. J. Corey, C. U. Kim, and P. F. Misco, Org. Syntheses, 58, 122 (1978).
17. The same aldehyde may be also prepared by the method of the Swern oxidation (ref. 19) in 50-60% yield.
18. W. S. Wadsworth, Jr., Org. Reactions, 25, 73 (1977).
19. A. J. Mancuso and D. Swern, Synthesis, 165 (1981) and references cited therein.