

Structures of Abnormal- and Normal-addition 1-Pyrazolines Produced from 2-Cyano-3,3-di-(or mono)- substituted-acrylates with Diazoalkanes

Wakatu Nagai* and Yumiko Hirata

Department of Chemistry, Nagoya Institute of Technology,
Showa-ku, Nagoya 466 Japan

Keiji Hosomi and Taiichi Higuchi

Department of Chemistry, Faculty of Science, Osaka City University,
Sumiyoshi-ku, Osaka 558 Japan

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Reactions of methyl 2-cyano-3-methyl-3-(*p*-substituted-phenyl)acrylates (**1**) with 1-phenyldiazoethane (**2**) produced the stable abnormal-addition 1-pyrazolines, **AP**, **4** [1]. The structure of *cis-syn-4a* (X = NO₂) was determined by X-ray crystallography. Thermal decomposition of **4** results in "true cycloreversion" to the starting materials. Stereochemistry and decomposition of the normal-addition 1-pyrazolines, **NP**, produced *in situ* from 2-cyano-3-(*p*-substituted-phenyl)acrylates and diazoalkanes, are also discussed.

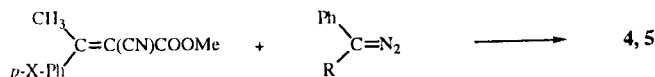
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Andrews [2] and Wilt [3] reported that 1,3-dipolar cycloaddition of 3-alkylacrylates with diazomethanes produced mixtures of normal-addition 1-pyrazolines and abnormal-addition 1-pyrazolines.

In our previous paper [4], we reported that the reactions of methyl (*E*)-2-cyano-3-(*p*-substituted-phenyl)acrylates with 1-phenyldiazoethane (**2**) produced stable abnormal-addition secondary pyrazolines, and described their "true cycloreversion" [5]. We also reported [4] on the independent syntheses of abnormal-addition 1-pyrazolines by means of the reactions of methyl (*E*)-2-cyano-3-(1-phenyl-1-*p*-substituted-phenylethyl)acrylates with **2**.

In this paper, we describe the reactions of methyl 2-cyano-3-methyl-3-(*p*-substituted-phenyl)acrylates **1** with **2** to produce the abnormal-addition 1-pyrazolines **4** [6] (Scheme I, Table 2). Finally, we compare the stereochemistry and formation mechanisms of abnormal- and normal-addition 1-pyrazolines **AP** and **NP**.

Scheme I



- | | |
|-------------------------------|--|
| 1a X = NO ₂ | 2 R = CH ₃ |
| b X = Cl | 3 R = C ₂ H ₅ |
| c X = H | |
| d X = CH ₃ | |
| e X = OCH ₃ | |

1 (*Z*): X-Ph is *cis* to COOCH₃
1 (*E*): X-Ph is *trans* to COOCH₃

4: *cis-syn-4*, *cis-anti-4*, *trans-syn-4*
5: *cis-syn-5*

Results.

Synthesis of 1-Pyrazolines.

1-Phenyldiazomethane (**2**), prepared by oxidation of acetophenone hydrazone with manganese dioxide [4], was reacted with methyl (*Z*)-2-cyano-3-methyl-3-(*p*-nitrophenyl)acrylate (**1a**) at -5 to 0°.

The mixture of products was chromatographed on silica gel to give 3-methyl-3-phenyl-4-cyano-4-carbomethoxy-5-methyl-5-(*p*-nitrophenyl)-1-pyrazoline (*cis-syn-4a*, 43%),

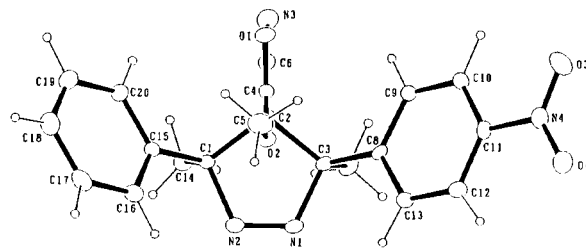


Figure 1a. Molecule of **4a**, viewed along the axis of the pyrazoline ring, with numbering scheme of the atoms.

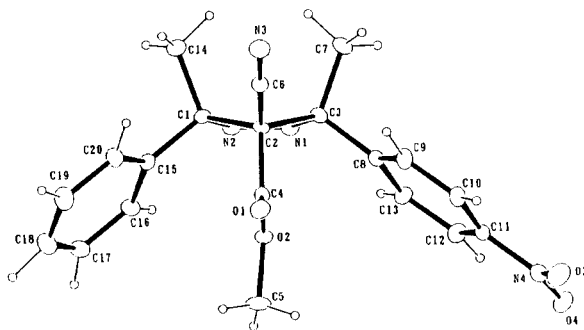


Figure 1b. Molecule of **4a**, viewed along the plane of the pyrazoline ring, with numbering scheme of the atoms.

Table 1
 Normal-addition to 1-Pyrazolines and their Decomposition Products

Compound No.	Pyrazolines		Starting materials						Products		Lit.
	NP		Olefins			Diazoalkanes			Olefins	Cyclopropanes	
	<i>para</i> X	<i>para</i> X'	R ₁	R ₂	Y	Z	R ₃	R ₄	PO	CP	
8a	-	H	H	H	Es	CN	PhX'	CH ₃	59 [a]	9.8	9
8b	-	Cl	H	H	Es	CN	PhX'	CH ₃	36	none	9
8c	-	CH ₃	H	H	Es	CN	PhX'	CH ₃	3.9	15	9
9	Br	-	PhX	H	CN	Es	H	H	86	none	10
10a-major	NO ₂	H	H	PhX	Es	CN	PhX'	CH ₃	(45) [b]	9	4
10b	Cl	H	H	PhX	Es	CN	PhX'	CH ₃	53 [a]	20	4
10c	CH ₃	H	H	PhX	Es	CN	PhX'	CH ₃	72 [a]	14	4
10a-minor	NO ₂	H	H	PhX	Es	CN	CH ₃	PhX'	(minor)	29	4
11-major	H	H	CH ₃	H	CN	Es	CH ₃	PhX'	(16) [b]	15	9
11-minor	H	H	CH ₃	H	CN	Es	PhX'	CH ₃	(minor)	8.5	9
12a	H	-	Ar ₁	H	CN	Es	H	H	22	none	this paper
12b	-	-	Ar ₂	H	CN	Es	H	H	76	none	11
12c	-	-	Ar ₃	H	CN	Es	H	H	92	none	12
13	-	H	H	Ar ₄	Es	CN	PhX'	CH ₃	none	32	9

[a] Contains secondary product *via* this compound. [b] Contains minor product; Ar₁ ...1-phenyl-1-(*p*-substituted phenyl)ethyl group, Ar₂ ...2,4,6-trimethylphenyl group, Ar₃ ...2-nitro-4-bromophenyl group, Ar₄ ...1-phenylethyl group, Es ... COOMe, COOEt.

 Table 2
 Abnormal-addition 1-Pyrazolines

Compound No.	Pyrazolines		Yield %	Starting materials				Lit		
	AP			Olefins		Diazoalkanes				
	<i>para</i> X	<i>para</i> X'		R ₁	R ₂	Y	Z		R ₃	R ₄
<i>trans-syn-6a</i>	H	H	47	Ar ₁	H	CN	Es	CH ₃	PhX'	4
<i>trans-syn-6b</i>	Cl	H	(<i>sec</i>) 17 [a]	Ar ₁	H	CN	Es	CH ₃	PhX'	4
<i>trans-syn-6c</i>	CH ₃	H	(<i>sec</i>) 14 [a]	Ar ₁	H	CN	Es	CH ₃	PhX'	4
<i>trans-syn-6d</i>	H	Cl	32	Ar ₁	H	CN	Es	CH ₃	PhX'	4
<i>trans-syn-6e</i>	H	CH ₃	34	Ar ₁	H	CN	Es	CH ₃	PhX'	4
<i>trans-anti-7a</i>	H	H	0.9	Ar ₁	H	CN	Es	PhX'	CH ₃	4
<i>cis-syn-4a</i>	NO ₂	H	43	CH ₃	PhX	CN	Es	CH ₃	PhX'	this paper
<i>cis-anti-4a</i>	NO ₂	H	4.9	Cl ₃	PhX	CN	Es	PhX'	CH ₃	ibid
<i>cis-syn-4b</i>	Cl	H	13	CH ₃	PhX	CN	Es	CH ₃	PhX'	ibid
<i>trans-syn-4b</i>	Cl	H	28	CH ₃	PhX	Es	CN	PhX'	CH ₃	ibid
<i>cis-syn-5</i>	NO ₂	H	27	Cl ₃	PhX	CN	Es	C ₂ H ₅	PhX'	ibid

[a] *sec* ... as a secondary pyrazoline *via* olefin PO. Ar₁ ... 1-phenyl-1-(*p*-substituted phenyl)ethyl group; Es ... COOMe.

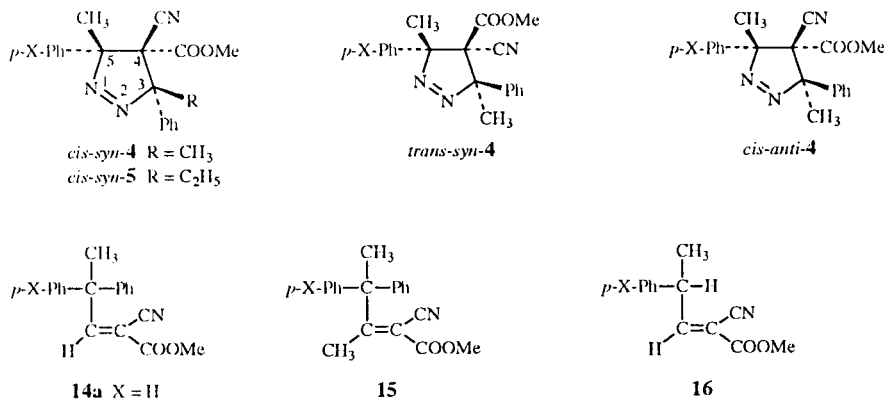
the isomer (*cis-anti-4a*, 4.9%), and 25% of (*Z*)-**1a** was recovered. *Cis-syn-4a* and *cis-anti-4a* are abnormal-addition 1-pyrazolines.

In the ¹H-nmr (deuteriochloroform) spectrum for *cis-syn-4a*, the methyl ester signal appeared at 2.59 ppm. This signal is at higher field than that of the usual methyl ester groups, because the methyl of **4a** is located between two phenyl groups on C(3) and C(5). On the other hand, the ester methyl signal of *cis-anti-4a* appeared at 3.34 ppm, because this methyl group is subject to anisotropy by only one phenyl ring. The methyl group located on C(3) of the pyrazoline ring of *cis-anti-4a* appeared at 1.49 ppm. This methyl group is situated in an *S-cis* position with respect to the ester group on C(4) of the pyrazoline ring, and is subject to anisotropy by the ester carbonyl group; thus, its signal appears at a higher magnetic field than that of *cis-syn-4a* (1.98 ppm). The methyl group located on

C(5) of the pyrazoline ring of both *cis-syn-4a* and *cis-anti-4a* appeared at 2.00 ppm, without any effect of anisotropy. The structure of *cis-syn-4a* was further supported by X-ray crystallography (Figure 1b).

The reaction of methyl (*E*)-2-cyano-3-methyl-3-(*p*-chlorophenyl)acrylate (**1b**) with **2** required 15 days for completion and produced 3-methyl-3-phenyl-4-cyano-4-carbomethoxy-5-methyl-5-(*p*-chlorophenyl)-1-pyrazoline (*cis-syn-4b*) as an oil (13%) and its isomer, *trans-syn-4b* as an oil (28%); in this case, 11% of (*Z*)-**1b** and 22% of (*E*)-**1b** were recovered.

In the ¹H-nmr (deuteriochloroform) spectrum for *cis-syn-4b*, the methyl ester signal appeared at 2.70 ppm. This signal was at a higher field than the methyl ester signal of the other isomer of **4b**, 3.32 ppm. Assignments for the *cis* and *trans* isomers were made as before on the basis of the anisotropic effect of the phenyl groups. The methyl group



at C(3) of the pyrazoline ring of *cis-syn-4b* and *trans-syn-4b* appeared at 2.00 ppm and 2.02 ppm respectively. These methyl groups are situated in an *S-trans* position with respect to the ester groups, and are not subject to anisotropy by the ester carbonyl groups, as explained for **4a**. The methyl group at C(5) of the pyrazoline ring of *trans-syn-4b* appeared at 1.57 ppm, at higher field than expected, because this methyl group is subject to the diamagnetic anisotropy of the ester carbonyl group, which is situated in a twisted *S-cis* position to the methyl group. On the other hand, the methyl group, on C(5) of the pyrazoline ring of *cis-syn-4b* appeared at 2.04 ppm, since it is free of diamagnetic anisotropy by the ester carbonyl group which is situated in an *S-trans* position to the methyl.

To verify the nmr assignments for the methyl groups on C(5) of **4a**, (*Z*)-**1a** was reacted with 1-phenyldiazopropane (**3**) for 6 days, and produced stereoselectively 3-ethyl-3-phenyl-4-cyano-4-carbomethoxy-5-methyl-5-(*p*-nitrophenyl)-1-pyrazoline (*cis-syn-5*), (27%).

In the ¹H-nmr (deuteriochloroform) spectrum of *cis-syn-5*, the two protons of the methylene in the ethyl group ($-CH_2-CH_3$) at C(3) are not equivalent to each other. One of them appeared at 2.52 ppm (nearly a quartet, $J = 4$ Hz), and the other at 2.08 ppm (nearly a quartet, $J = 4$ Hz). The three protons of the methyl in the ethyl group ($-CH_2-CH_3$) appeared at 1.08 ppm (triplet, $J = 4$ Hz). A methyl singlet at 2.62 ppm may be assigned to the methyl ester, as in the case of **4a**. The remaining methyl singlet appeared at 2.00 ppm and must be assigned to C(5). Accordingly, the signal at 2.00 ppm in *cis-syn-4b* is also assigned to C(5).

When the substituent X in the 3-phenylacrylate is electron-donating, the compound becomes essentially unreactive; thus, methyl (*E*)-2-cyano-3-methyl-3-(*p*-methylphenyl)acrylate (**1d**) failed to react with **2** over 15 days and 96% was recovered as (*E*)-**1d**, without isomerization. Similarly, the acrylic ester with X = *p*-methoxy **1e** (*E/Z* = 11:1) failed to react with **2** over 9 days; 77% was recovered without change in the isomerization. The unsubstituted compound **1c** (X = H) (*E/Z* = 2.6:1) also failed to undergo addition over 9 days; however, the recovered material (97%) showed an isomer ratio *E/Z* = 5.6:1 and did undergo isomerization.

True Cycloreversion of **4a**.

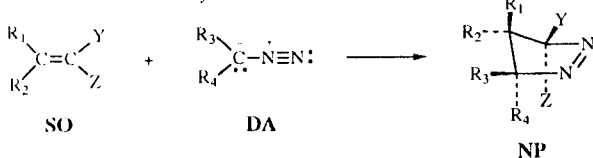
A benzene-*d*₆ solution of *cis-syn-4a* was heated at 120° for 7 hours according to ¹H-nmr, the compound had decomposed into (*E*)-**1a** (55%), (*Z*)-**1a** (45%) and acetophenazine, which might have been formed by loss of nitrogen from the diazo compound [4]. This phenomenon is an example of "true cycloreversion"; in this case, (*Z*)-**1a** is initially formed by true cycloreversion and then changes to (*E*)-**1a** by thermal isomerization.

Reactions by Way of Normal-addition to 1-Pyrazolines which are Formed *in situ*.

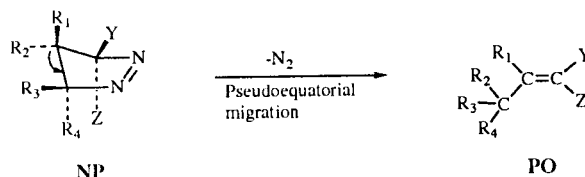
The 1,3-dipolar cycloaddition reactions (Schemes II and V) which we have performed are summarized in Tables I and 2. The normal-addition 1-pyrazolines, **NP**, produced *in situ* from 2-cyano-3-substituted-acrylates, **SO**, with diazoalkanes, **DA**, are very unstable [4]. The structures of **NP** were reconstructed from the structures of the final

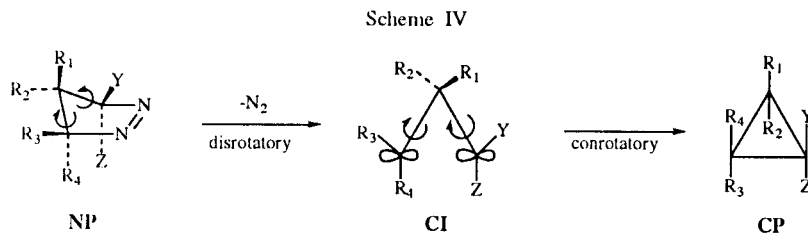
Scheme II

Normal-addition to a 1-Pyrazoline

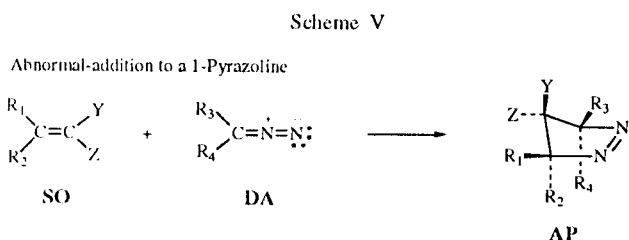


Scheme III





reaction products, the acrylates with chain extension on the β -carbon, **PO** (Scheme III), and the cyclopropane derivatives **CP** (Scheme IV). Carrie [7] and McGreer [8] have also reported structures of some normal-addition 1-pyrazolines produced from 2-cyanoacrylates with aliphatic diazomethanes.



In 1,3-dipolar cycloaddition reactions of 2-cyano-3-substituted-acrylates **SO** with diazomethanes, **DA**, steric factors in the structures of **SO** and **DA** determine which reaction takes priority, normal addition (Scheme II) or abnormal addition (Scheme V).

Reaction of methyl (*E*)-2-cyano-3-(1,1-diphenylethyl)acrylate (**14a**) with diazomethane (no substituent) produced methyl (*E*)-2-cyano-3-methyl-3-(1,1-diphenylethyl)acrylate (**15a**) only (24% yield), without evidence of a cyclopropane derivative. It is assumed that **15a** was formed *via* the normal-addition 1-pyrazoline, **NP**, (**12a**) *in situ*. Reaction [3] of (*E*)-**14a** ($X = H$) with **2** ($X' = H$) produced an abnormal-addition 1-pyrazoline **AP**. It is evident from the above example that, even if the same substrate, **SO**, for example **14** is used, the mode of addition can vary with the nature of the diazo reagent **DA**.

Results of X-ray Crystallography of **4a**.

X-ray diffraction data of *cis-syn-4a* were obtained with a Rigaku Denki AFC-6 diffractometer; $C_{20}H_{18}N_4O_4$, MW 378.4, space group $P2_1/c$, $a = 12.508 \text{ \AA}$, $b = 8.356 \text{ \AA}$, $c = 18.205 \text{ \AA}$, $\alpha = \gamma = 90^\circ$, $\beta = 96.305^\circ$, $D_{\text{calc}} = 1.327$, $V = 1892 \text{ \AA}^3$, $Z = 4$, $\lambda(\text{MoK}\alpha) = 0.7107 \text{ \AA}$, $\mu(\text{MoK}\alpha) = 1.028 \text{ cm}^{-1}$, No. of Ind Ref = 2481, $F > 2 \text{ sig}(F_o) = 1544$, Final conventional $R = 0.055$, $R_w = 0.051$.

Figure 1a shows the molecule, viewed along the axis of the pyrazoline ring, and numbering scheme of the atoms. Figure 1b shows the molecule, viewed along the plane of the pyrazoline ring. The bond distances are shown in Table 3 and the bond angles in Table 4. The envelope type pyrazoline ring and its bond distances (\AA) are shown in

Figure 2. The C(1)–C(15) bond (phenyl) makes an angle of 104° with the C(3)–C(8) bond (*p*-nitrophenyl). The methyl ester group is located between two phenyl rings and bends toward the *endo* direction. The pyrazoline ring is in the envelope conformation, C(2) protruding from the C(1)–N(2)–N(1)–C(3) plane by 0.41 \AA . The dihedral angle between the C(1)–C(2)–C(3) plane and the (C)–N(2)–N(1)–C(3) plane is $\theta = 24.4^\circ$ (Figure 2) [13]. This angle seems to be little different from these of the normal-addition 1-pyrazoline of Dewulf ($\theta = 26.8^\circ$) [14] and of Roussaux ($\theta = 29.6^\circ$) [15]. The length of the N(1)–N(2) bond (1.236 \AA) is close to 1.244 \AA [14] and 1.249 \AA [15]. The other bond distances of **4a** correspond closely to those reported by Dewulf [14] and Roussaux [15].

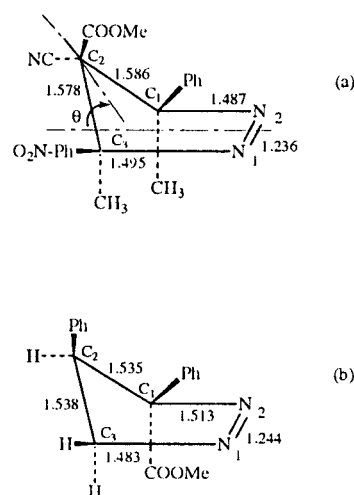


Figure 2a. Abnormal-addition to a 1-pyrazoline ring of **4a** with the bond distances (\AA) and the dihedral angle between the two planes, [13].
Figure 2b. Normal-addition to a 1-pyrazoline ring of Dewulf's compound with the bond distances (\AA), [13,14].

Discussion.

From these results, we are led to conclude that normal-addition 1-pyrazolines, **NP**, are produced from 2-cyano-3-substituted acrylates, **SO**, with diazoalkanes, **DA**, when the substituents of both **SO** and **DA** have small steric requirement. Abnormal-addition 1-pyrazolines, **AP**, are produced from **SO** with 1-phenyldiazoethanes; moreover, the substituents of **SO** must have a larger combined steric effect than " CH_3 and Ph" or " $1,1$ -diphenylethyl and H". Normal-addition 1-pyrazolines, **NP**, are very unstable,

Table 3
Bond distances of **4a**. [a]

O1 -C4	1.197(6) Å	C2 -C6	1.461(6) Å
O2 -C4	1.320(5)	C3 -C7	1.543(7)
O2 -C5	1.446(6)	C3 -C8	1.510(7)
O3 -N4	1.224(6)	C8 -C9	1.386(7)
O4 -N4	1.217(6)	C8 -C13	1.381(7)
N1 -N2	1.236(5)	C9 -C10	1.381(7)
N1 -C3	1.495(6)	C10 -C11	1.365(7)
N2 -C1	1.487(6)	C11 -C12	1.372(7)
N3 -C6	1.145(6)	C12 -C13	1.382(7)
N4 -C11	1.474(6)	C15 -C16	1.380(7)
C1 -C2	1.586(6)	C15 -C20	1.371(7)
C1 -C14	1.539(7)	C16 -C17	1.396(7)
C1 -C15	1.522(6)	C17 -C18	1.370(8)
C2 -C3	1.578(6)	C18 -C19	1.364(8)
C2 -C4	1.513(6)	C19 -C20	1.387(7)

[a] The standard deviation of the least significant figure of each distance is given in parenthesis.

Table 4
Bond angles of **4a**. [a]

C4 -O2 -C5	117.4(4) °	C7 -C3 -C8	108.5(4) °
N2 -N1 -C3	113.8(4)	O1 -C4 -O2	125.6(4)
N1 -N2 -C1	114.3(4)	O1 -C4 -C2	124.7(4)
O3 -N4 -O4	123.4(4)	O2 -C4 -C2	109.8(4)
O3 -N4 -C11	117.7(4)	N3 -C6 -C2	178.2(5)
O4 -N4 -C11	118.9(4)	C3 -C8 -C9	119.6(4)
N2 -C1 -C2	102.1(3)	C3 -C8 -C13	121.9(4)
N2 -C1 -C14	106.2(4)	C9 -C8 -C13	118.4(4)
N2 -C1 -C15	111.0(4)	C8 -C9 -C10	121.9(5)
C2 -C1 -C14	114.0(4)	C9 -C10 -C11	117.3(5)
C2 -C1 -C15	113.8(4)	N4 -C11 -C10	118.3(4)
C14 -C1 -C15	109.3(4)	N4 -C11 -C12	118.3(4)
C1 -C2 -C3	101.6(3)	C10 -C11 -C12	123.4(4)
C1 -C2 -C4	110.9(3)	C11 -C12 -C13	118.0(5)
C1 -C2 -C6	112.1(4)	C8 -C13 -C12	121.1(5)
C3 -C2 -C4	111.4(3)	C1 -C15 -C16	121.5(4)
C3 -C2 -C6	112.6(4)	C1 -C15 -C20	118.5(4)
C4 -C2 -C6	108.2(4)	C16 -C15 -C20	119.9(4)
N1 -C3 -C2	102.1(3)	C15 -C16 -C17	119.5(5)
N1 -C3 -C7	105.5(4)	C16 -C17 -C18	119.9(5)
N1 -C3 -C8	111.8(4)	C17 -C18 -C19	120.3(5)
C2 -C3 -C7	115.1(4)	C18 -C19 -C20	120.2(5)
C2 -C3 -C8	113.5(4)	C15 -C20 -C19	120.1(5)

[a] The standard deviation of the least significant figure of each angle is given in parenthesis.

even at -40° , decomposing to release nitrogen and to give a longer chain olefin, **PO**, than starting olefin, **SO**, and cyclopropane derivatives, **CP**. Abnormal-addition 1-pyrazolines, **AP**, are stable solids; under conditions of thermolysis or photolysis, they may decompose with "true cycloreversion", to return to starting materials **SO** and **DA**.

Structures of **NP** produced *in situ*, were reconstructed from the structures of **PO** and **CP** and the decomposition (Schemes III and IV). McCreer [8,16] suggested "pseudo equatorial migration" in the course of decomposition of normal-addition 1-pyrazolines (Scheme III). Crawford [17] and Hoffman [18] suggested " π_g -cyclopropane intermediates" in another route to decomposition of normal-addition 1-pyrazolines (Scheme IV). In Crawford's report [19], thermal decomposition of *cis*-3,5-dimethyl 1-pyrazoline

was found to be non stereospecific, and he reversed his opinion on " π_g -cyclopropane intermediates". In our case, the decomposition of **NP** occurs at such low temperature that the products would be produced under kinetic control. On the basis of analysis of our products **PO** and **CP**, we believe these proposals of "pseudo equatorial migration" and " π_g -cyclopropane intermediate" to be valid.

Generalizations.

In this section, the numbering of the pyrazoline ring is based on the scheme in Figure 2.

1. In the pyrazoline **NP**, in the case of $R_1 = R_2 = H$ and $R_3 = PhX$ *syn* to $Y = COOR'$, both PhX and $COOR'$ will be equatorial and $R_4 = CH_3$, $Z = CN$ must be axial. As the result, the 2-cyanoacrylate **PO** will have a 3-(1-*p*-substituted-phenyl)ethyl substituent because of "pseudo-equatorial migration" of R_2 onto C(3) and only one cyclopropane derivative through a π_g -cyclopropane intermediate (see **8**, Table 1).

2. If the substituent in **NP** are $R_1 = Ar_n$ ($n = 1, 2, 3$), $R_2 = H$, $R_3 = H$, $R_4 = H$, $Y = CN$, and $Z = COOR'$ (formed from (*E*)-olefin **SO**), R_1 and Z must be axial for migration of R_2 onto C(3) even though R_1 is a very bulky group; consequently, 3- Ar_n -2-cyanoacrylate with a new methyl group on C(3) is produced, without formation of any cyclopropane (see **12**, and Table 1). Reaction of (*E*)-2-cyanocinnamate with diazomethane produces (*E*)-2-cyano-3-methylcinnamate by the same mechanism (**9**, $R_1 = PhX$, Table 1).

3. In the case of $R_1 = H$, $R_2 = PhX$, $Y = COOR'$, $Z = CN$ (formed from (*E*)-olefin **SO**), 1-phenyldiazoethane adds to form **NP** with $R_3 = PhX'$ and $R_4 = CH_3$ and the three bulky groups, PhX , PhX' , and $COOR'$ are equatorial as Deleux [20] has indicated. Consequently, PhX on C(2) and PhX' on C(3) assume an *S-trans* relationship in order to reduce steric interaction between them; PhX on C(2) can undergo "pseudoequatorial migration" to form 2-cyano-3-(1,1-diphenylethyl)acrylate in addition to one isomer of **CP** (Table 1, **10** major, $X = Cl, H, CH_3, CH_3O$).

4. The reaction of (*E*)-2-cyano-3-(*p*-nitrophenyl)acrylate with **DA** produces olefin **PO** and two isomers of the cyclopropane **CP**. In this case, we suggest that the 1-pyrazoline **NP** exists in two types, **10a**-major and **10a**-minor: **10a**-major has $R_1 = H$, $R_2 = PhX$, $R_3 = PhX'$, and $R_4 = CH_3$; **10a**-minor has $R_1 = H$, $R_2 = PhX$, but $R_3 = CH_3$ and $R_4 = PhX'$. In **10a**-major, PhX ($X = NO_2$) is placed *S-trans* to PhX' in order to reduce electronic repulsion. As a result, R_2 migrates onto C(3) and produces olefin **PO** having a 1,1-diphenylethyl group on C(3) of the acrylate, in addition to formation of **CP** ($R_3 = Ph$, $R_4 = CH_3$) through a π_g -cyclopropane intermediate (Scheme III). In **10a**-minor, PhX on C(2) and PhX' on C(3) are *S-cis* and PhX will be unable to migrate to C(3) because of the steric hindrance

between them. Thus, **10a**-minor produces another cyclopropane derivative **CP** ($R_3 = \text{CH}_3$, $R_4 = \text{Ph}$) through a π_g -cyclopropane intermediate.

5. 1-Pyrazoline **NP** (compound **11**) was produced *in situ* from (*E*)-2-cyanocrotonate with **DA**. From the structure of the olefin **PO** which is produced by decomposition of **11**, it appeared that the methyl group on C(2) did not migrate; therefore the methyl group (R_1) is placed in the axial position and COOR' (*Z*) also axial. Because PhX' is disposed to take a position *syn* to COOR' in pyrazoline **NP**, **11**-major has $R_3 = \text{CH}_3$, $R_4 = \text{PhX}'$ and gives 15% yield of a cyclopropane derivative while unfavorable **11**-minor, in which PhX' is anti to COOR' ($R_3 = \text{PhX}'$, $R_4 = \text{CH}_3$), gives 8.5% yield of another cyclopropane derivative.

6. 1-Pyrazoline **13** is termed a secondary pyrazoline [4] because it was produced *in situ* from (*E*)-2-cyano-3-(1-phenylethyl)acrylate (**16**) [9] with **2**. In this case, only one cyclopropane derivative **CP** was produced, but olefin **PO** was not. From the structure of product **CP**, we reasoned that **13** has $R_1 = \text{H}$, $R_2 = 1\text{-phenylethyl}$, $R_3 = \text{Ph}$, and $R_4 = \text{CH}_3$, so that three large groups, Ph, 1-phenylethyl, and COOR' are in stable equatorial positions; moreover, Ph took a position *syn* to COOR'. Hydrogen on C(2) does not migrate onto C(3) because it is an axial position; the 1-phenylethyl group on C(2) could not migrate to C(3) because of strong steric interference between the 1-phenylethyl group and the substituent on C(3). Thus, 1-pyrazoline **13** could produce only the cyclopropane derivative **CP** (32% yield) *via* the π_g -cyclopropane intermediate (**CD**).

For comparison of steric control, the following experiments were carried out: the reactions of **2** with **16**, and of **2** with **14**. The former combination produced a normal-addition 1-pyrazoline, *trans-anti-13*; but, the latter combination produced the abnormal-addition 1-pyrazoline, *trans-syn-6a* (47% yield) and *trans-anti-7a* (0.9% yield). The results showed that phenyl *syn* to COOR' is a favorable arrangement.

Reaction of (*Z*)-**1a** with **2** produced more *cis-syn-4a* than *cis-anti-4a*, because the conformation of cinnamate was retained and the Ph group preferred a position *syn* to COOR'. Results of X-ray crystallography of **4a** also confirmed this tendency. Reaction of (*E*)-**1b** with **2** produced more *trans-syn-4b* than *cis-syn-4b*; however, **1b** also isomerized due to the long reaction time.

True cycloreversion of *cis-syn-4a* produced (*E*)-**1a** (55% yield) and (*Z*)-**1a** (45% yield). These results show that the (*E*)-conformation of **1a** is more favorable than the (*Z*)-conformation under the conditions of thermodynamic control [10].

Decomposition of the normal-addition 1-pyrazoline with a COOR' substituent involves, according to Dewulf [14] and Rousseaux [15], initial rupture of the N(2)-C(1) bond and is followed by cleavage of the N(1)-C(3) bond to release nitrogen. In the abnormal-addition 1-pyrazoline (ex-

ample **4a**, Figure 2), the cleavage of the C(1)-C(2) bond and the C(3)-N(1) bond occurs, and resulting in a "true cycloreversion."

EXPERIMENTAL

General Procedure.

Reactions of Methyl 2-Cyano-3-methyl-3-(*p*-substituted-phenyl)acrylates with 1-Phenyldiazoalkanes.

To the deep violet solution of 1-phenyldiazoalkane **2** or **3**, prepared from 0.048 mole of alkylphenylketone hydrazone, was added a solution of 0.024 mole of methyl 2-cyano-3-methyl-3-(*p*-substituted-phenyl)acrylate, **1a** or **1b**, in 25 ml of dichloromethane at -5° to 0° . The reaction mixture was stirred for several days at room temperature until the deep color of the diazo compound had changed to light yellow. The solvent was evaporated under reduced pressure at 40 to 50° ; the residual mixture was fractionated by chromatography on silica gel with a mixture of chloroform and carbon tetrachloride (6:4). The isolated compounds were recrystallized from 95% ethanol. The isolated products are described below.

Reaction of Methyl (*Z*)-2-Cyano-3-methyl-3-(*p*-nitrophenyl)acrylate (**1a**) with **2**.

Compound (*Z*)-**1a**, mp $158\text{--}163^\circ$ was allowed to react with **2** for 5 days at room temperature; *cis-syn-4a*, mp $167\text{--}168^\circ$ (43% yield) and *cis-anti-4a*, mp $161\text{--}163^\circ$ (4.9% yield), were isolated and 25% (*Z*)-**1a** was recovered.

Cis-syn-4a had $^1\text{H-nmr}$ (deuteriochloroform): δ 1.98 (s, 3H), 2.00 (s, 3H), 2.59 (s, ester 3H), 7.30 (arom 5H), 7.78 and 8.15 (A_2B_2 , arom 4H); ms: m/z (relative intensity) 378 (57, M^+), 350 (19, $M^+ - N_2$), 302 (24, $M^+ - \text{Ph}$), 246 (33, $M^+ - 132$), 201 (100, methyl 2-cyano-3-methylcinnamate), 132 (29, methyl phenyldiazomethane).

Anal. Calcd. for $C_{20}H_{18}N_4O_4$: C, 63.48; H, 4.80; N, 14.80. Found: C, 63.31; H, 4.68; N, 14.80.

Cis-anti-4a had $^1\text{H-nmr}$ (deuteriochloroform): δ 1.49 (s, 3H), 2.00 (s, 3H), 3.34 (s, ester 3H), 7.30 (arom 5H), 7.88 and 8.15 (A_2B_2 , arom 4H); ms: m/z (relative intensity) 378 (2, M^+), 350 (1.3), 246 (100).

Anal. Calcd. for $C_{20}H_{18}N_4O_4$: C, 63.48; H, 4.80; N, 14.80. Found: C, 63.66; H, 4.73; N, 14.80.

Reaction of Methyl (*E*)-2-Cyano-3-methyl-3-(*p*-chlorophenyl)acrylate (**1b**) with **2**.

Compound (*E*)-**1b**, mp $145\text{--}147^\circ$ was allowed to react with **2** for 15 days at room temperature.

Cis-syn-4b was obtained in 13% yield, *trans-syn-4b* in 28% yield; 22% of (*E*)-**1b**, 11% of (*Z*)-**1b**, and 1.25 g of acetophenone were also isolated.

Cis-syn-4b was obtained as an oil; $^1\text{H-nmr}$ (deuteriochloroform): δ 2.00 (s, 3H), 2.04 (s, 3H), 2.70 (s, ester 3H), 7.3 to 7.5 (arom, 9H); ms: m/z (relative intensity) M^+ (no appearance), 341 and 339 (1.2% and 3.1%, $M^+ - N_2$), 105 (100, Ph-C- CH_3).

Trans-syn-4b was obtained as an oil; $^1\text{H-nmr}$ (deuteriochloroform): δ 2.02 (s, 3H), 1.57 (s, 3H), 3.32 (s, ester 3H), 7.2 to 7.4 (arom 9H); ms: m/z (relative intensity), M^+ (no appearance), 341 and 339 (1.0% and 2.9%, $M^+ - N_2$), 105 (100, Ph-C- CH_3).

Reaction of (*Z*)-**1a** with 1-Phenyldiazopropane (**3**).

Compound **3** was prepared from propiophenone hydrazone by

the same method as for **2**, and was allowed to react with (*Z*)-**1a**, mp 158-163° for 6 days at room temperature. *Cis-syn-5a*, mp 130-132° (27% yield) was obtained; ¹H-nmr (deuteriochloroform): δ 1.08 (t, J = 4, 3H), 2.00 (s, 3H), 2.08 (q, J = 4, 1H), 2.52 (q, J = 4, 1H), 2.62 (s, ester 3H), 7.38 (arom, 5H), 7.80 and 8.25 (A₂B₂, arom 4H); ms: m/z (relative intensity) M⁺ (no appearance), 364 (1, M⁺ -N₂), 305 (0.5, 364 -COOCH₃), 246 (18, M⁺ -EtC(C₆H₅)N₂), 229 (100, C₆H₄(NO₂)C(CH₂)C(CN)COOCH₃), 215 (16, C₆H₅(Et)C=C(CN)COOCH₃), 199 (50).

Anal. Calcd. for C₂₁H₂₀N₄O₄: C, 64.27; H, 5.14; N, 14.28. Found: C, 64.25; H, 4.97; N, 14.43.

Thermolysis of *cis-syn-4a*.

A solution of 570 mg of *cis-syn-4a* in 5 ml of benzene-d₆ was sealed into a quartz nmr tube and the solution was heated at 120° in an oil-bath for 7 hours. The solution was cooled to room temperature and its ¹H-nmr spectrum was measured. (*E*)-**1a** was obtained in 55% yield; δ 2.11 (s, 3H), 3.38 (s, ester 3H), 6.75 and 7.80 (A₂B₂, arom 4H). (*Z*)-**1a** was obtained in 45% yield; δ 1.81 (s, 3H), 3.11 (s, ester 3H), 6.45 and 7.78 (A₂B₂, arom 4H), and acetophenonazine 2.02 (s, 6H). The reaction products were separated by chromatography on silica gel with a mixture of chloroform-carbon tetrachloride (1:1) as the eluant to give 160 mg (43% yield) of (*Z*)-**1a**, mp 168-170°, 130 mg (35% yield) of (*E*)-**1a**, and 290 mg (41% yield) of acetophenonazine.

Reaction of Methyl 2-Cyano-3-(1,1-diphenylethyl)acrylate (**14a**) with Diazomethane.

To a solution of 3.63 g (0.0124 mole) of **14a** in 78 ml of ether, 0.0166 mole of diazomethane, prepared from 5.4 g of *N*-methyl-*N*-nitroso-*p*-toluenesulfonamide, was added at -5 to 0°. After the mixture had been stirred at room temperature overnight, the solvent was evaporated under reduced pressure. The product was isolated by chromatography on silica gel with a mixture of chloroform-carbon tetrachloride (6:4) as the eluant whereupon 914 mg (24% yield) of methyl (*E*)-2-cyano-3-methyl-3-(1,1-diphenylethyl)acrylate (**15a**) was isolated. Likewise 415 mg of (*E*)-**15a**, mp 99-100° was obtained by recrystallization from 95% ethanol; ¹H-nmr (deuteriochloroform): δ 2.14 (s, 3H), 2.17 (s, 3H), 3.82 (s, ester 3H), 7.26 (s, arom 10H); ms: m/z (relative intensity) 305 (100, M⁺), 245 (23, M⁺ -CH₃), 200 (24); ir (Nujol): 1720 (ester C=O), 2220

cm⁻¹ (CN).

Anal. Calcd. for C₂₀H₁₉NO₂: C, 78.66; H, 6.27; N, 4.59. Found: C, 78.48; H, 6.17; N, 4.88.

REFERENCES AND NOTES

- [1] In this paper, the compound groups are designated with the following acronyms: Starting olefins...**SO**, Diazoalkanes...**DA**, Normal addition 1-pyrazolines...**NP**, Produce olefins...**PO**, π₂-Cyclopropane intermediates...**CI**, Cyclopropanes...**CP**, Abnormal addition 1-pyrazolines...**AP**.
- [2] S. D. Andrews, A. C. Day, and A. N. McDonald, *J. Chem. Soc. (C)*, 787 (1969).
- [3] J. W. Wilt, V. A. Curtis, and C. O. Yang, *J. Org. Chem.*, **47**, 3721 (1982).
- [4] W. Nagai and Y. Hirata, *J. Org. Chem.*, **54**, 635 (1989).
- [5] G. Bianti and R. Gandolfi, 1,3-Dipolar Cycloaddition Chemistry, Vol **2**, A. Padwa, ed, John Wiley and Sons, New York, 1984, p 539.
- [6] The numbering of the 1-pyrazoline ring follows IUPAC rules and differs from Figure 1 and Figure 2 (numbering scheme for X-ray analysis).
- [7] R. Danion-Bougot and R. Carrie, *Org. Magn. Reson.*, **5**, 453 (1973).
- [8] D. E. McGreer and Y. Y. Wigfield, *Can. J. Chem.*, **47**, 3965 (1969).
- [9] W. Nagai and Y. Hirata, *J. Org. Chem.*, **43**, 626 (1978).
- [10] W. Nagai and T. Miwa, *Nippon Kagaku Zasshi*, **89**, 819 (1968).
- [11] Y. Hirata and W. Nagai, *Nippon Kagaku Kaishi*, 1341 (1972).
- [12] W. Nagai, *Nippon Kagaku Zasshi*, **91**, 362 (1970).
- [13] Figure 2 (a) θ = 24.4°, C(2) protrudes from the plane by 0.41 Å in **4a**; Figure 2 (b) θ = 26.8°, C(2) protrudes from the plane by 0.45 Å in Dewulf's compound [14].
- [14] B. Dewulf, J. Meunier-Piret, J. P. Putzeys, and M. Van Meerssche, *Cryst. Struct. Commun.*, **4**, 175 (1975).
- [15] M. P. Rousseaux, J. Meunier-Piret, J. P. Putzeys, G. Germain, and M. Van Meerssche, *Acta Cryst.*, **28B**, 1720 (1972).
- [16] D. E. McGreer, I. M. E. Masters, and M. T. H. Liu, *J. Chem. Soc., Perkin Trans. II*, 1791 (1975).
- [17] R. J. Crawford and A. Mishra, *J. Am. Chem. Soc.*, **88**, 3963 (1966); R. J. Crawford and G. L. Erickson, *ibid.*, **89**, 3907 (1967).
- [18] R. Hoffmann, *J. Am. Chem. Soc.*, **90**, 1475 (1968).
- [19] R. Moore, A. Mishra, and R. J. Crawford, *Can. J. Chem.*, **46**, 3305 (1968).
- [20] J. P. Deleux, G. Leroy, and J. Weiler, *Tetrahedron*, **29**, 1135 (1973).