

Original Research Article

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Synthesis of a Novel Unsaturated Polyolefin Intermediates, Aldehyde and Fatty Acid

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Novel unsaturated compounds with the required skip-conjugated (Z,Z)-double bonds configuration are synthesized through a coupling of aldehydes with phosphonium salt through a series of Wittig reactions as a main step. The products were diagnosed by using NMR spectrum, infrared (IR) and mass spectrometer techniques. It is concluded that these products could widely be used as a fatty acid and a useful intermediates in the synthesis of pheromones instead of insecticides, and several chemical reactions.

Introduction

Many natural biologically active products bear skipped alkene units with all Z configuration which are known as polyunsaturated compound like polyunsaturated fatty acid.¹ The importance of polyunsaturated fatty acids in diet and human health is well documented. Fatty acids have several usages which retain them important. Some cellular functions do use them as energy storage molecules and as hydrophobic core of membranes. They also maintain a favourable effect on human diseases such as arthritis,² renal disorders,³ cancer,⁴ and contribute into various signalling pathways.

Recently, fatty acid functional studies have been considered as an attractive model in several areas. All of the enzymes which produce omega-6 and omega-3 fatty acids are synthesized by the *Caenorhabditis elegans*.^{5,6} Generally, polyunsaturated fatty acids molecules consist a group of Z-double bonds separated by CH₂, 'skip-conjugated' or methylene-interrupted systems. This system is similar to many pheromonal system. Most of this type of polyunsaturated molecules have been prepared by controlled hydrogenation of a skip-conjugated polyacetylene,^{7,8} or isolated from the natural sources. Other references reported that the

ability to use 6,6-di-alkoxy-Z-hex-3-en-1-al and a range of related systems, as homologating agents to synthesis same type of compounds using Wittig reactions.⁹⁻¹²

The objectives of this study are to synthesize several useful intermediates which contain (5Z,7Z,8Z and 9Z) double bond formation. These products may easily be utilized in many fields to prepare some intermediates to implement in preparation of pheromones, polyunsaturated aldehydes and fatty acid compounds in high yields and low costs.

Methodology

Experimental

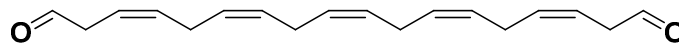
General

Chemicals used were obtained from commercial suppliers (Sigma, Aldrich, and Alfa Ayser) or prepared from them by the methods described. All reagents and solvents used were of reagent grade unless otherwise stated.

Silica gel (Merck 7736) and silica gel plates used for column chromatography and thin layer chromatography were obtained from Aldrich; separated components were detected using variously UV light, I₂ and phosphomolybdic acid solution in IMS followed by charring. Anhydrous magnesium sulfate was used to dry organic solutions. Infra-red (IR) spectra were carried out on a Perkin-Elmer 1600 F.T.I.R. spectrometer as liquid films or KBr disc (solid).

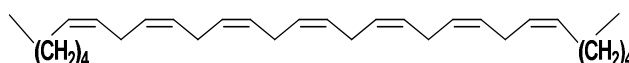
NMR spectra were carried out on a Bruker AC250 or Advance 400 spectrometer. Mass spectra were recorded on Bruker Micro TOF using electron impact ionization or by direct insertion matrix-assisted laser desorption / ionisation-time of flight mass spectrometry (MALDI-TOF MS).

Synthesis of (3Z,6Z,9Z,12Z,15Z)-octadeca-3,6,9,12,15-Pentaenedial (2)



Formic acid 80 %^{12,13} (6 mL) was added dropwise to a stirred solution of (3Z,6Z,9Z,12Z,15Z)-1,1,18,18-tetramethoxyoctadeca-3,6,9,12,15-pentaene¹⁴ (0.20 g, 0.60 mmol) in dioxane (6 mL) at room temperature. The mixture was stirred at room temperature for 1.5 hrs, followed by the addition of water (10 mL). The product was extracted with dichloromethane (3 x 25 mL) and the combined organic layers were washed with sat.aq. NaHCO₃ (15 mL), brine (15 mL) and dried over MgSO₄ then evaporated to give a crude product which was purified by column chromatography on silica eluting with petrol:ethyl acetate (5:1) to give (3Z,6Z,9Z,12Z,15Z)-octadeca-3,6,9,12,15-pentaenedial (2) (0.135 g, 90%).

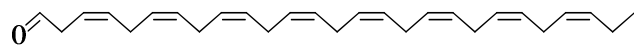
Synthesis of (6Z,9Z,12Z,15Z, 18Z, 21Z,24Z)-Triaconta-6,9,12,15,18,21,24-Heptaene (4)



Sodium bis(trimethylsilyl)amide (4 ml) was added to a stirred solution of hexyltriphenylphosphonium bromide (3)(0.5 g, 1.2 mmol) at -78 °C.

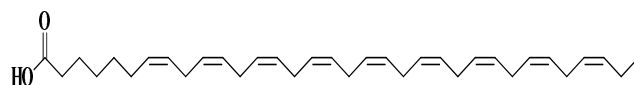
The reaction mixture was gradually warmed to room temperature then cooled down again to -78 °C and (3Z,6Z,9Z,12Z,15Z)-octadeca-3,6,9,12,15-pentaenedial (2) (0.27 g, 1 mmol) was added. The reaction was quenched as above to give (6Z,9Z,12Z,15Z,18Z,21Z,24Z)-triaconta-6,9,12,15,18,21,24-heptaene (4)(0.3 g, 75 %).

Synthesis of (3Z,6Z,9Z,12Z,15Z,18Z, 21Z, 24Z)-Heptacos-3,6,9,12,15,18,21,24-Octaenal (6)



Using the same procedure as above formic acid 80 % (3 mL) was added dropwise to a stirred solution (3Z,6Z,9Z,12Z, 15Z,18Z, 21Z,24Z)-1,1-dimethoxyheptacos-3,6,9, 12,15,18,21,24-octaene (5) (0.2 g, 0.47 mmol) in dioxane (3 mL) at room temperature. The mixture was stirred at room temperature for 1.5 hrs, followed by the addition of water (5 mL). The product was extracted with dichloromethane (3 x 20 mL) and the combined organic layers were washed with sat.aq. NaHCO₃ (10 mL), brine (10 mL) and dried over MgSO₄ then evaporated to give a crude product which was purified by column chromatography on silica eluting with petrol:ethyl acetate (5:1) to give (3Z,6Z,9Z,12Z,15Z,18Z,21Z,24Z)-heptacos-3,6,9,12,15,18,21,24-octaenal (6) (0.13 g, 76 %).

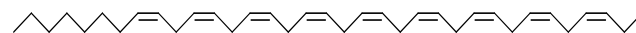
Synthesis of (7Z,10Z,13Z, 16Z,19Z, 22Z,25Z,28Z,31Z)-Tetratriaconta-7,10,13, 16,19,22,25,28,31-Nonaenoic acid (9)



Sodium bis(trimethylsilyl)amide (3ml) was added dropwise to a stirred slurry of (6-carboxy-hexyl) triphenylphosphonium bromide (7)(0.5 g, 1.1 mmol) in dry THF (20 mL) -78 °C, under nitrogen. The reaction mixture was allowed to reach room temperature and stirred for 30 min, then cooled again to -78 °C, and (3Z,6Z,9Z, 12Z,15Z,18Z,21Z,24Z)-heptacos-3,6,9, 12,15,18,21,24-octaenal (6)(0.2 g, 0.8 mmol) in dry THF (3 mL) was added. The mixture was stirred and allowed slowly to reach room temperature, then cooled to 0 °C

and quenched with sat. aq.NH₄Cl (15 mL). The product was extracted with ethyl acetate (3 x 50 mL). The combined organic layers were dried over MgSO₄ and evaporated. The residue was purified by column chromatography on silica eluting with petrol to give (7Z,10Z,13Z,16Z,19Z,22Z,25Z,28Z,31Z)-tetratriaconta-7,10,13,16,19,22,25,28,31-nonaenoic acid (9) (0.22 g, 84 %).

Synthesis of (3Z,6Z,9Z,12Z,15Z,18Z,21Z , 24Z, 27Z)- Pentatriaconta-3,6,9,12,15,18, 21,24,27-Nonaene (10)



Using the same procedure as above, (3Z,6Z,9Z,12Z,15Z,18Z,21Z,24Z,27Z)-pentatriaconta-3,6,9,12,15,18,21,24,27-nonaene (10)(0.27 g, 81 %) was prepared by using octyltriphenylphosphonium bromide (0.5 g, 1.1 mmol), sodium bis(trimethylsilyl)amide (3mL) and (3Z,6Z, 9Z,12Z,15Z,18Z,21Z,24Z)-heptacos-3,6,9, 12,15,18,21,24-octaenal (0.27 g, 0.7 mmol) in THF (15 mL) under nitrogen. The reaction was worked up as before and the product was purified by column chromatography eluting with petrol : ethylacetate (5:2).

Results and Discussion

Our interest in the stereoselective cis-Wittig olefination has led to the proposal of a new strategy for the synthesis of polyunsaturated fatty acids which are featured by methylene-interrupted cis double bonds. Our approach is based on the oxidative coupling of the ylid derived from the previously described.

It is known that the acetal which has been used to prepare pheromones containing Z-alkenes.^{3,4,5} Continuous with what we had been prepared later we successfully to insert di-acetal in new chemical reactions to

syntheses several novel polyunsaturated compounds like aldehyde, fatty acid and intermediates with skip-conjugated (Z,Z)-double bonds.

In this step was the selective conversion of bis-acetal (1) to the corresponding di-aldehyde, by deprotection of the di-acetal (3Z,6Z,9Z,12Z,15Z)-1,1,18,18-tetra-methoxyocta-deca-3,6,9,12,15-pentaene with 80% formic acid in dioxane which led to the corresponding unstable aldehyde (3Z,6Z,9Z,12Z,15Z)-octadeca-3,6,9,12,15-pentaenedial (2) in 90% yield.

The ^1H NMR spectrum of aldehyde (2) showed a triplet at δ 9.69 (2H, J 1.8 Hz) for the aldehyde protons. The olefinic protons were observed as a four proton multiplet next to the aldehyde groups between 5.7 and 5.5 and eight proton multiplet at δ 5.4 for the other alkenes protons, and the methylene protons next to the aldehyde as a doublet at δ 3.23 (4H, J 7.1 Hz). The methylene protons between and next to the five double bonds appeared as a broad multiplet at δ 2.83 (8H).

The ^{13}C NMR showed signals at δ 199.3 for the carbonyl carbon of the aldehyde, at δ 42.4 for the carbon next to the aldehyde carbon, and showed the required ten alkene carbons between δ 133.1- 118.6. The signals occurred at δ 25.9 and 25.6 for the methylene groups between alkene double bonds. The infrared spectrum confirmed the success of the deprotection, showing an absorbance at 1731 cm^{-1} corresponding to the aldehyde carbonyl group. This pentaenedial (2) was used directly in the next step, a Wittig reaction with several alkyltriphenylphosphonium bromide (3) and base to give several products with heptaene group.

The Wittig Reaction

The Wittig reaction is the key step in this

strategy. This, in general, is a reaction between an aldehyde or a ketone (A) with a triphenyl phosphonium ylide (B), forming an alkene in the cis or trans configuration. A high selectivity for an (E) or (Z) alkene can be achieved, depending on the conditions employed in the reaction or the substance of the starting material.

The Wittig reaction in general gives product (C) in the Z-configuration unless the ylid (B) is stabilised by an electron withdrawing substituent. It has been reported that the stereochemistry of the product is dependent on the oxaphosphetane elimination step. The initial step in the Wittig reaction treats the phosphonium salt with a base to form an ylid (D). The stability of that ylide leads to either the (Z) or (E) configuration of the alkenes (Z) and (E); a non-stabilised ylide (D) leads to the (Z) isomer, while a more stable gives the (E) isomer.¹⁵ The stability of the ylide (D) is due to the R-group in the phosphonium salt; this contains an electron withdrawing group and makes the ylide (D) more stable.^{16,17}

Other conditions can affect the stereochemistry of the product of a Wittig reaction.¹⁸ The solvent used in the reaction can affect the stereochemistry of the product. Reitz et al. demonstrated the effect of the solvent and in general concluded that THF, DME, ether and tert-butyl methyl ether are the solvents of choice for higher yields of (Z) isomers, while alcohols and DMSO should be avoided.¹⁹ The base used to generate the anion from the phosphonium salt can affect the (Z/E) ratio of the product. Potassium bases give a higher ratio of cis isomers to trans isomers, while sodium bases are less selective and lithium bases give a higher ratio of trans to cis isomers (Fig. 5).²⁰

In the current study, reaction of the bromide with triphenylphosphine to obtain Wittig

salts with different chain lengths (3) ($n=4,5$ and 6). This can readily be used as an intermediate to prepare a range of molecules containing seven skip-conjugated Z-alkenes (4).

The Wittig coupling was used between triphenyl phosphonium salt (3) and pentaene aldehyde (3Z,6Z,9Z,12Z,15Z)-octadeca-3,6,9,12,15-pentaenedial (2), the reaction had been in dry THF at low temperature, in the presence of sodium bis(trimethylsilyl)amide as a base, to give compound (4), the structures of which were confirmed by their mass spectra, IR and the NMR spectra.

The ^1H NMR spectra of (4) showed disappearing aldehydes groups signals, and two chine with several methylene groups ($n=4,5$ and 6) were appeared as mention in a figure above. For example, NMR spectrum of the compound (4) when $n=4$ showed multiplets signal between δ 5.4 and δ 5.3 which corresponded to sets of overlapping double bonds, The two sets of methylene protons situated between the double bonds appeared as a multiplet at δ 2.8. The methylene protons next to the double bond appear as a signal at δ 2.0, while the chain methylene groups appear as a signal at δ 1.2, and the signal at δ 0.9 were for the two terminal methyl groups. The ^{13}C NMR spectra showed the required number of resonances, including seven alkene protons signals between δ 130 and δ 127 ppm. The terminal methyl carbon signals were observed at δ 14.06 and δ 14.1 ppm. No trace of trans or conjugated compounds could be found by ^{13}C NMR and ^1H NMR analysis.

In the second line we successfully entered the (3Z,6Z,9Z,12Z,15Z,18Z,21Z,24Z)-1,1-dimethoxyheptacos-3,6,9,12,15,18,21,24-octaene (5), which we prepared in our Ph.D. study to synthesis a novel very long

polyunsaturated aldehyde (6), fatty acid (9) and several intermediate with eight and nine alkene double bonds (10) respectively.

The acetate (5) was treated with formic acid 80 % in dioxane to deprotect the acetal group, and produce the unstable aldehyde give (3Z,6Z,9Z,12Z,15Z,18Z,21Z,24Z)-heptacos-3,6,9,12,15,18,21,24-octaenal (6), in 76 % yield.

The proton NMR spectrum of this displayed the aldehyde proton as a triplet at δ 9.68 (J 1.8 Hz), and the sixteen alkene protons as a multiplet between δ 5.74 and 5.29, reflecting the presence of eight double bonds within the molecule. A broad doublet at δ 3.23 refer to the methylene protons next to the aldehyde function group, a multiplet occurred between δ 2.89 to 2.79 for the methylene protons between the eight double bonds. The methylene protons next to the terminal alkyl group appeared at δ 2.08 while the terminal methyl group appeared as a triplet at δ 0.98.

By coupling the phosphonium salt (7) and aldehyde (6) in a Wittig reaction using sodium bis(trimethylsilyl)amide, (7Z,10Z,13Z,16Z,19Z,22Z,25Z,28Z,31Z)-tetratriaconta-7,10,13,16,19,22,25,28,31-nonaenoic acid (9) was obtained in a 84% yield, while the coupling of same aldehyde (6) with the phosphonium salt (8) lead to (3Z,6Z,9Z,12Z,15Z,18Z,21Z,24Z,27Z)-pentatriaconta-3,6,9,12,15,18,21,24,27-nonaene (10) in a 81 % yield.

The ^1H NMR spectrum of the nonaenoic acid (9) showed a multiplet between δ 5.48 and 5.28 for the eighteen alkene protons, reflecting the presence of nine double bonds within the molecule. A multiplet occurred at δ 2.91 – 2.78 for the methylene protons between the nine double bonds. The alkyl chain signals between alkene and carboxylic

acid group appeared at δ 2.36, 2.18, 1.67 and 1.43 respectively. The methylene protons next to the terminal alkyl group appeared at δ 2.08 while the terminal methyl group appeared as a triplet at δ 0.98. However, the

aldehyde signal had disappeared while a new signal appeared at δ 11.18, corresponding to the carboxylic acid group proton.

Table.1 Mass, NMR and IR Analysis of Compound (3Z,6Z,9Z,12Z,15Z)-Octadeca-3,6,9,12,15-Pentaenedial

Mass	272.177
δ H (500 MHz)	9.69 (2H, t, J = 1.8 Hz), 5.79 – 5.50 (4H, m), 5.50 – 5.26 (6H, m), 3.23 (4H, d, J = 7.1 Hz), 2.83 (8H, t, J = 7.1 Hz).
δ^{13} C (101 MHz)	199.31, 133.10, 128.72, 128.07, 127.21, 118.71, 42.49, 25.97, 25.66.
$\nu_{\max}/\text{cm}^{-1}$	2927, 2861, 1731, 1609, 1493, 1451, 1402, 727.

Table.2 Mass, NMR and IR Analysis of Compound to (6Z,9Z,12Z,15Z,18Z,21Z,24Z)-Triaconta-6,9,12,15,18,21,24-Heptaene

Mass	408.37
δ H (500 MHz)	5.45 – 5.30 (14H, br, m), 2.91 – 2.78 (12H, br, m), 2.05 (4H, m), 1.42 – 1.23 (12H, m), 0.90 (6H, t, J = 6.8 Hz).
δ^{13} C (101 MHz)	130.49, 128.59, 128.28, 128.18, 128.09, 127.85, 127.53, 31.52, 29.32, 27.22, 25.64, 22.57, 14.06.
$\nu_{\max}/\text{cm}^{-1}$	2926, 1744, 1655, 1493, 1456, 1363, 1237, 1036, 824, 721 cm^{-1} .

Table.3 Mass, NMR and IR Analysis of Compound (3Z,6Z,9Z,12Z,15Z,18Z,21Z,24Z)-Heptacos-3,6,9,12,15,18,21,24-Octaenal (6)

Mass	378.29
δ H (500 MHz)	9.68 (1H, t, J 1.8), 5.74 – 5.65 (2H, m), 5.64 – 5.57 (2H, m), 5.45 – 5.29 (12H,m), 3.23 (2H, br d, J 7.1), 2.89 – 2.79 (14H, br m), 2.11 – 2.04 (2H, br m), 0.98 (3H, t, J 7.5).
δ^{13} C (101 MHz)	199.32, 133.12, 132.05, 128.82, 128.36, 128.26, 128.07, 127.89, 127.14, 118.69, 42.49, 25.97, 25.65, 25.53, 20.55, 14.26.
$\nu_{\max}/\text{cm}^{-1}$	2925, 2860, 1733, 1609, 1558, 1494, 1055, 723.

Table.4 Mass, NMR and IR Analysis of Compound (7Z,10Z,13Z,16Z,19Z,22Z,25Z,28Z,31Z)-Tetratriaconta-7,10,13,16,19,22,25,28,31-Nonaenoic acid (9)

Mass	490.38
$\delta^1\text{H}$ (500 MHz)	11.18 (1H, m), 5.48 – 5.28 (18H, m), 2.91 – 2.78 (16H, m), 2.41 – 2.32 (2H, m), 2.18 (2H, m), 2.15 – 2.02 (2H, m), 1.67 (2H, dt, J = 15.3, 7.5 Hz), 1.43 (4H, dt, J = 14.8, 7.5 Hz), 0.98 (3H, t, J = 7.5).
$\delta^{13}\text{C}$ (101 MHz)	179.5, 132.0, 129.5, 128.5, 128.3, 128.24, 128.21, 128.1, 128.0, 128.0, 127.8, 127.0, 33.8, 28.9, 26.8, 25.6, 25.5, 24.2, 20.5, 14.2.
$\nu_{\text{max}}/\text{cm}^{-1}$	3444, 3013, 2962, 2930, 2860, 1709, 1658, 1609, 1493, 724.

Table.5 Mass, NMR and IR Analysis of Compound (3Z,6Z,9Z,12Z,15Z,18Z,21Z,24Z,27Z)-Pentatriaconta-3,6,9,12,15,18,21,24,27-Nonaene (10)

Mass	474.42
$\delta^1\text{H}$ (500 MHz)	5.36 (18 H, m), 2.82 (16H, br pent., J 5.28), 2.0 (2H,m), 2.18 (2H, br sextet, J 7.48 Hz), 1.31 (10H, m), 1.08 (3H, t, J 7.56 Hz), 0.90 (3H, t, J 6.56 Hz).
$\delta^{13}\text{C}$ (101 MHz)	132.0, 130.4, 128.5, 128.4, 127.98, 127.9, 127.5, 127.0, 31.8, 29.6, 29.3, 29.2, 27.2, 25.7, 25.6, 25.5, 22.6, 20.5, 14.2, 14.1.
$\nu_{\text{max}}/\text{cm}^{-1}$	2926, 2859, 1750, 1609, 1493, 724.

Fig.1 First Line of the Work

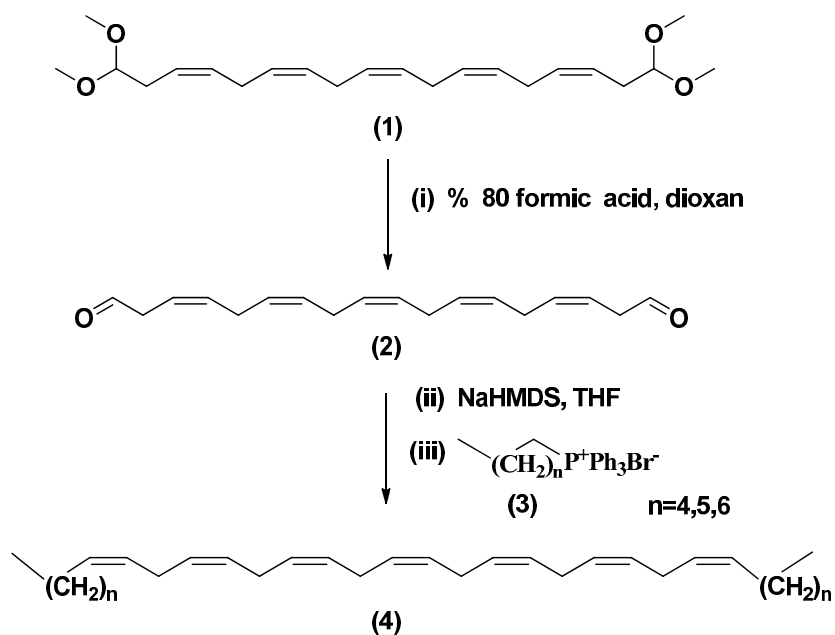


Fig.2 Second Line of the Work

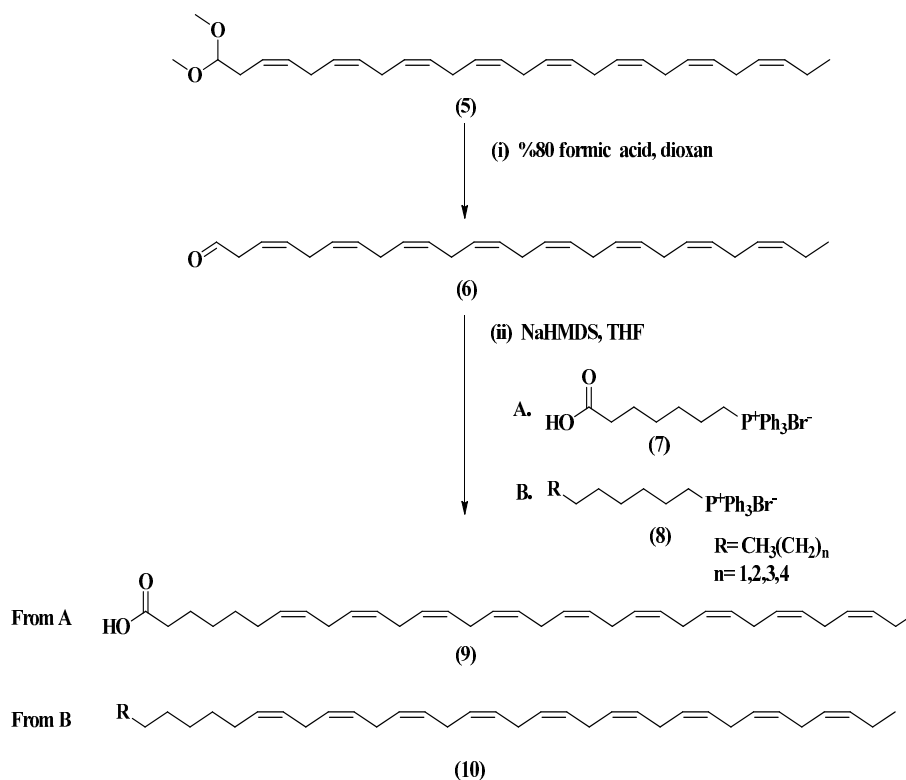


Fig.3 Preparation of (3Z,6Z,9Z,12Z,15Z)-Octadeca-3,6,9,12,15-Pentaenedial (2)

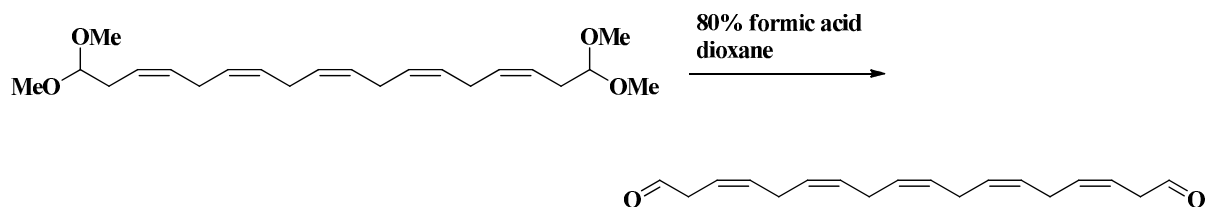


Fig.4 General Scheme of the Wittig Reaction

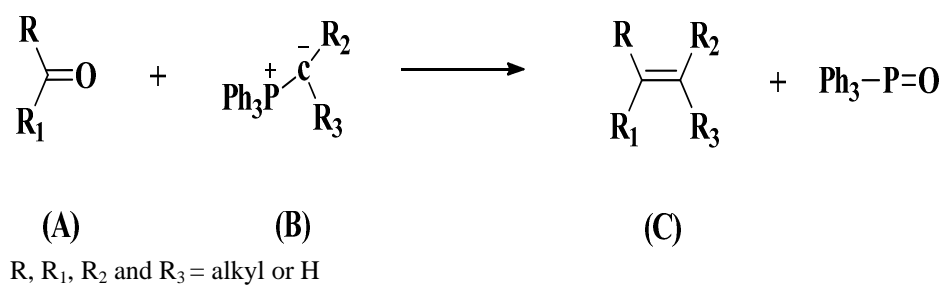


Fig.5 Forming Cis in the Wittig Reaction

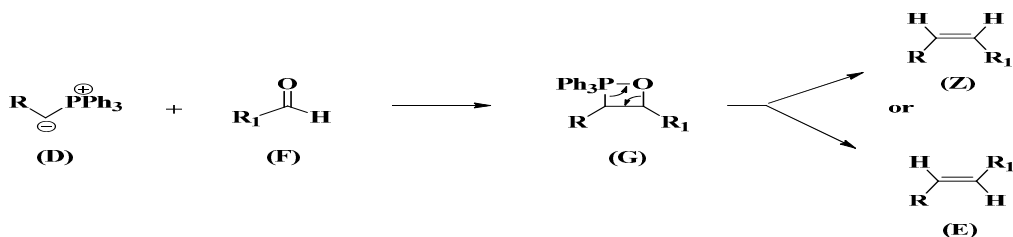


Fig.6 Preparation of (6Z,9Z,12Z,15Z,18Z,21Z,24Z)-Triaconta-6,9,12,15,18,21,24-Heptaene (4)

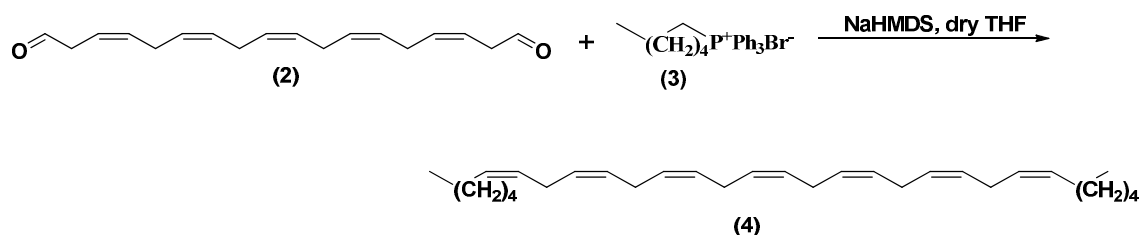


Fig.7 Preparation of (3Z,6Z,9Z,12Z,15Z,18Z,21Z,24Z)-Heptacos-3,6,9,12,15,18,21,24-Octaenal (6)

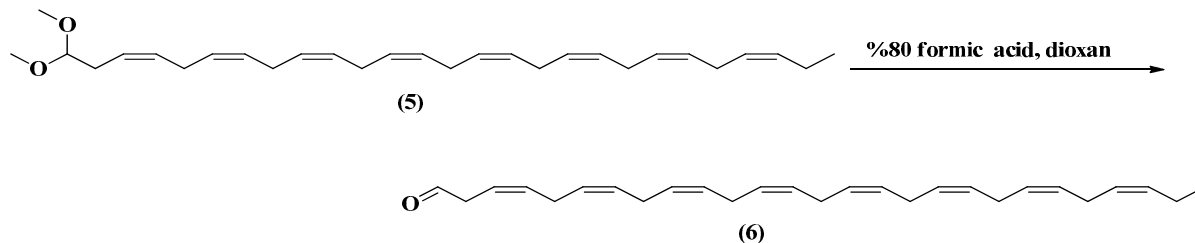
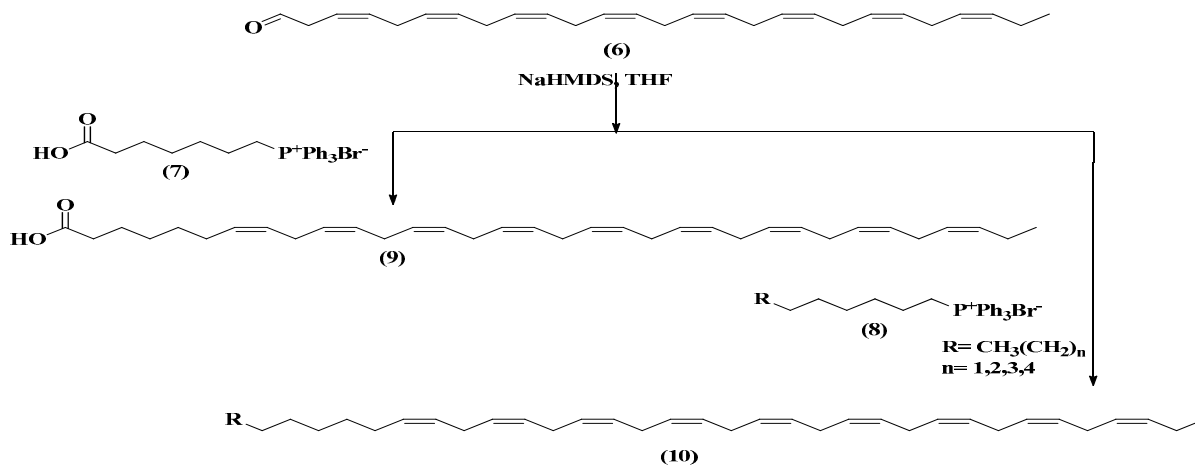
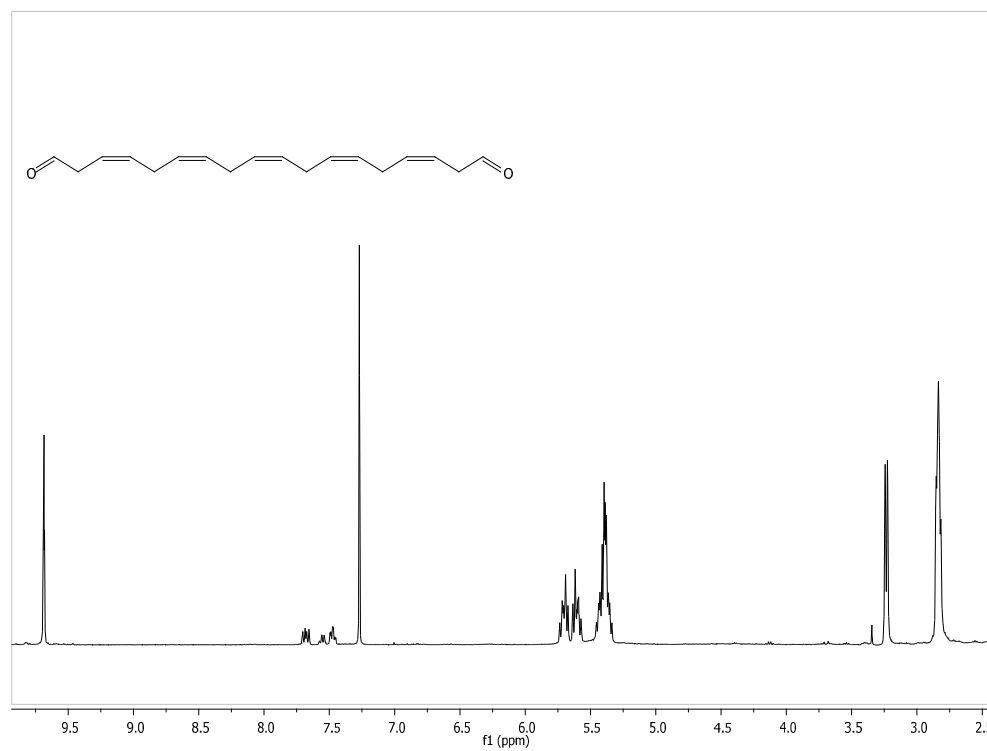
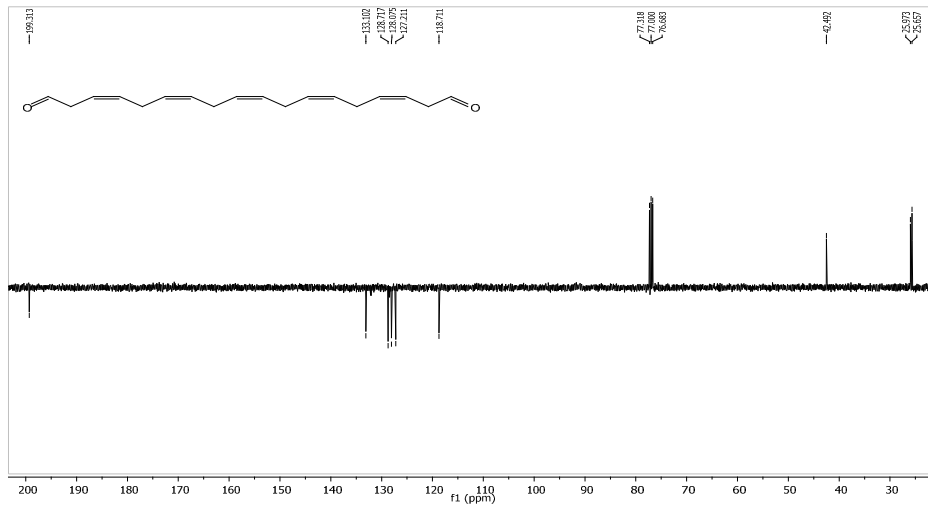
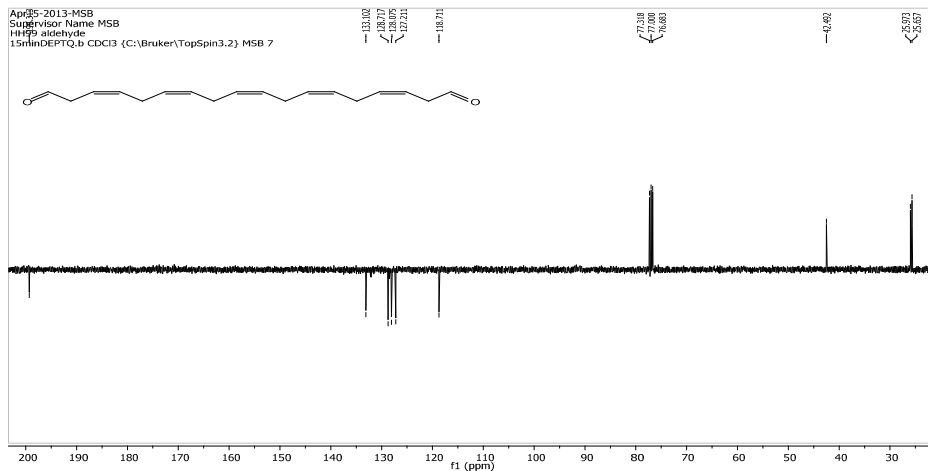


Fig.8.Preparation of Compound 9 and Compound 10

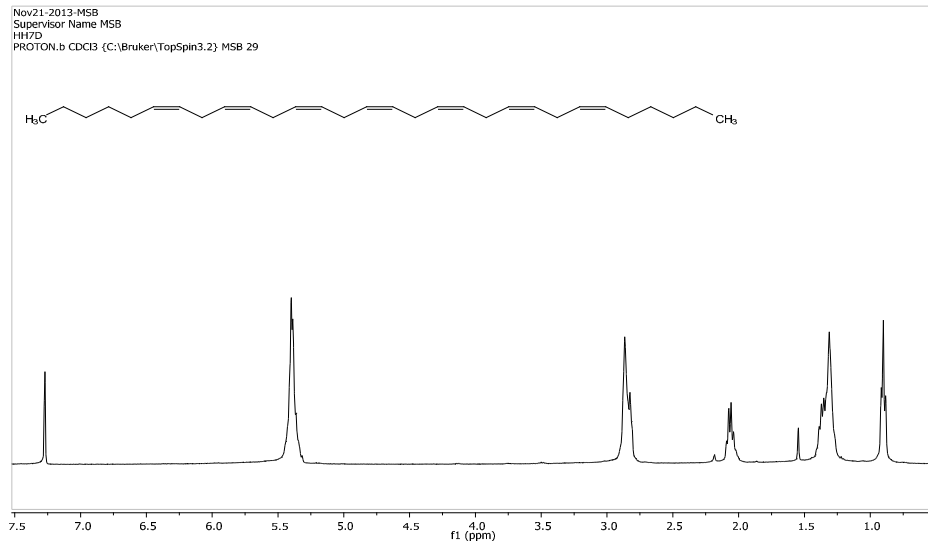


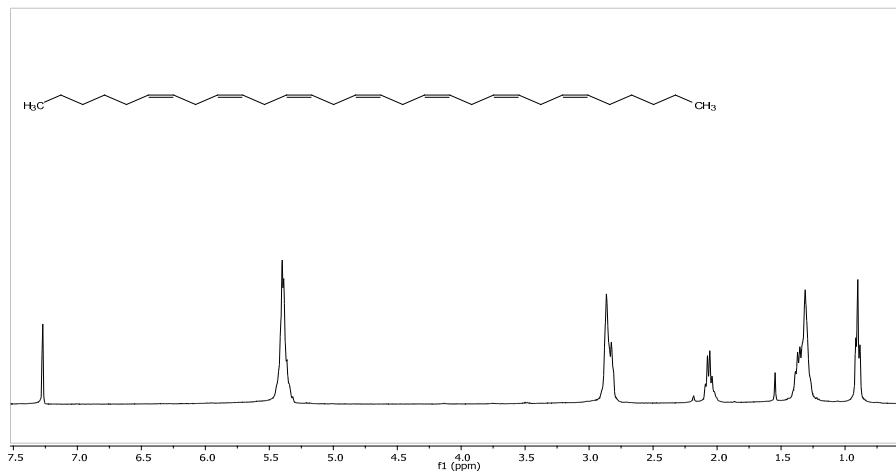


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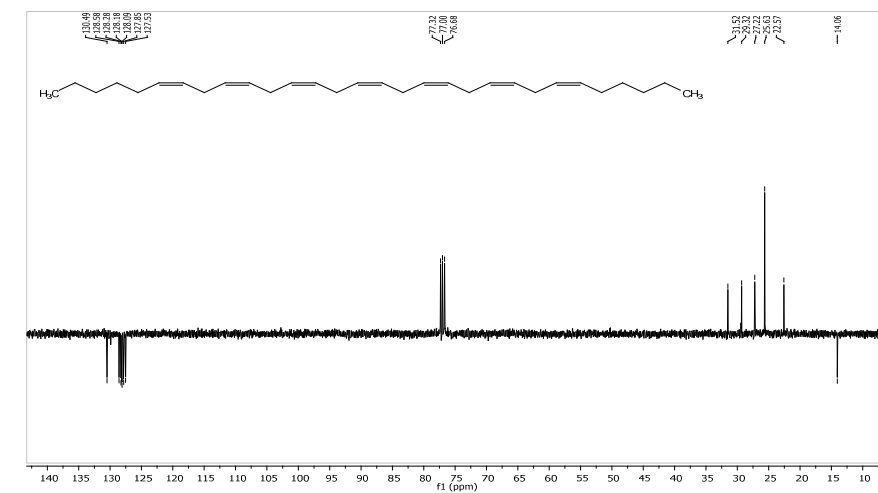
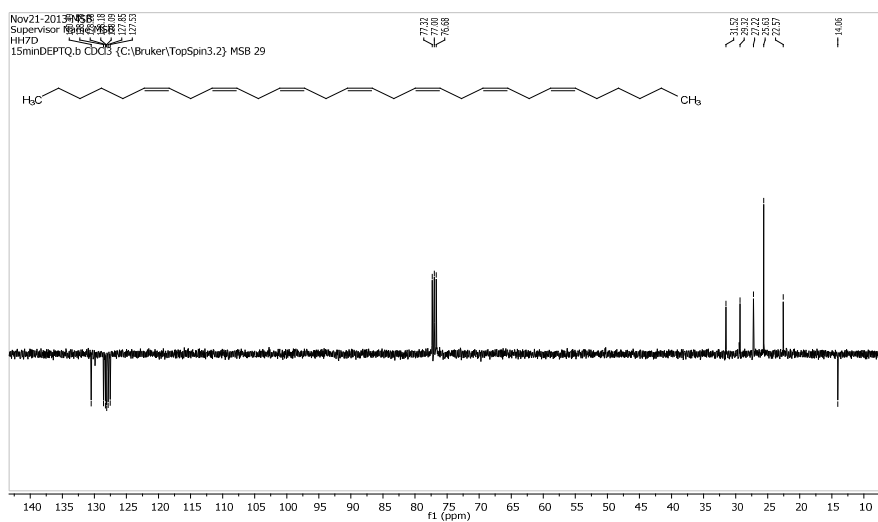


Dept-CNMR of compound (2) CDCl₃

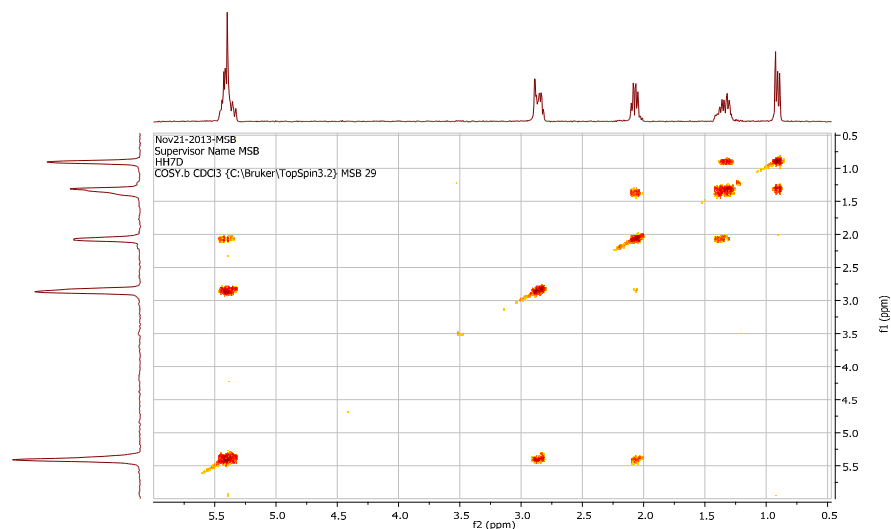




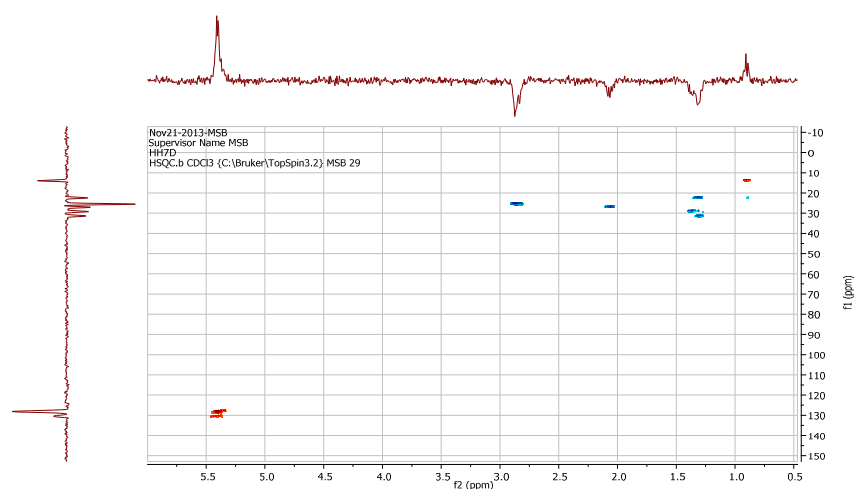
¹H NMR of compound (4) in CDCl₃



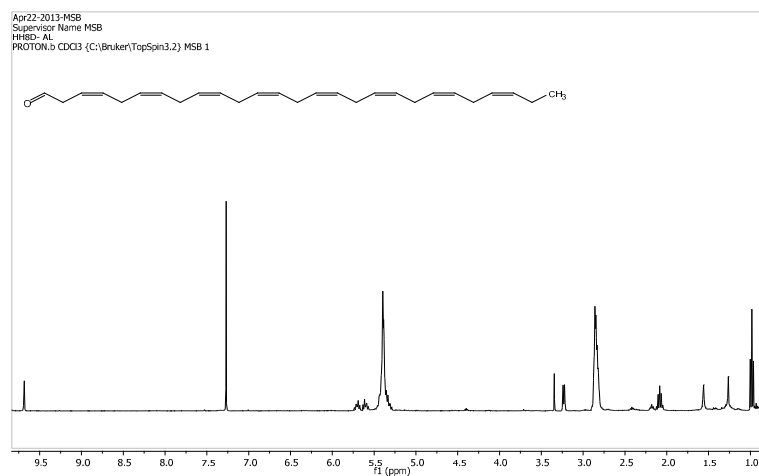
DEPT-135 NMR of compound (4) in CDCl₃

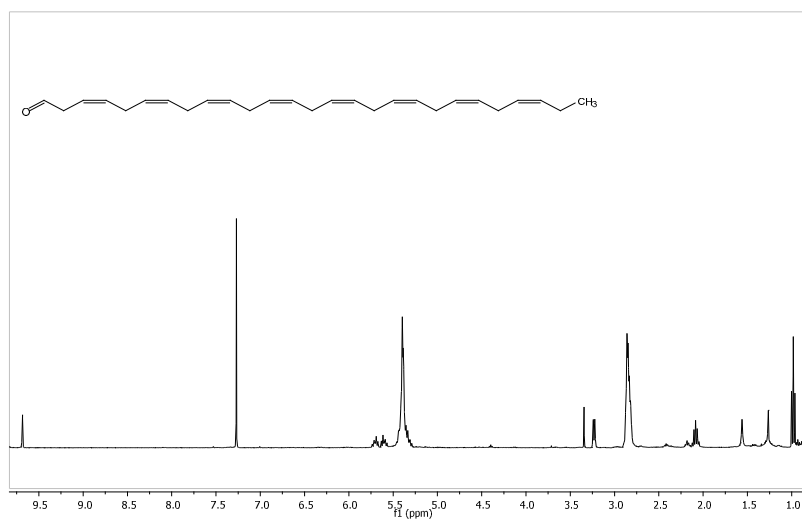


COSY NMR of compound (4) CDCl₃

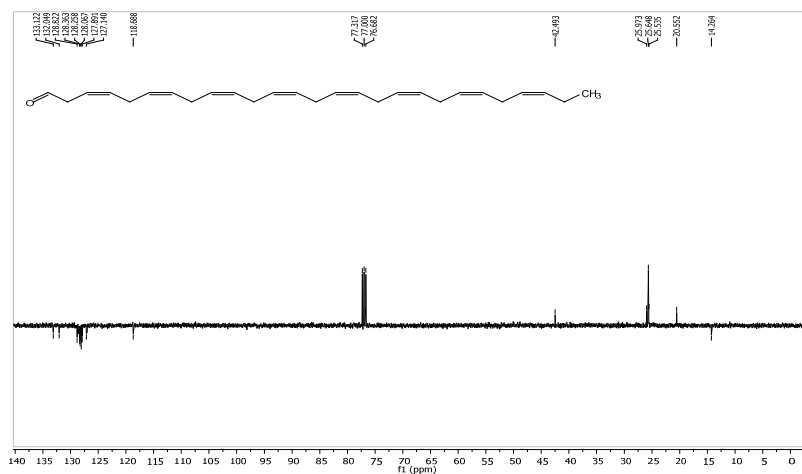
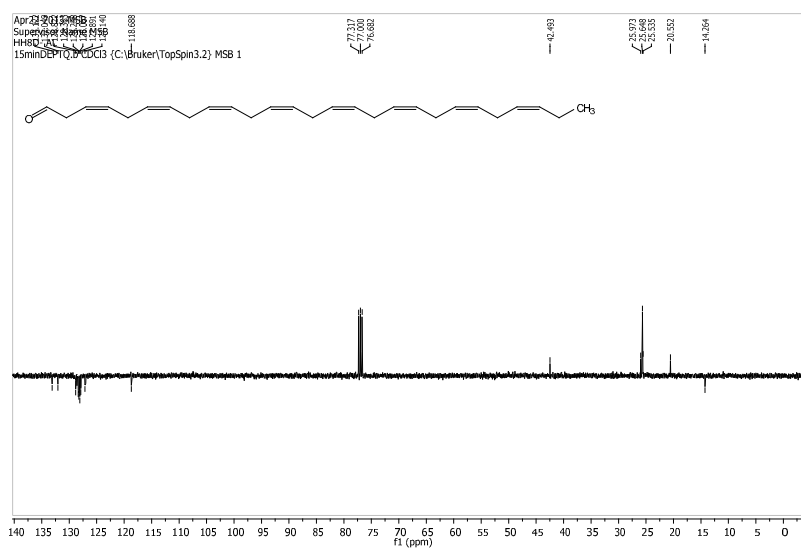


HSQC NMR of compound (4) CDCl₃

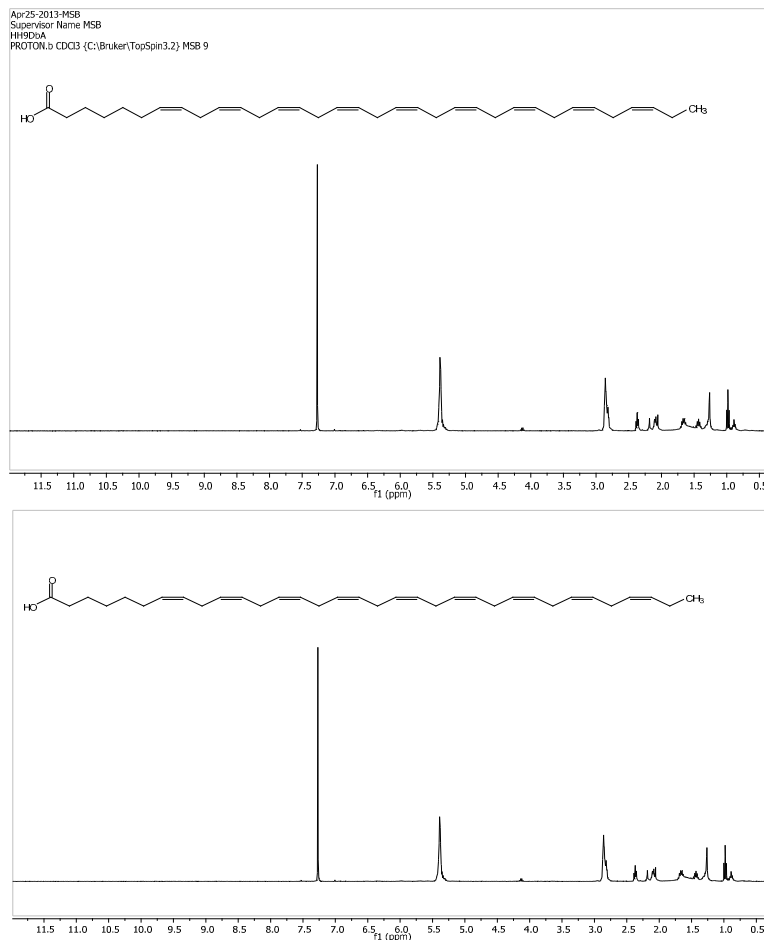




¹H NMR of compound (6) in CDCl₃



DEPT-CNMR of compound (6) CDCl₃



¹H NMR of compound (9) in CDCl₃

The ¹³C NMR spectrum showed the required number of resonances, including the carbonyl carbon signal at δ 179.5, with the alkene carbons resonating between δ 132 and 127 ppm, and with signals occurring at δ 33.8, 28.9, 26.8, 25.6, 25.5, 24.2, 20.5 respectively and finally a signal at 14.2 for the carbons of the terminal methyl groups. The IR spectrum included a broad peak at 3444 cm⁻¹ for the OH stretch and a peak at 1709 cm⁻¹ for the C=O stretch.

However, the Wittig reaction was used to prepare several useful compounds with by extending the eightene motif of (6) by CH₃(CH₂)_n when n= 1,2,3 and 4 carbon atoms respectively, employing Wittig salts of different chain lengths in dry THF at low temperature, in the presence of sodium

bis(trimethylsilyl)amide as a base, to give (10) the structures of which were confirmed by their mass spectra and the NMR spectra, and IR. Similar data approximately had been obtained when the (3Z,6Z,9Z,12Z,15Z,18Z,21Z,24Z,27Z)-pentatriaconta-3,6,9,12,15,18,21,24,27-nonaene (10) was prepared, except the aldehyde signal had disappeared while a new signal appeared corresponding to the second terminal methylene group, With the appearance of new signals belonging to the series methylene groups and some shifting for the signals which close to the function groups as mention in experimental data.

In conclusion, controlled wittig reaction conditions between phosphonium salt and an pentaene aldehydes which formed from

unsaturated acetal and diacetal leads to the formation unsaturated alkenes compounds with Z-double bonds configuration. These products could widely be used in the synthesis of insect pheromones instead of insecticides, fatty acid and may also be as useful intermediate compounds in many chemical reactions.

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