RSC Advances

This article can be cited before page numbers have been issued, to do this please use: G. S. Naidu, R. Singh, M. Kumar and S. K. Ghosh, *RSC Adv.*, 2016, DOI: 10.1039/C6RA01729K.

ROYAL SOCIETY OF CHEMISTRY

www.rsc.org/advances

View Article Online
DOI: 10.1039/C6RA01729K

Synthesis of highly functionalized [3]dendralenes and their Diels-Alder reaction displaying unexpected regioselectivity

Gonna Somu Naidu[a], Rekha Singh[a], Mukesh Kumar[b] and Sunil K. Ghosh*[a]

[a] Bio-Organic Division

[b]Solid State Physics Division

Bhabha Atomic Research Centre, Trombay, Mumbai 400085, India

*Corresponding author

Tel: +91-22-25595012; Fax: +91-22-25505151

E-mail: ghsunil@barc.gov.in

Abstract

Acyclic tetrasubstituted [3]dendralenes stable towards D-A cyclodimerization have been prepared by double olefination of substituted dienyl phosphonates with dimethylsulfonium methylide followed by H-W-E olefination of the formed butadienylphosphonoacetates with aldehydes. X-ray structure of a [3]dendralene with 4-position benzyl substitution reveals that electron rich diene exists in *s-trans* conformation leading to stability. This structural preference of dendralenes leads to an unusual regioselectivity in the D-A reaction wherein deactivated diene participated in the process displaying *endo* selectivity. The steric bulk of the groups at 2 and 4 positions governs the regioselectivity and dominates the electronic effects. For dendralenes possessing 4-methyl substituent, the electronically rich diene participated in D-A reaction. These

View Article Online
DOI: 10.1039/C6RA01729K

D-A adducts failed to undergo further cycloaddition owing to steric crowding which results in *gauche* conformation of the diene as evidenced by X-ray structures of the adducts.

Introduction

Depending upon the type of atom connectivity (unbranched or branched, cyclic or acyclic), four fundamental hydrocarbon families of oligoalkene structures are possible as presented in Fig.1. Dendralenes are the first family of the branched oligoalkenes which feature cross conjugation.[1-6] They did not receive proper attention primarily due to their unpredictable stability and lability for Diels-Alder (D-A) cyclodimerization or oligomerization. Recently they have gained popularity as they display unique properties different from normal oligoenes.[7-16] This created interest in various fields such as polymer chemistry,[7-10] electro chemistry,[11-13] material chemistry[14,15] and theoretical chemistry.[16] For synthetic chemists, dendralenes are fascinating molecules because they own a huge potential that can be harnessed by subjecting them to tandem D-A reactions also known as diene-transmissive D-A (DTDA)[17] sequences for quick generation of complex multicyclic scaffolds from simple acyclic substrates in an atom economical manner. Also several bioactive natural products[18-21] possess dendralenes as core structures.

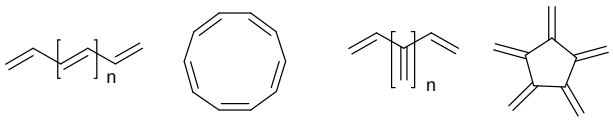


Fig. 1 Fundamental classes of alkenic hydrocarbons

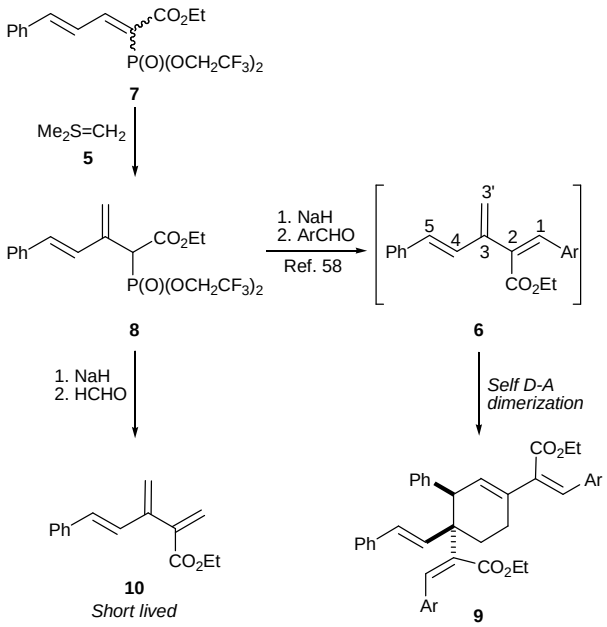
View Article Online
DOI: 10.1039/C6RA01729K

Early synthetic methods of dendralenes comprised of various classical approaches of olefin synthesis *viz.* pyrolysis,[22-24] Mitsunobu dehydration,[25] β-elimination[26] and thermal decomposition of vinyl sulfolenes[27,28] which often involved harsh reaction conditions. Of late many groups have reported the synthesis of dendralenes mediated by various transition metals.[29-47] Majority of these methods lead to unsubstituted or scantly substituted dendralenes. Some of the approaches lead to [3]dendralenes functionalized in cyclic systems.[34-36] Only a handful of methods yield amply substituted acyclic [3]dendralenes such as dimerization of allenes,[37,38] elimination of 1,3-dienic allylic carbonates[39] and enyne metathesis.[40-42]

Earlier we had reported[48] a novel olefination methodology using Corey-Chaykovsky dimethylsulfonium methylide (DMSM) **5**[49] with various activated olefins providing interesting products.[50-57] Later this methodology was augmented for sequential double olefination of vinyl phosphonates to provide substituted 1,3-dienes with high regio- and stereo-selectivity.[51,52] Subsequently, we employed this methodology for the intended synthesis of 1,5-diaryl-2-alkoxycarbonyl [3]dendralenes **6** from dienyl phosphonates **7** via 1,3-butadien-2-ylphosphonoacetate intermediate **8** as depicted in Scheme 1.[58] Unfortunately the desired [3]dendralenes could not be isolated owing to their high reactivity. Under the reaction conditions, these functionalized [3]dendralenes underwent an *in situ* D-A cyclodimerization to provide highly functionalized cyclohexenes **9** with excellent regio- and stereo-control. Since then, we were in the process of optimizing[59] the substituents on the [3]dendralene skeleton which would enhance their stability thus granting them at our disposal for isolation, characterization and reactivity studies especially for D-A reaction. Herein we report the aforementioned sequential double olefination process on appropriately substituted dienyl phosphonates for the synthesis of highly functionalized [3]dendralenes that are stable against D-A cyclodimerization

View Article Online
DOI: 10.1039/C6RA01729K

under ambient conditions and their D-A reaction with *N*-methylmaleimide (NMM) as a representative dienophile.



Scheme 1 Synthesis of [3]dendralenes

Results and Discussion

Lately, Sherburn and coworkers have reported the studies pertaining to the stability and reactivity of various thinly substituted dendralenes.[60,61] Their findings reveal that odd dendralenes are more reactive in comparison to their even counterparts. The observation has also been corroborated by DFT calculations which suggest that odd dendralenes prefer D-A reactive *s-cis* conformation whereas even dendralenes predominantly remain in D-A unreactive *s-trans* conformation. The study also divulges that the conjugating terminal substituents (at C_1 or C_5) accelerate the rate of D-A cyclodimerisation of [3]dendralenes contrary to the substituents at C_2, C_3 and C_4 which have little effect on the dimerisation reactivity.[60]

View Article Online
DOI: 10.1039/C6RA01729K

In cognizance with the above facts to accomplish our goal of synthesizing functionalized and stable [3]dendralenes, we decided to exclude one of the terminal substituent on our earlier reported[58] [3]dendralenes **6** to obtain 2,5-disubstituted [3]dendralenes. The corresponding [3]dendralene **10** was synthesized from dienic phosphonate **7** via 1,3-butadien-2-ylphosphonoacetate **8** intermediate and formaldehyde was used as the aldehyde component (Scheme 1). Interestingly, the [3]dendralene **10**, although short lived, could be isolated and characterized by ^{1}H NMR. This exemplified the dramatic effect of substituent on the reactivity and stability of the [3]dendralenes akin to Sherburn's observation.

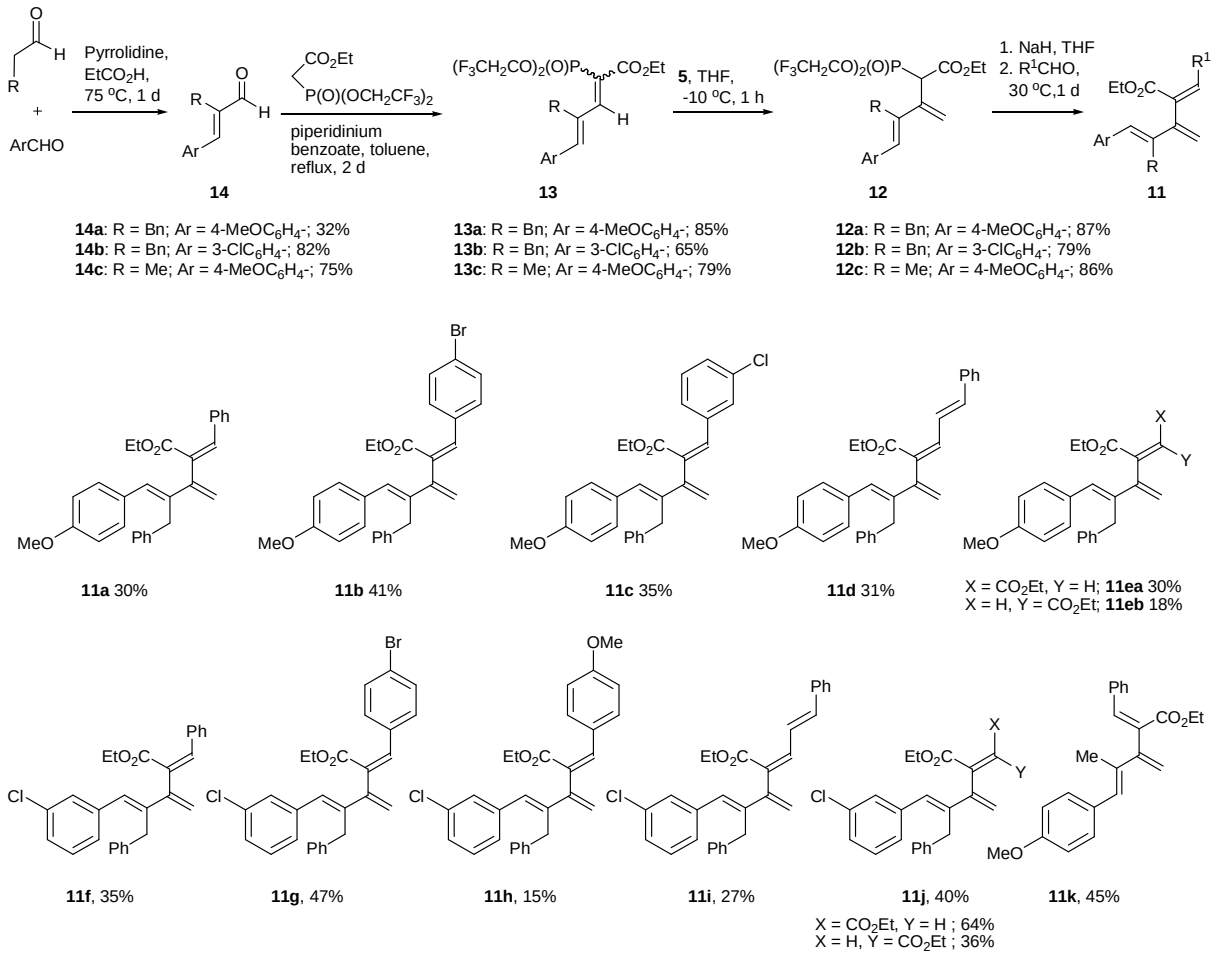
For further enhancement of the stability of [3]dendralenes, we decided to add a substituent at 4-postion of our earlier reported[58] [3]dendralenes **6** which would bestow 1,2,4,5-tetrasubstituted [3]dendralenes **11**. At the outset, we decided to introduce a benzyl substituent at 4-position of the reported [3]dendralenes **6**. For this, *p*-anisaldehyde was reacted with 3-phenylpropanal in the presence of catalytic amount of pyrrolidine and propionic acid[62] which provided α,β unsaturated aldehyde **14a** (Scheme 2). Piperidinium benzoate catalysed Knoevenagel condensation of **14a** with ethyl bis-(2,2,2-trifluroethyl)-phosphonoacetate furnished the desired dienyl phosphonate **13a** as an inseparable 1/1 mixture of two geometrical isomers of the double bond attached to phosphonate group as judged from ^{1}H NMR. When this phosphonate **13a** was reacted with DMSM **5** generated using Me_3SI and *n*-BuLi in THF, the desired olefination took place to give the appropriately substituted butadien-2-ylphosphonoacetate **12a**. The phosphonoacetate **12a** was then reacted with sodium hydride followed by benzaldehyde in THF which provided the 1,2,4,5-tetrasubstituted [3]dendralene **11a**. We were gratified to note that the dendralene **11a** was stable towards D-A cyclodimerization at ambient temperature. Subsequently, the butadien-2-ylphosphonoacetate **12a** was reacted with a

View Article Online
DOI: 10.1039/C6RA01729K

few more aldehydes under standard HWE conditions to give the desired 1,2,4,5-tetrasubstituted [3]dendralenes (**11b-e**) (Scheme 2) with one of the terminal aryl group (5 position) having an electron donating substituent (4-OMe) in moderate yields but with high stereoselectivity except for the product **11e** where ethyl glyoxalate was used as the aldehyde component. The dendralene **11e** was obtained as a separable mixture of *Z* and *E* diastereoisomers (**11ea**:**11eb**, 60:40) for the double bond generated due to H-W-E reaction.

To examine the electronic effect of substitution on terminal aryl rings on the reactivity of 1,2,4,5-tetrasubstituted [3]dendralenes, we decided to have mildly electron withdrawing 3-chloro substituent at the 5-position aryl ring. To achieve this, 2-benzyl-3-(3-chlorophenyl) prop-2-enal **14b** was converted to dienic phosphonate **13b** as an inseparable 6:4 mixture of two diastereoisomers and then to butadien-2-ylphosphonoacetate **12b** as shown in Scheme 2. This phosphonoacetate **12b** upon reaction with different aldehydes provided another series of 1,2,4,5-tetrasubstituted [3]dendralenes (**11f-j**) in moderate yields with very high selectivity except for **11j** which was produced as an inseparable mixture of *Z/E* diastereoisomers (double bond substituted with ester groups) in a ratio of 64/36. All these product dendralenes are stable towards D-A cyclodimerization at ambient temperature.

View Article Online
DOI: 10.1039/C6RA01729K



Scheme 2 Synthesis of densely substituted isolable [3]dendralenes

Our next goal was to change the 4-position substituent to a sterically less demanding substituent like a methyl group instead of benzyl. To achieve this, prop-2-enal **14c** was converted to 4-methyl substituted [3]dendralene **11k** via butadien-2-ylphosphonoacetate **12c** as depicted in Scheme 2. Like previous cases, phosphonate **13c** was also formed as an inseparable 1/1 mixture of diastereoisomers and the product dendralene **11k** was also stable at room temperature.

The structure of the dendralene **11a** was confirmed by single crystal X-ray crystallography (Fig. 2) which also revealed its interesting conformational preferences in the solid state. The dienic part encompassing double bonds at 1 and 3 positions are in quasi *s-cis*

View Article Online
DOI: 10.1039/C6RA01729K

conformation while the diene component covering double bonds at 3 and 4 positions are in *s-trans* conformation. DFT calculations[60] have shown that in unsubstituted [3]dendralenes, one dienic component exists predominantly as *s-cis* conformation and the other dienic unit as *s-trans* conformation. The present X-ray crystal structure of dendralene **11a** confirms it for the first time.

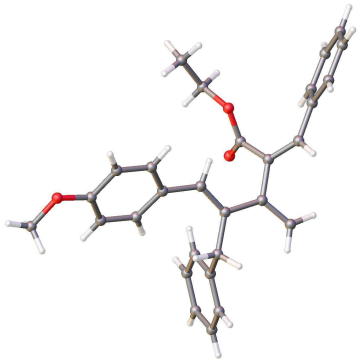


Fig. 2 X-Ray structure of **11a**

As mentioned earlier the conjugating terminal substituents (at C_1 or C_5) are known to have a marked accelerating influence on the cyclodimerisation rate of [3]dendralenes whereas the substituents at C_2, C_3 and C_4 have little effect on the dimerization reactivity.[60,61] In our earlier attempted [3]dendralenes **6** (Scheme 1),[58,59] there were two conjugating terminal substituents at C_1 and C_5 and one substituent at C_2 position. None of those dendralenes could be isolated because they were unstable and underwent D-A cyclodimerisation. In the present study, the [3]dendralene **10** had one conjugating terminal substituent (C_5) and one substituent at C_2 position which was short lived, but could be isolated and ^{1}H NMR spectrum could be recorded as a signature of its formation. Interestingly, [3]dendralenes **11a-11l** having two conjugating terminal substituents at C_1 and C_5 have been stabilized by the two substituents at C_2 and C_4 positions. Thus it can be inferred that the substituents at C_2, C_4 have a substantial influence on rendering the stability to [3]dendralenes (Fig. 3).

View Article Online
DOI: 10.1039/C6RA01729K

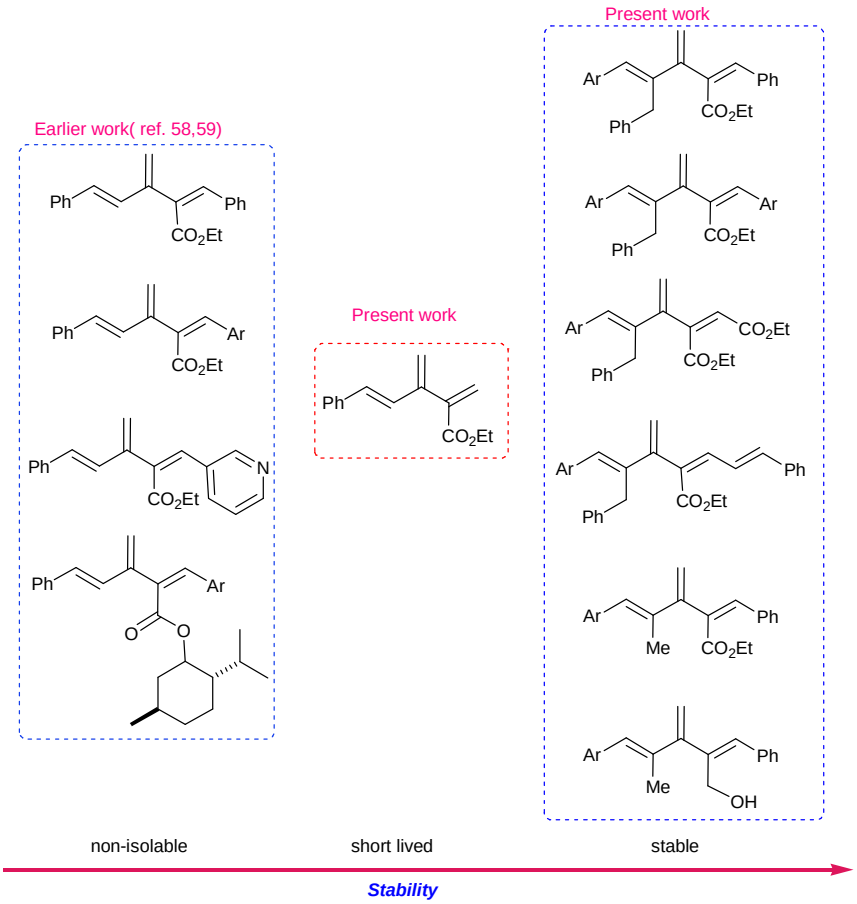
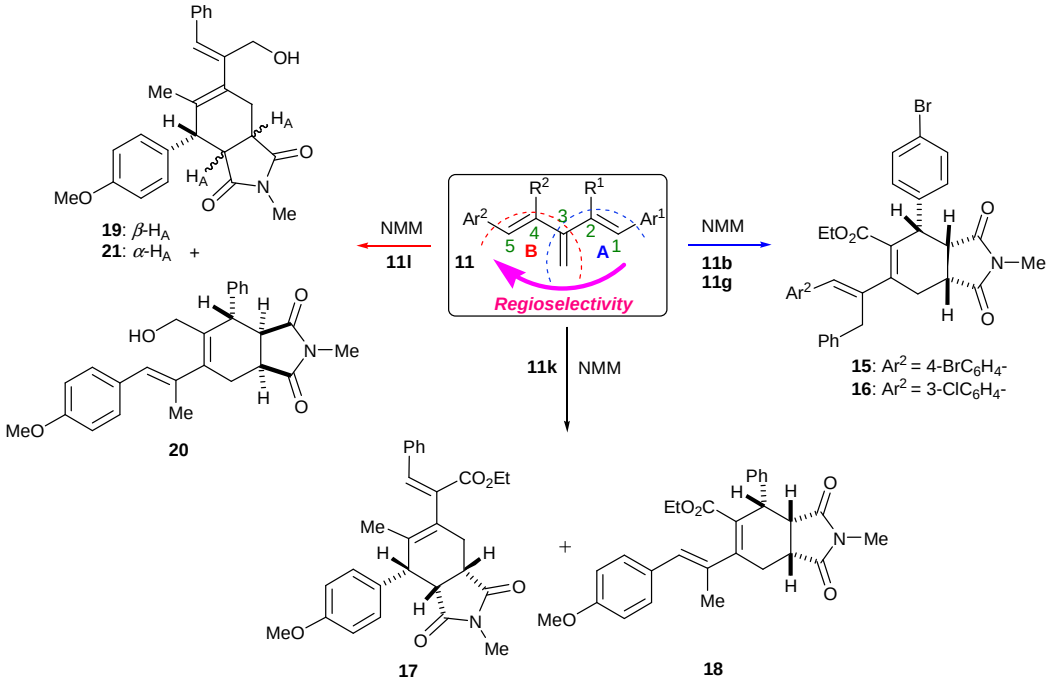


Fig. 3 Stability of substituted [3]dendralenes

After accomplishing our goal of obtaining 1,2,4,5-tetrasubstituted [3]dendralenes **11a-k** which are stable towards D-A cyclodimerization, we next aimed to examine their reactivity for intermolecular D-A reaction with NMM as dienophile. When 1,5-diaryl-2-ethoxycarbonyl-4-benzyl [3]dendralene **11b** was reacted with 1.0 molar equivalent of NMM in refluxing benzene, it furnished a mixture of stereoisomeric D-A adducts out of which the major stereoisomer **15** (69%) was easily separated from the mixture where as the minor isomers could not be identified (Scheme 3). This major isomer **15** was found to be *endo*-isomer as confirmed by X-ray crystallography (Fig. 4). It is noticeable that the D-A reaction had taken place at the diene 'A' incorporating double bonds at 1,3 positions thus indicating that these two double bonds exist in

View Article Online
DOI: 10.1039/C6RA01729K

s-cis conformation in solution also as was observed in solid state by the X-ray structure (Fig. 2). It is noteworthy that the electronically rich diene'B' encompassing double bonds at 3,4 positions is unable to participate in the D-A reaction owing to *s-trans* conformation that was preferred due to steric bulk of the benzyl group which results in high barrier of *s-trans* ⇆ *s-cis* interconversion. This allowed the electronically deactivated diene to participate in the D-A reaction.



Dendralene	Ar^1	R^1	R^2	Ar^2	Product from Diene A	Product from Diene B
11b	4-BrC_6H_4-	CO_2Et	Bn	4-$MeOC_6H_4$-	**15** (69%)	-
11g	4-BrC_6H_4-	CO_2Et	Bn	3-ClC_6H_4-	**16** (62%)	-
11k	Ph	CO_2Et	Me	4-$MeOC_6H_4$-	**18** (41%)	**17** (48%)
11l	Ph	CH_2OH	Me	4-$MeOC_6H_4$-	**20** (10%)	**19** (65%) *endo* **21** (4%) *exo*

Scheme 3 Diels–Alder reaction of [3]dendralenes

View Article Online
DOI: 10.1039/C6RA01729K

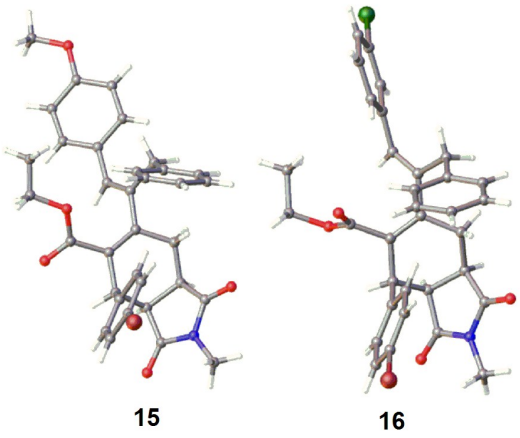


Fig.4 X-Ray structures of **15, 16**

In order to examine if any stereoelectronic effect is operating from the conjugating aryl substituents at 1 or 5 positions on the D-A reaction, [3]dendralene **11g** was reacted with 1.0 molar equivalent of NMM in refluxing toluene which furnished a mixture of D-A adducts. From the mixture of products, the major diastereoisomer **16** was obtained in 62% yield (Scheme 3) as *endo*-isomer which was confirmed by single crystal X-ray crystallography (Fig. 4). The minor isomers could not be identified. Once again the DA reaction took place at the diene'A' incorporating double bonds at 1,3 positions thus indicating that these two double bonds exist in *s-cis* conformation in solution state which is sterically less demanding. The electronic effect of substituent at 5-position aryl group did not play any role because the diene'B' incorporating double bonds at 3,4 positions comprising this substituent probably preferred *s-trans* conformation.

To quell the steric effect, 4-methyl substituted [3]dendralene **11k** was reacted with NMM which resulted in formation of regioisomeric adducts **17** and **18** (Scheme 3) in a ratio of 54:46, respectively. This suggests that now the steric hinderence was moderated thus both the dienes 'A' and 'B' have very similar preference for *s-cis* conformation and could participate in the D-A

View Article Online
DOI: 10.1039/C6RA01729K

reaction. The D-A adducts **17** and **18** could not be separated. Thus, their structural analysis was performed on a 54:46 mixture of the two regioisomers, where most of the signals were clearly distinguishable. The stereochemistry and regiochemistry of the products **17** and **18** was ascertained on the basis of COSY and ROESY interactions from the inseparable mixture (for detail interpretations, see the SI). For isomer **17**, a strong ROESY interactions between protons at δ 3.85 (ArC*H*) ↔ δ 7.08 (*ortho* H of Ar), and between δ 6.77 (PhC*H*) ↔ δ 7.40-7.31 (*ortho* H of Ph) (Fig. 5) indicate that diene component comprise of double bonds at 3,4 positions participated in the D-A reaction. The ROESY interaction between protons at δ 3.85 (ArC*H*) and δ 3.17-3.13 (NCOC*H*CH_2) further supports for the *endo* addition of NMM (Fig. 5). For isomer **18**, strong ROESY interactions between protons at δ 4.56 (PhC*H*) ↔ δ 7.09 (*ortho* H of Ph) and between δ 6.27 (ArC*H*) ↔ δ 7.30-7.18 (*ortho* H of Ar) indicate that diene component comprising of double bonds at 1,3 positions participated in D-A reaction and interaction between protons at δ 4.56 (PhC*H*) ↔ δ 3.23-3.19 (NCOC*H*CH_2) suggests the *endo* nature of the product (Fig. 5).

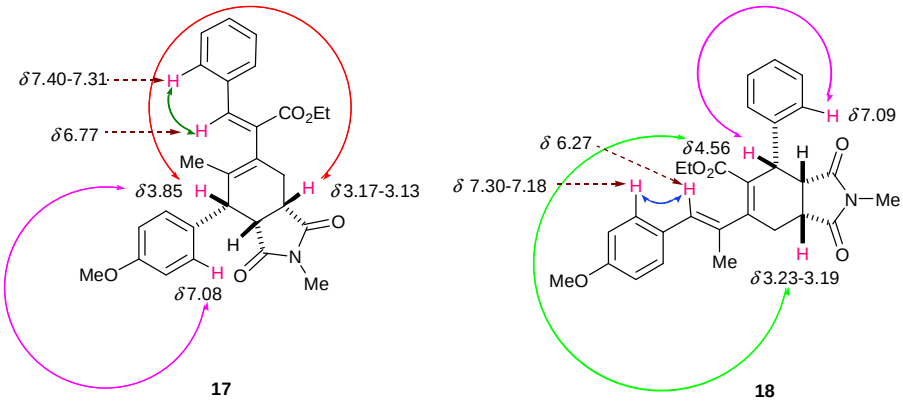
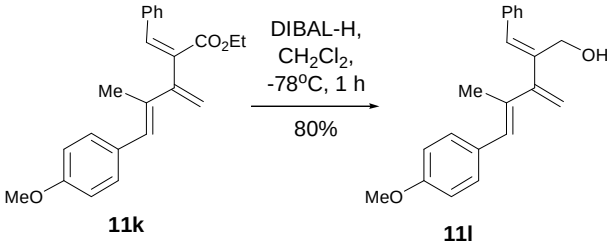


Fig. 5 ROESY interactions of **17** and **18**

Despite our repeated efforts, these Diels-Alder adducts **15**, **16** and the mixture of **17** and **18** did not undergo further D-A reaction with several dienophiles. This failure could be chiefly attributed to the stereoelectronic effects of substituents to adopt an *s-cis* conformation of the

View Article Online
DOI: 10.1039/C6RA01729K

dienic system in the D-A adducts which is a prerequisite for D-A reaction. The X-ray crystal structures of **15** and **16** also supported this fact where it is clearly seen that the diene component is in a *gauche* conformation. To address the electronic effect, the ester functionality in the dendralene **11k** was reduced using DIBAL-H to obtain a new alcoholic [3]dendralene **11l** (Scheme 4).



11k **11l**

Scheme 4 Preparation of [3]dendralene **11l**

When **11l** was reacted with 1.0 molar equivalent of NMM in refluxing toluene, it furnished a mixture of three isomers **19**, **20** and **21** in a ratio of 80:14:6 (Scheme 3) respectively from which all the individual isomers are separated by chromatography. The structure of **19** was established by single crystal X-ray crystallography (Fig. 6). The structure of **21** was assigned by studying the ^{1}H NMR of **19** and **21**. Both the spectra showed similarity except that ArC*H* in **21** was a singlet thus suggesting *trans* relationship of the two protons *viz*. ArC*H* and ArCHC*H*. The structure of **20** was ascertained on the basis of COSY and ROESY interactions. The positive ROESY interactions between protons at δ 4.47 (PhC*H*) ↔ δ 7.36 (*ortho* H of Ph), between δ 6.48 (ArC*H*) ↔ δ 7.28 (*ortho* H of Ar), between δ 4.47 (PhC*H*) ↔ 4.37(HOCH_AH$_B$), and between δ 4.47 (PhC*H*) ↔ δ 3.79 (HOCH$_A$$H_B$) are indicative of the depicted regiochemistry whereas the absence of ROESY interaction between protons at δ 4.47 (PhC*H*) ↔ δ 2.53-2.45 (NCOC*H*CH$_2$) suggests *exo* nature of the product (Fig. 7). The main difference between

View Article Online
DOI: 10.1039/C6RA01729K

structures **18** (Fig. 5) and **20** (Fig. 7) is the stereochemistry at the ring junction. In case of compound **18**, we could get a positive ROESY peak due to *cis* disposition of protons at the ring junction and benzylic proton. Therefore in case of compound **20**, on the basis of analogy from the absence of ROESY peak between protons at δ 4.47 (PhC*H*) $\leftrightarrow$ δ 2.53-2.45 (NCOC*H*CH_2) we concluded that the protons at ring junction are *trans* with respect to the benzylic proton. This apparently *exo* product **20** probably is not due to *exo*-mode D-A reaction but due to small amount of double bond isomerisation during heating which then underwent *endo*-selective D-A with NMM. No *endo*-isomer with this regioselectivity was found in the reaction mixture which suggests that the diene 'A' (Scheme 3) with depicted stereochemistry preferred for *s-trans* conformation. Thus the stereoselectivity i.e. *endo:exo* ratio (**19**:**21**) was 93:7, whereas the regioselectivity (**19**,**21**:**20**) was 86:14. It is interesting to note that diene 'B' (Scheme 3) encompassing double bonds at 3, 4 positions predominantly participated in the D-A reaction unlike in dendralenes **11k**, **11b** and **11g**. Hence there was a switch over of regioselectivity from diene 'A' to diene 'B' (Scheme 3) as the substituents on the [3]dendralenes were changed.

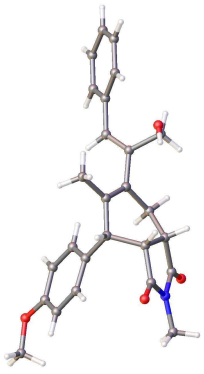


Fig. 6 X-Ray structure of **19**

View Article Online
DOI: 10.1039/C6RA01729K

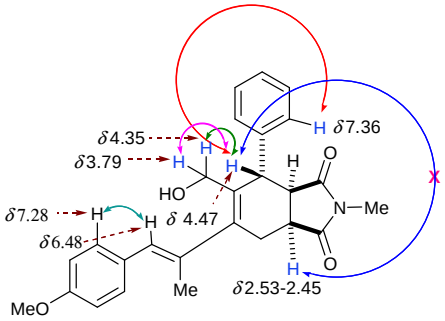


Fig. 7 ROESY interactions of **20**

Conclusions

In conclusion we have achieved our goal of the synthesis of stable and highly functionalized [3]dendralenes. The present work is a systematic study encompassing synthesis of 1,2,4,5-tetrasubstituted [3]dendralenes in acyclic systems and study of their reactivity pattern. It is evident that substituents at 2 and 4 positions of [3]dendralenes drastically diminish its reactivity for self D-A dimerisation reactions irrespective of their electronic nature (electron donating or withdrawing) hence imparting stability. This is due to D-A unfavoured *s-trans* conformation of the dienic components caused by the substituent at these positions. From the D-A reaction studies, it became apparent that steric effect outweighs electronic activation or deactivation. Sterically hindered 4-benzyl substituted [3]dendralene switched the regioselectivity of the D-A reaction with NMM in favour of electronically deactivated diene component with ethoxycarbonyl substitution at 2-position. In case of 4-methyl substiuted [3]dendralene, the electronically rich diene component participated in D-A with NMM. The D-A reactions are highly *endo* selective. We were unable to engage the first D-A adduct for DTDA sequence with reactive dienophiles. This could be attributed to the steric effect of the dense functionalities which prevent the diene to adopt *s-cis* conformation which is a prerequisite for its success. Nonetheless these D-A adducts could be promising candidates for biological studies as many of

View Article Online
DOI: 10.1039/C6RA01729K

the isoindole derivatives display myriad of biological properties *viz.* antimicrobial, antiviral, analgesic, antiinflamatory and antitumor activities.[63]

Experimental section:

General Information

All reactions were performed in oven-dried (120 °C) or flame-dried glass apparatus under dry N_2 or argon atmosphere. Tetrahydrofuran (THF) was dried by distillation from sodium/benzophenone ketyl. *n*-BuLi (1.6 M in hexane) was purchased from Aldrich. All the aldehydes were purchased from Aldrich and were freshly distilled prior to use. TLC was carried out using Merck silica gel 60 F_{254} plates. Column chromatography was performed on silica gel (230–400 mesh). ^{1}H NMR spectra were recorded on 200, 300, 500, 600 MHz, ^{13}C NMR spectra were recorded with 50, 75, 125, 150 MHz and ^{31}P NMR spectra were recorded on 121.5 MHz spectrometer using $CDCl_3$, C_6D_6, CD_3COCD_3 as the solvents. The spectra were referenced to residual chloroform (δ 7.25 ppm, ^{1}H; 77.00 ppm, ^{13}C), partially deuterated acetone (δ 2.05 ppm, ^{1}H; 29.9, 206.7 ppm, ^{13}C), partially deuterated benzene (δ 7.16 ppm, ^{1}H; 128.4 ppm, ^{13}C) and H_3PO_4 as external reference (δ 0.00 ppm, ^{31}P). IR spectra were carried out on the FT-IR-spectrometer using NaCl discs, and wave numbers were given in cm^{-1}. Melting points (m.p) were uncorrected. A high-resolution mass spectrum was obtained using a high-resolution ESI-TOF mass spectrometer.

General procedure for aldehydes 14a-c: A solution of 3-phenylpropanal (3.2 mL, 24.3 mmol, 1 equiv), 4-methoxybenzaldehyde (29.5 mL, 243 mmol, 10 equiv), pyrrolidine (0.6 mL, 7.3 mmol, 0.3 equiv) and propionic acid (0.55 mL, 7.3 mmol, 0.3 equiv) were heated at 75 ºC for 24 h under argon atmosphere. Excess 4-methoxybenzaldehyde was distilled out and the residue was

View Article Online
DOI: 10.1039/C6RA01729K

purified by column chromatography (petroleum ether-EtOAc; 95:5) to provide the aldehyde **14a** (1.96 g, 32%) as orange coloured viscous liquid. The same procedure was followed for the preparation of compounds **14b,c**.

(E)-2-Benzyl-3-(4-methoxyphenyl)acrylaldehyde (14a)[64]*:* R_f (hexane-EtOAc, 90:10) = 0.35; IR v_{max}: 3058, 3028, 3002, 2954, 2931, 2908, 2836, 2715, 2566, 1683, 1667, 1624, 1592, 1508, 1495, 1453, 1305, 1252, 1210, 1175, 1148, 1032, 956, 887, 828, 736, 700 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$): δ 9.66 (s, 1 H, CHO), 7.46 (d, J = 9.0 Hz, 2 H, Ar), 7.44 (s, 1 H, ArC*H*), 7.27-7.19 (m, 5 H, Ph), 6.90 (d, J = 8.8 Hz, 2 H, Ar), 3.97 (s, 2 H, PhCH_2), 3.82 (s, 3 H, OCH_3); ^{13}C NMR (50 MHz, $CDCl_3$): δ 194.9, 161.0, 151.5, 138.2, 137.9, 131.8, 128.4, 127.7, 126.9, 126.0, 114.2, 55.1, 30.1.

(E)-2-Benzyl-3-(3-chlrophenyl)acrylaldehyde (14b)[64]*:* Following the general procedure, isolated yield (1.36 g, 82%) as yellow coloured viscous liquid; R_f (hexane-EtOAc, 90:10) = 0.4; IR v_{max}: 3083, 3061, 3027, 2927, 2826, 2717, 1682, 1627, 1599, 1561, 1494, 1474, 1453, 1394, 1206, 1142, 1077, 956, 890, 784, 737, 697 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$): δ 9.68 (s, 1 H, CHO), 7.45-7.11 (m, 10 H, Ar, Ph, C=CH), 3.90 (s, 2 H, PhCH_2); ^{13}C NMR (50 MHz, $CDCl_3$): δ 194.7, 149.4, 141.7, 138.0, 136.1, 134.7, 130.0, 129.7, 129.5, 128.6, 127.9, 127.5, 126.3, 30.3.

(E)-3-(4-Methoxyphenyl)-2-methylacrylaldehyde (14c)[65]*:* Following the general procedure, isolated yield (5.2 g, 75%) as yellow coloured viscous liquid; R_f (hexane-EtOAc, 80:20) = 0.48; IR v_{max}: 3007, 2961, 2935, 2837, 2716, 1682, 1622, 1598, 1571, 1514, 1443, 1407, 1321, 1304, 1258, 1177, 1116, 1034, 1014, 763, 571, 562, 538 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 9.54 (s, 1 H, CHO), 7.53 (d, J = 8.4 Hz, 2 H, Ar), 7.19 (s, 1 H, ArC*H*), 6.97 (d, J = 8.4 Hz, 2 H, Ar), 3.86

View Article Online
DOI: 10.1039/C6RA01729K

(s, 3 H, OCH_3), 2.08 (s, 3 H, C=CCH_3); ^{13}C NMR (150 MHz, $CDCl_3$): δ 195.3, 160.6, 149.7, 136.0, 131.9, 127.8, 114.1, 55.2, 10.7.

General procedure for phosphonates 13a-c: A solution of aldehyde **14a** (2.4 g, 9.5 mmol, 1 equiv), ethyl bis-(2,2,2-trifluroethyl)-phosphonoacetate (3.6 g, 9.5 mmol, 1 equiv) and piperdinium benzoate (394 mg, 1.9 mmol, 0.2 equiv) in toluene (25 mL) was heated under reflux for 2 d in a flask fitted with Dean-Stark apparatus. The reaction mixture was then brought to room temperature, diluted with water and extracted with ethyl acetate. The organic extract was concentrated under the reduced pressure and the residue purified by column chromatography (petroleum ether-EtOAc; 85:15) to give phosphonate **13a** as inseparable mixture of two *E/Z* isomers (3.15 g, 85%) as brown coloured viscous liquid. The same procedure was followed for the preparation of compounds **13b,c**.

(2E/Z,4E)-Ethyl 4-benzyl-2-[bis(2,2,2-trifluoroethoxy)phosphoryl]-5-(4-methoxyphenyl)penta-2,4-dienoate (13a): R_f (hexane-EtOAc, 80:20) = 0.29; Found: C, 53.10; H, 4.20. Calc. for $C_{25}H_{25}F_6O_6P$: C, 53.01; H, 4.45%; IR ν_{max}: 3063, 3028, 3002, 2970, 2939, 2907, 1720, 1605, 1579, 1508, 1496, 1455, 1419, 1296, 1251, 1175, 1104, 1071, 1032, 962 cm^{-1}; ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.63 (d, *J* =25.8 Hz, 1 H, ArC=CC*H*=C, 2*Z*), 7.40 (d, *J* = 25.8 Hz, 1 H, ArC=CC*H*=C, 2*E*), 7.29-7.12 (m, 14 H, Ph, Ar), 6.89 (d, *J* = 8.4 Hz, 2 H, Ar, 2*Z*), 6.87 (s, 1 H, ArC*H*, 2*Z*), 6.86 (d, *J* = 9.0 Hz, 2 H, Ar, 2*E*), 6.83 (s, 1 H, ArC*H*, 2*E*), 4.34-4.08 (m, 8 H, 2 × OCH_2CF_3), 4.24 (q, *J* = 7.2 Hz, 2 H, OCH_2CH$_3$, 2*Z*), 3.99 (q, *J* = 7.2 Hz, 2 H, OCH_2CH$_3$, 2*E*), 3.98 (s, 2 H, PhCH_2, 2*Z*), 3.82 (s, 3 H, OCH_3, 2*Z*). 3.80 (s, 3 H, OCH_3, 2*E*), 3.79 (s, 2 H, PhCH_2, 2*E*), 1.28 (d, *J* = 7.2 Hz, 3 H, OCH_2CH_3, 2*Z*), 1.09 (d, *J* = 7.2 Hz, 3 H, OCH_2CH_3, 2*E*); ^{13}C NMR (150 MHz, $CDCl_3$): δ 164.3 (d, *J* = 13.9 Hz, 2*Z*), 163.8 (d, *J* = 14.8 Hz, 2*E*), 160.1, 156.1 (d, *J* =

View Article Online
DOI: 10.1039/C6RA01729K

6.3 Hz, 2*Z*), 154.8 (d, *J* = 7.2 Hz, 2*E*), 143.1 (2*Z*), 139.6 (2*Z*), 138.5 (2*E*), 138.0 (2*Z*), 133.5 (d, *J* = 19.9 Hz, 2*E*), 133.2 (d, *J* = 21.3 Hz, 2*Z*), 131.4 (2*E*), 131.1 (2*Z*), 128.9 (2*E*), 128.4 (2*Z*), 128.3 (2*E*), 128.1 (2*Z*), 127.8 (2*E*), 126.5 (2*E*), 126.3 (2*Z*), 122.4 (dq, *J* = 275.8, 9.7 Hz), 120.6 (d, *J* = 186.4 Hz, 2*E*), 118.5 (d, *J* = 184.3 Hz, 2*Z*), 114.0 (2*Z*), 113.8 (2*E*), 62.3 (q, *J* = 37.9 Hz, 2*Z*), 62.2 (q, *J* = 37.9 Hz, 2*E*), 61.8, 55.1, 41.3 (2*E*), 34.8 (2*Z*), 13.6 (2*E*), 13.3 (2*Z*).

(2E/Z,4E)-Ethyl 4-benzyl-2-[bis(2,2,2-trifluoroethoxy)phosphoryl]-5-(3-chlorophenyl)penta-2,4-dienoate (13b): Following the general procedure, inseparable mixture 60:40 of two *E/Z* isomers were isolated, yield (1.42 g, 65%) as brown coloured viscous liquid; R_f (hexane-EtOAc, 80:20) = 0.45; Found: C, 50.37; H, 3.59. Calc. for $C_{24}H_{22}ClF_6O_5P$: C, 50.50; H, 3.88%; IR ν_{max}: 3064, 2982, 1723, 1594, 1495, 1454, 1419, 1374, 1173, 1070, 963, 879 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.55 (dd, *J* = 25.5, 1.5 Hz, 1 H, ArCHCC*H*=C, 2*Z*), 7.36 (dd, *J* = 25.8, 1.2 Hz, 1 H, ArCHCC*H*=C, 2*E*), 7.30-7.05 (m, 18 H, Ar, Ph), 7.04 (s, 1 H, ArC*H*, 2*E*), 6.65 (s, 1 H, ArC*H*, 2*Z*), 4.35-4.12 (m, 10 H, 2 × OCH_2CF$_3$, OCH_2CH$_3$, 2*Z*), 4.08 (q, *J* = 7.2 Hz, 2 H, OCH_2CH$_3$, 2*E*), 3.91 (s, 2 H, PhCH_2, 2*E*), 3.76 (s, 2 H, PhCH_2, 2*Z*), 1.27 (t, *J* = 7.2 Hz, 3 H, OCH$_2$CH_3, 2*Z*), 1.15 (t, *J* = 7.2 Hz, 3 H, OCH$_2$CH_3, 2*E*); ^{13}C NMR (75 MHz, $CDCl_3$): δ 164.1 (d, *J* = 13.6, 2*E*), 163.4 (d, *J* = 14.8, 2*Z*), 155.2 (d, *J* = 6.5, 2*E*), 154.7 (d, *J* = 6.8, 2*Z*), 139.0 (2*E*), 137.8 (2*E*), 137.6 (2*Z*), 137.4 (2*E*), 137.1 (2*Z*), 136.6 (d, *J* = 21.0, 2*E*), 135.0 (2*Z*), 134.4 (d, *J* = 19.1, 2*Z*), 129.9 (2*E*), 129.7 (2*Z*), 129.3, 129.1, 128.6, 128.3, 127.6 (2*Z*), 127.1 (2*E*), 126.9 (2*Z*), 126.7 (2*E*), 123.3 (d, *J* = 185.6, 2*Z*), 122.4 (dq, *J* = 266.6, 9.3), 121.3 (d, *J* = 183.6, 2*E*), 62.4 (q, *J* = 37.7), 62.1, 42.0 (2*Z*), 35.3 (2*E*), 13.7 (2*Z*), 13.6 (2*E*).

(2E/Z,4E)-Ethyl 2-[bis(2,2,2-trifluoroethoxy)phosphoryl]-5-(4-methoxyphenyl)-4-methylpenta-2,4-dienoate (13c): Following the general procedure, inseparable mixture 1:1 of two E/Z isomers

View Article Online
DOI: 10.1039/C6RA01729K

were isolated, yield (6.14 g, 79%) as brown coloured viscous liquid; R_f (hexane-EtOAc, 80:20) = 0.25; Found: C, 46.48; H, 3.98. Calc. for $C_{19}H_{21}F_6O_6P$: C, 46.54; H, 4.32%; IR ν_{max} : 2965, 2937, 2909, 1720, 1606, 1578, 1509, 1305, 1258, 1175, 1101, 1071, 960 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$): δ 7.63 (d, J = 26.4 Hz, 1 H, ArC=CCH=C, 2*Z*), 7.39 (d, J = 25.8 Hz, 1 H, ArC=CCH=C, 2*E*), 7.34 (d, J = 9.0 Hz, 2 H, Ar, 2*E*), 7.15 (d, J = 8.4 Hz, 2 H, Ar, 2*Z*), 6.94 (s, 1 H, ArC*H*, 2*E*), 6.92 (d, J = 9.0 Hz, 2 H, Ar, 2*E*), 6.89 (d, J = 8.4 Hz, 2 H, Ar, 2*Z*), 6.87 (s, 1 H, ArC*H*, 2*Z*), 4.46-4.37 (m, 8 H, 2 × OCH_2CF_3), 4.30 (q, J = 7.2 Hz, 4 H, OCH_2CH_3), 3.84 (s, 3 H, OCH_3, 2*E*), 3.82 (s, 3 H, OCH_3, 2*Z*), 2.04 (s, 3 H, $C=CCH_3$, 2*E*), 2.03 (s, 3 H, $C=CCH_3$, 2*Z*), 1.33 (t, J = 7.2 Hz, 6 H, OCH_2CH_3); ^{13}C NMR (125 MHz, $CDCl_3$): δ 165.1 (d, J = 13.2 Hz, 2*E*), 164.7 (d, J = 16.2 Hz, 2*Z*), 160.1, 156.6 (d, J = 7.2 Hz, 2*E*), 152.1 (d, J = 7.1 Hz, 2*Z*), 144.3 (2*E*), 140.7 (2*Z*), 131.7, 131.6 (2*Z*), 131.3 (2*E*), 128.5 (2*Z*), 128.3 (2*E*), 122.5 (dq, J = 266.4, 9.5 Hz), 120.0 (d, J = 189.9 Hz, 2*Z*), 116.7 (d, J = 187.5 Hz, 2*E*), 114.0, 62.5 (dq, J = 39.2, 3.6 Hz), 62.0, 55.2, 21.4, 15.6, 13.7.

General procedure for butadien-2-ylphosphonoacetate 12a-c: *n*-BuLi (0.89 mL, 1.6 M, 1.43 mmol, 3 equiv) was added drop wise to a stirred suspension of trimethylsulfonium iodide (292 mg, 1.43 mmol, 3 equiv) in THF (10 mL) at -10 ºC under argon atmosphere and stirred for 20 min at the same temperature. Later, a solution of dienic phosphonate **13a** (270 mg, 0.47 mmol, 1 equiv) in THF (5 mL) was cannulated into the reaction mixture and stirred for 1 h. The temperature of the reaction mixture was allowed to rise slowly to room temperature followed by dilution of the reaction mixture with water and extraction with ethyl acetate. The organic layer was concentrated and column chromatography (petroleum ether-EtOAc; 85:15) was done to obtain the diene **12a** (0.24 g, 87%) as pale yellow liquid. The same procedure was followed for the preparation of compounds **12b,c**.

View Article Online
DOI: 10.1039/C6RA01729K

(4E)-Ethyl 4-benzyl-2-[bis(2,2,2-trifluoroethoxy)phosphoryl]-5-(4-methoxyphenyl)-3-methylene-4-pentenoate 12a*:* R_f (hexane-EtOAc, 80:20) = 0.34; Found: C, 53.98; H, 4.93. Calc. for $C_{26}H_{27}F_6O_6P$: C, 53.80; H, 4.69%; IR ν_{max}: 3058, 3024, 2969, 2938, 2911, 2840, 1729, 1649, 1602, 1574, 1542, 1510, 1456, 1417, 1369, 1299, 1258, 1173, 1104, 1070, 1032, 965, 878, 844, 699, 660 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$): δ 7.30-7.27 (m, 2 H, Ph), 7.21-7.20 (m, 5 H, Ph, Ar), 6.94 (s, 1 H, ArC*H*), 6.83 (d, *J* = 8.4 Hz, 2 H, Ar), 5.57 (d, *J* = 4.8 Hz, 1 H, C=CH_AH_B), 5.51 (d, *J* = 4.8 Hz, 1 H, C=CH_AH_B), 4.48-4.36 (m, 4 H, 2 × OCH_2CF_3), 4.34 (d, *J* = 24 Hz, 1 H, POCH), 4.17 (q, *J* = 7.2 Hz, 2 H, OCH_2CH_3), 3.95 (d, *J* = 16.8 Hz, 1 H, PhCH_AH_B), 3.88 (d, *J* = 16.8 Hz, 1 H, PhCH_AH_B), 3.79 (s, 3 H, OCH_3), 1.22 (t, *J* = 7.2 Hz, 3 H, OCH_2CH_3); ^{13}C NMR (125 MHz, $CDCl_3$): δ 167.1, 158.9, 139.2, 137.7, 135.6, 130.8, 129.9, 129.2 (d, *J* = 9.4 Hz), 128.5, 128.0, 126.0, 122.8 (dq, *J* = 181.3, 9.1 Hz), 119.8 (d, *J* = 8.5 Hz), 113.8, 63.5-62.0 (m), 62.3, 55.1, 48.1 (d, *J* = 145.3 Hz), 34.6, 13.7; ^{31}P NMR (121.5 MHz, $CDCl_3$): δ 23.4.

(4E)-Ethyl 4-benzyl-2-[bis(2,2,2-trifluoroethoxy)phosphoryl]-5-(3-chlorophenyl)-3-methylene-4-pentenoate (12b)*:* Following the general procedure, isolated yield (0.18 g, 79%) as pale yellow liquid; R_f (hexane-EtOAc, 80:20) = 0.25; Found: C, 51.37; H, 4.39. Calc. for $C_{25}H_{24}ClF_6O_5P$: C, 51.34; H, 4.14%; IR ν_{max}: 3063, 3028, 2968, 2932, 2878, 1734, 1718, 1603, 1594, 1560, 1497, 1472, 1456, 1417, 1297, 1264, 1170, 1100, 1070, 962 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$): δ 7.30-7.15 (m, 9 H, Ar, Ph), 6.92 (s, 1 H, ArC*H*), 5.64 (d, *J* = 4.8 Hz, 1 H, C=CH_AH_B), 5.58 (d, *J* = 5 Hz, 1 H, C=CH_AH_B), 4.50-4.06 (m, 5 H, 2 × OCH_2CF_3, POCH), 4.17 (q, *J* = 7.2 Hz, 2 H, OCH_2CH_3), 3.93 (d, *J* = 16.6 Hz, 1 H, PhCH_AH_B), 3.82 (d, *J* = 16.4 Hz, 1 H, PhCH_AH_B), 1.22 (t, *J* = 7.2 Hz, 3 H, OCH_2CH_3); ^{13}C NMR (50 MHz, $CDCl_3$): δ 167.0 (d, *J* = 1.5 Hz), 138.8 (d, *J* = 6 Hz), 138.7, 138.6, 137.4(d, *J* = 8 Hz), 134.2, 129.8, 129.7, 128.7, 128.6, 128.0, 127.5, 126.5,

View Article Online
DOI: 10.1039/C6RA01729K

126.3, 120.4 (dq, J = 276, 8 Hz) 121.2 (d, J = 9 Hz), 62.8, (dq, J = 32, 6 Hz), 62.5, 48.3 (d, J = 145 Hz), 34.6, 13.8; ^{31}P NMR (121.5 MHz, $CDCl_3$): δ 23.1.

(4E)-Ethyl 2-[bis(2,2,2-trifluoroethoxy)phosphoryl]-5-(4-methoxyphenyl)-4-methyl-3-methylene-4-pentenoate (12c): Following the general procedure, isolated yield (700 mg, 86%) as pale yellow liquid; R_f (hexane-EtOAc, 80:20) = 0.3; Found: C, 47.79; H, 4.85. Calc. for $C_{20}H_{23}F_6O_6P$: C, 47.63; H, 4.60%; IR ν_{max}: 2971, 2938, 2914, 2838, 1730, 1609, 1509, 1460, 1415, 1371, 1302, 1161, 1068, 1033, 960 cm^{-1}; ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.21 (d, J = 8.4 Hz, 2 H, Ar), 6.89 (d, J = 8.4 Hz, 2 H, Ar), 6.64 (s, 1 H, ArC*H*), 5.60 (d, J = 4.8 Hz, 1 H, C=CH_AH$_B$), 5.59 (d, J = 6.0 Hz, 1 H, C=CH$_A$$H_B$), 4.51-4.35 (m, 4 H, 2 × OCH_2CF_3), 4.38 (d, J = 24 Hz, 1 H, POCH), 4.25 (q, J = 7.2 Hz, 1 H, OCH_AH$_B$CH$_3$), 4.24 (q, J = 7.2 Hz, 1 H, OCH$_A$$H_BCH_3$), 3.82 (s, 3 H, OCH_3), 2.04 (s, 3 H, C=CCH_3), 1.28 (t, J = 7.2 Hz, 3 H, OCH_2CH_3); ^{13}C NMR (125 MHz, $CDCl_3$): δ 167.3, 158.5, 139.4 (d, J = 8.2 Hz,), 134.2, 130.5, 129.8, 128.0, 122.4 (dq, J = 270, 28 Hz), 118.0 (d, J = 8.2 Hz), 113.5, 62.6 (dq, J = 8.6, 24.7 Hz), 62.4, 55.1, 48.1 (d, J = 144.4 Hz), 16.1, 13.8; ^{31}P NMR (121.5 MHz, C_6D_6): δ 23.7.

(E)-Ethyl 2,3-dimethylene-5-phenylpent-4-enoate (10): A solution of diene **8** (0.29 g, 0.63 mmol), in THF (6 mL) was cannulated to a suspension of NaH (0.028 g, 55% in oil, 0.63 mmol) in THF (1 mL) at 0 ºC. After 15 min, formaldehyde gas was bubbled through this reaction mixture for 5 min and 10 min. The reaction mixture was diluted with water and extracted with 20% EtOAc in hexanes. The organic extract was concentrated under reduced pressure to give **10**. Attempt to purify this material by chromatography was not successful due to degradation by dimerization and polymerization. R_f (hexane-EtOAc, 95:5) = 0.5; ^{1}H NMR (200 MHz, $CDCl_3$): δ 7.40-7.18 (m, 5H, Ph), 6.89 (d, J = 16.2 Hz, 1 H, PhC*H*), 6.38 (d, J = 1.2 Hz, 1 H,

View Article Online
DOI: 10.1039/C6RA01729K

$EtCO_2C=CH_AH_B$), 6.36 (d, *J* = 16.2 Hz, 1 H, PhCH=C*H*), 5.75 (d, *J* = 1.2 Hz, 1H, $EtCO_2C=CH_AH_B$), 5.38 (s, 1 H, PhCH=CHC=CH_AH_B), 5.23 (s, 1 H, PhCH=CHC=CH_AH_B), 4.23 (q, *J* = 7.2 Hz, 2 H, OCH_2), 1.28 (t, *J* = 7.2 Hz, 3 H, OCH_2CH_3).

General procedure for [3]dendralenes 11a-k: A solution of butadien-2-ylphosphonoacetate **12a** (190 mg, 0.33 mmol, 1 equiv) in THF (5 mL) was cannulated to a suspension of sodium hydride (15 mg, 55% in oil, 0.33 mmol, 1 equiv) in THF (1 mL) under argon atmosphere and stirred for 5 min. Then freshly distilled benzaldehyde (34 µL, 0.33 mmol, 1 equiv) was added and stirred at room temperature for 24 h. The reaction mixture was diluted with water and extracted with ethyl acetate. The organic layer was concentrated under the reduced pressure and purified by column chromatography (petroleum ether-EtOAc; 95:5) to obtain the dendralene **11a** (42 mg, 30%) as white solid. The same procedure was followed for the preparation of dendralenes **11b-k**.

(2Z,4E)-Ethyl 4-benzyl-2-benzylidene-5-(4-methoxyphenyl)-3-methylenepent-4-enoate (11a): R_f (Benzene) = 0.85; mp 92-93 ºC; Found: C, 82.26; H, 6.83. Calc. for $C_{29}H_{28}O_3$: C, 82.05; H, 6.65%; IR ν_{max}: 3081, 2959, 2923, 2855, 1715, 1604, 1573, 1508, 1494, 1463, 1455, 1370, 1304, 1256, 1210, 1175, 1095, 1029 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$): δ 7.35-7.23 (m, 12 H, Ar, 2 × Ph), 6.90 (s, 1 H, PhC*H*), 6.84 (s, 1 H, ArC*H*), 6.84 (d, *J* = 9.0 Hz, 2 H, Ar), 5.27 (s, 1 H, C=CH_AH_B), 5.24 (s, 1 H, C=CH_AH_B), 4.19 (q, 2 H, *J* = 7.2 Hz, OCH_2CH_3), 3.94 (s, 2 H, $PhCH_2$), 3.79 (s, 3 H, OCH_3), 1.16 (t, *J* = 7.2 Hz, 3 H, OCH_2CH_3); ^{13}C NMR (150 MHz, $CDCl_3$): δ 169.0, 158.9, 148.7, 139.8, 136.4, 135.8, 135.7, 134.9, 132.4, 130.1, 129.8, 128.7, 128.6, 128.5, 128.4, 126.1, 117.1, 113.9, 61.1, 55.4, 35.5, 14.0. Recrystalization of compound **11a** from ethyl acetate/hexane gave crystals suitable for single crystal X-ray analysis.

View Article Online
DOI: 10.1039/C6RA01729K

(2Z,4E)-Ethyl 2-(4-bromobenzylidene)-4-benzyl-5-(4-methoxyphenyl)-3-methylenepent-4-enoate (11b): Following the general procedure, isolated yield (43 mg, 41%) as pale yellow liquid; R_f (Benzene) = 0.75; Found: C, 69.14; H, 5.57. Calc. for $C_{29}H_{27}BrO_3$: C, 69.19; H, 5.41%; IR ν_{max}: 2956, 2923, 2853, 1715, 1698, 1649, 1607, 1555, 1538, 1508, 1487, 1457, 1369, 1275, 1247, 1179, 1106, 1070, 1036 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$): δ 7.46 (d, 2 H, J = 8.4 Hz, Ar), 7.31-7.19 (m, 9 H, Ar, Ph), 6.85 (s, 1 H, 4-BrC_6H_4CH), 6.83 (d, J = 8.8 Hz, 2 H, Ar), 6.73 (s, 1 H, 4-$CH_3OC_6H_4CH$), 5.25 (s, 1 H, C=CH_AH_B), 5.24 (s, 1 H, C=CH_AH_B), 4.18 (q, J = 7.2 Hz, 2 H, O$CH_2$$CH_3$), 3.91 (s, 2 H, Ph$CH_2$), 3.79 (s, 3 H, OCH_3), 1.17 (t, J = 7.2 Hz, 3 H, OCH_2CH_3); ^{13}C NMR (150 MHz, $CDCl_3$): δ 168.6, 158.9, 148.6, 139.7, 136.6, 136.3, 134.6, 133.6, 132.5, 131.5, 130.2, 130.1, 129.7, 128.6, 128.5, 126.1, 122.5, 117.4, 113.9, 61.2, 55.3, 35.5, 14.1.

(2Z,4E)-Ethyl 2-(3-chlorobenzylidene)-4-benzyl-5-(4-methoxyphenyl)-3-methylenepent-4-enoate (11c): Following the general procedure, isolated yield (57 mg, 35%) as pale yellow liquid; R_f: (hexane-EtOAc, 95:5) = 0.4; Found: C, 75.91; H, 5.93. Calc. for $C_{29}H_{27}ClO_3$: C, 75.89; H, 5.93%; IR ν_{max}: 3065, 2924, 2866, 2833, 1717, 1605, 1562, 1510, 1495, 1464, 1453, 1371, 1366, 1336, 1304, 1255, 1206, 1177, 1089, 1034 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$): δ 7.38-7.19 (m, 11 H, Ar), 6.87 (s, 1 H, 3-ClPhC*H*), 6.84 (d, J = 9.0 Hz, 2 H, 4-OCH_3Ph), 6.76 (s, 1 H, 4-OCH_3PhC*H*), 5.27 (s, 1 H, C=CH_AH_B), 5.26 (s, 1 H, C=CH_AH_B), 4.20 (q, J = 7.2 Hz, 2 H, O$CH_2$$CH_3$), 3.93 (s, 2 H, Ph$CH_2$), 3.79 (s, 3 H, OCH_3), 1.18 (t, J = 7.2 Hz, 3 H, OCH_2CH_3); ^{13}C NMR (150 MHz, $CDCl_3$): δ 168.5 158.9, 148.4, 139.7, 137.5, 137.3, 136.2, 134.3, 133.2, 132.5, 130.2, 129.7, 129.6, 128.6, 128.5, 128.3, 126.7, 126.1, 117.5, 113.9, 61.3, 55.4, 35.5, 14.0.

(2Z,4E)-Ethyl 2-[(E)-3-benzyl-4-(4-methoxyphenyl)buta-1,3-dien-2-yl]-5-phenylpenta-2,4-dienoate (11d): Following the general procedure, isolated yield (43 mg, 31%) as yellow liquid;

View Article Online
DOI: 10.1039/C6RA01729K

R_f (hexane-EtOAc, 90:10) = 0.53; Found: C, 82.63; H, 6.72. Calc. for $C_{31}H_{30}O_3$: C, 82.64; H, 6.71%; IR ν_{max}: 3062, 3024, 2956, 2928, 2839, 1702, 1609, 1592, 1508, 1495, 1453, 1369, 1301, 1246, 1217, 1175, 1149, 1036, 976 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$): δ 7.86 (dd, J = 15.5, 11.5 Hz, 1 H, PhCH=C*H*CH=C), 7.51 (d, J = 7.0 Hz, 2 H, Ar), 7.38-7.17(m, 10 H, 2 × Ph), 6.81 (d, J = 9.0 Hz, 2 H, Ar), 6.80 (d, J = 15.5 Hz, 1 H, PhC*H*), 6.76 (s, 1 H, ArC*H*), 6.71 (d, J = 11.5 Hz, 1 H, PhCH=CHC*H*=C), 5.24 (s, 1 H, C=CH_AH_B), 5.17 (s, 1 H, C=CH_AH_B), 4.26 (q, J = 7 Hz, 2 H, OCH_2CH$_3$), 3.93 (s, 2 H, PhCH_2), 3.78 (s, 3 H, OCH$_3$), 1.29 (t, J = 7 Hz, 3 H, OCH$_2$CH_3); ^{13}C NMR (125 MHz, $CDCl_3$): δ 167.1, 158.7, 149.0, 141.0, 140.0, 139.7, 136.6, 132.8, 131.6, 129.9, 129.8, 128.6, 128.5, 128.3, 128.2, 127.2, 125.8, 125.5, 116.3, 113.7, 60.5, 55.1, 34.8, 14.2.

Synthesis of 11ea/eb: Following the general procedure, a 6:4 mixture of *Z/E* isomers (^1H NMR) were isolated as colourless liquid. The individual isomers were separated by chromatography.

Diethyl 2-[(E)-3-benzyl-4-(4-methoxyphenyl)buta-1,3-dien-2-yl]maleate (11ea): Isolated yield (55 mg, 30%); R_f (hexane-EtOAc, 80:20) = 0.54; Found: C, 74.08; H, 6.82. Calc. for $C_{26}H_{28}O_5$: C, 74.26; H, 6.71%; IR ν_{max}: 3059, 2980, 2960, 2932, 2835, 1720, 1610, 1510, 1500, 1453, 1396, 1364, 1333, 1254, 1176, 1092, 1035 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$): δ 7.29-7.25 (m, 4 H, Ar, Ph), 7.21-7.18 (m, 3 H, Ph), 6.86 (d, J = 9.0 Hz, 2 H, Ar), 6.77 (s, 1 H, ArC*H*), 6.00 (s, 1 H, C*H*CO$_2$Et), 5.30 (s, 1 H, C=CH_AH_B), 5.27 (s, 1 H, C=CH_AH_B), 4.31 (q, J = 7.0 Hz, 2 H, OCH_2CH$_3$), 4.22 (q, J = 7.0 Hz, 2 H, OCH_2CH$_3$), 3.85 (s, 2 H, PhCH_2), 3.80 (s, 3 H, OCH$_3$), 1.31 (t, 3 H, J = 7.0 Hz), 1.30 (t, J = 7.0 Hz, 3 H, OCH$_2$CH_3); ^{13}C NMR (125 MHz, $CDCl_3$): δ 167.3, 164.9, 158.9, 148.7, 146.0, 139.0, 135.5, 133.0, 129.9, 129.1, 128.4, 126.0, 121.0, 120.1, 113.8, 61.5, 60.9, 55.2, 35.5, 14.0, 13.9.

View Article Online
DOI: 10.1039/C6RA01729K

Diethyl 2-((E)-3-benzyl-4-(4-methoxyphenyl)buta-1,3-dien-2-yl)fumarate (11eb): Isolated yield (33 mg, 18%); R_f (hexane-EtOAc, 80:20) = 0.52; IR ν_{max}: 3061, 2981, 2837, 1722, 1607, 1510, 1495, 1391, 1250, 1032 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$): δ 7.28-7.18 (m, 7 H, Ar, Ph), 6.77 (d, J = 8.8 Hz, 2 H, Ar), 6.41 (s, 1 H, ArC*H*), 5.93 (s, 1 H, C*H*CO_2Et), 5.39 (s, 1 H, C=CH_AH_B), 5.02 (s, 1 H, C=CH_AH_B), 4.37 (q, J = 7.0 Hz, 2 H, OC$H_2$$CH_3$), 4.16 (q, J = 7.2 Hz, 2 H, OC$H_2$$CH_3$), 3.76 (s, 3 H, OCH_3), 3.52 (s, 2 H, PhCH_2), 1.37 (t, J = 7.0 Hz, 3 H, OCH_2CH_3), 1.25 (t, J = 7.2 Hz, 3 H, OCH_2CH_3); ^{13}C NMR (50 MHz, $CDCl_3$): δ 167.6, 165.2, 158.8, 147.1, 143.0, 138.7, 135.9, 129.9, 129.8, 129.4, 128.6, 128.3, 126.4, 123.7, 118.3, 113.7, 61.6, 60.9, 55.2, 45.6, 14.0.

(2Z,4E)-Ethyl 4-benzyl-2-benzylidene-5-(3-chlorophenyl)-3-methylenepent-4-enoate (11f): Following the general procedure, isolated yield (54 mg, 35%) as colourless liquid; R_f (hexane-EtOAc, 95:5) = 0.5; Found: C, 78.62; H, 6.12. Calc. for $C_{28}H_{25}ClO_2$: C, 78.40; H, 5.87%; IR ν_{max}: 3060, 3026, 2981, 2959, 2871, 1716, 1636, 1589, 1556, 1490, 1476, 1453, 1373, 1213, 1095 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.35-7.18 (m, 14 H, Ar, 2×Ph), 6.88 (s, 1 H, PhC*H*), 6.83 (s, 1 H, ArC*H*), 5.33 (s, 1 H, C=CH_AH_B), 5.29 (s, 1 H, C=CH_AH_B), 4.21 (q, J = 7.2 Hz, 2 H, OC$H_2$$CH_3$), 3.90 (s, 2 H, PhC$H_2$), 1.17 (t, J = 7.2 Hz, 3 H, OCH_2CH_3); ^{13}C NMR (75 MHz, $CDCl_3$): δ 168.7, 148.0, 139.6, 139.3, 139.0, 135.5, 135.3, 135.0, 134.2, 131.1, 129.6, 128.8, 128.5, 128.4, 128.3, 127.2, 126.6, 126.2, 118.0, 61.1, 35.4, 13.9.

(2Z,4E)-Ethyl 2-(4-bromobenzylidene)-4-benzyl-5-(3-chlorophenyl)-3-methylenepent-4-enoate (11g): Following the general procedure, isolated yield (240 mg, 47%) as pale yellow liquid; R_f (hexane-EtOAc, 90:10) = 0.75; Found: C, 66.50; H, 4.92. Calc. for $C_{28}H_{24}BrClO_2$: C, 66.22; H, 4.76%; IR ν_{max}: 3061, 3026, 2979, 2926, 1720, 1591, 1561, 1486, 1453, 1371, 1343,

View Article Online
DOI: 10.1039/C6RA01729K

1302, 1276, 1211, 1073, 1046, 1010 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$): δ 7.47 (d, J = 8.6 Hz, 2 H, Ar), 7.36-7.15 (m, 11 H, Ar, Ph), 6.82 (s, 1 H, ArC*H*), 6.70 (s, 1 H, ArC*H*), 5.29 (s, 1 H, C=C$H_A$$H_B$), 5.28 (s, 1 H, C=C$H_A$$H_B$), 4.18 (q, J = 7 Hz, 2 H, OCH_2CH$_3$), 3.87 (s, 2 H, PhCH_2), 1.17 (t, J = 7 Hz, 3 H, OCH$_2$CH_3); ^{13}C NMR (50 MHz, $CDCl_3$): δ 168.4, 147.9, 139.4, 139.1, 138.9, 136.0, 134.4, 134.2, 133.7, 131.5, 131.1, 130.1, 129.6, 128.8, 128.5, 128.4, 127.3, 126.6, 126.2, 122.5, 118.2, 61.2, 35.4, 13.9.

(2Z,4E)-Ethyl 2-(4-methoxybenzylidene)-4-benzyl-5-(3-chlorophenyl)-3-methylenepent-4-enoate (11h): Following the general procedure, isolated yield (28 mg, 15%) as colourless liquid; R_f (hexane-EtOAc, 95:5) = 0.28; IR ν_{max}: 3061, 3029, 2956, 2930, 2838, 1714, 1709, 1601, 1565, 1507, 1453, 1376, 1295, 1255, 1201, 1178, 1097, 962 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.34-7.17 (m, 11 H, Ar, Ph), 6.88 (d, J = 8.7 Hz, 2 H, Ar), 6.86 (s, 1 H, ArC*H*), 6.75 (s, 1 H, ArC*H*), 5.29 (s, 1 H, C=C$H_A$$H_B$), 5.26 (s, 1 H, C=C$H_A$$H_B$), 4.23 (q, J = 7.2 Hz, 2 H, OCH_2CH$_3$), 3.89 (s, 2 H, PhCH_2), 3.84 (s, 3 H, OCH_3), 1.21 (t, J = 7.2 Hz, 3 H, OCH$_2$CH_3); ^{13}C NMR (75 MHz, $CDCl_3$): δ 169.0, 159.8, 148.4, 139.7, 139.3, 139.1, 134.8, 134.2, 133.1, 132.2, 140.0, 130.3, 129.6, 128.8, 128.5, 128.4, 127.2, 126.6, 126.1, 117.6, 113.8, 61.0, 55.3, 35.4, 14.0; HRMS (ESI-TOF) m/z: $[M + H]^+$ Calcd for $C_{29}H_{28}ClO_3$ 459.1721; Found 459.1723.

(2Z,4E)-Ethyl 2-[(E)-3-benzyl-4-(3-chlorophenyl)buta-1,3-dien-2-yl]-5-phenylpenta-2,4-dienoate (11i): Following the general procedure, isolated yield (37 mg, 27%) as yellow liquid; R_f (hexane-EtOAc, 95:5) = 0.54; Found: C, 79.25; H, 5.80. Calc. for $C_{30}H_{27}ClO_2$: C, 79.19; H, 5.98%; IR ν_{max}: 3058, 3027, 2979, 2929, 2869, 1705, 1615, 1592, 1561, 1496, 1476, 1447, 1367, 1317, 1304, 1221, 1206, 1159, 1150, 1096, 1045, 1033 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.86 (dd, J = 15.6, 11.4 Hz, 1 H, PhCH=C*H*CH), 7.53-7.50 (m, 2 H, Ar), 7.39-7.11 (m, 12 H, Ar,

View Article Online
DOI: 10.1039/C6RA01729K

2 × Ph), 6.82 (d, *J* = 15.6 Hz, 1 H, PhC*H*=CHCH), 6.73 (s, 1 H, ArC*H*), 6.70 (dd, *J* = 11.4, 0.9 Hz, 1 H, PhCH=CHC*H*=C), 5.31 (s, 1 H, C=CH_AH_B), 5.23 (s, 1 H, C=CH_AH_B), 4.27 (q, *J* = 7.2 Hz, 2 H, OCH_2CH$_3$), 3.89 (s, 2 H, PhCH_2), 1.31 (t, *J* = 7.2 Hz, 3 H, OCH$_2$CH_3); ^{13}C NMR (75 MHz, $CDCl_3$): δ 167.0, 148.6, 141.5, 140.2, 139.8, 139.6, 139.2, 136.6, 134.2, 132.3, 130.4, 129.5, 128.8, 128.5, 128.2, 127.3, 127.1, 126.6, 126.1, 125.4, 117.7, 60.7, 34.8, 14.3.

Diethyl 2-[(E)-3-benzyl-4-(3-chlorophenyl)buta-1,3-dien-2-yl]maleate (11j): Following the general procedure, isolated yield (54 mg, 40%) as colourless liquid. The product was contaminated with 36% of diethyl 2-[(*E*)-3-benzyl-4-(3-chlorophenyl)buta-1,3-dien-2-yl]fumarate and could not be separated. R_f (hexane-EtOAc, 95:5) = 0.26; Found: C, 70.80; H, 5.98. Calc. for $C_{25}H_{25}ClO_4$: C, 70.67; H, 5.93%; IR ν_{max}: 3063, 3026, 2979, 2934, 2906, 2871, 1723, 1615, 1591, 1562, 1241, 1182, 1100, 1027 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.34-7.14 (m, 18 H, Ar, Ph), 6.75 (s, 1 H, ArC*H*, *Z*), 6.40 (s, 1 H, ArC*H*, *E*), 5.99 (s, 1 H, CHCO$_2$Et, *Z*), 5.91 (s, 1 H, CHCO$_2$Et, *E*), 5.44 (s, 1 H, C=CH_AH_B, *E*), 5.35 (s, 1 H, C=CH_AH_B, *Z*), 5.30 (s, 1 H, C=CH_AH_B, *Z*), 5.06 (s, 1 H, C=CH_AH_B, *E*), 4.40 (q, *J* = 7.0 Hz, 2 H, OCH_2CH$_3$, *E*), 4.33 (q, *J* = 7.0 Hz, 2 H, OCH_2CH$_3$, *Z*), 4.24 (q, *J* = 7.0Hz, 2 H, OCH_2CH$_3$, *Z*), 4.19 (q, *J* = 7.0 Hz, 2 H, OCH_2CH$_3$, *E*), 3.81 (s, 2 H, PhCH_2, *Z*), 3.58 (s, 2 H, PhCH_2, *E*), 1.39 (t, *J* = 7.0 Hz, 3 H, OCH$_2$CH_3, *E*), 1.33 (t, *J* = 7.0 Hz, 3 H, OCH$_2$CH_3, *Z*), 1.32 (t, *J* = 7.0 Hz, 3 H, OCH$_2$CH_3, *Z*), 1.28 (t, *J* = 7.0 Hz, 3 H, OCH$_2$CH_3, *E*); ^{13}C NMR (125 MHz, $CDCl_3$): δ 167.3 (*E*), 167.2 (*Z*), 164.9 (*E*), 164.8 (*Z*), 148.3 (*Z*), 146.9 (*E*), 145.4 (*Z*), 142.4 (*E*), 139.9 (*E*), 138.9 (*Z*), 138.5 (*Z*), 138.4 (*Z*), 138.0 (*E*), 137.7 (*E*), 134.3 (*Z*), 134.1 (*E*), 131.8 (*Z*), 129.6 (*E*), 129.4 (*Z*), 128.9 (*E*), 128.8 (*Z*), 128.6 (*E*), 128.5, 127.4 (*Z*), 127.2 (*E*), 126.6 (*Z*), 126.5 (*E*), 126.3 (*Z*), 123.9 (*E*), 121.1 (*Z*), 121.0 (*E*), 118.5 (*E*), 61.6, 61.0, 45.5 (*E*), 35.6 (*Z*), 14.1, 14.0.

View Article Online
DOI: 10.1039/C6RA01729K

(2Z,4E)-Ethyl 2-benzylidene-5-(4-methoxyphenyl)-4-methyl-3-methylenepent-4-enoate (11k): Following the general procedure, isolated yield (100 mg, 45%) as colourless liquid; R_f (hexane-EtOAc, 95:5) = 0.42; Found: C, 79.52; H, 6.89. Calc. for $C_{23}H_{24}O_3$: C, 79.28; H, 6.94%; IR ν_{max}: 3070, 3036, 2364, 2326, 1962, 1812, 1717, 1611, 1509, 1479, 1251, 1214, 1177, 1036 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) : δ 7.36-7.26 (m, 7 H, Ar, Ph), 6.91 (d, J = 8.4 Hz, 2 H, Ar), 6.85 (s, 1 H, PhC*H*), 6.62 (s, 1 H, ArC*H*), 5.37 (s, 1 H, C=CH_AH_B), 5.32 (s, 1 H, C=CH_AH_B), 4.22 (q, J = 6.9 Hz, 2 H, OCH_2CH$_3$), 3.84 (s, 3 H, OCH$_3$), 2.13 (s, 3 H, C=CCH$_3$), 1.17 (t, J = 6.9 Hz, 3 H, OCH$_2$CH_3); ^{13}C NMR (75 MHz, $CDCl_3$): δ 169.1, 158.3, 150.5, 135.6, 135.5, 134.7, 130.4, 129.7, 128.5, 128.3, 115.3, 113.6, 61.0, 55.3, 17.0, 13.9.

(2Z,4E)-2-Benzylidene-5-(4-methoxyphenyl)-4-methyl-3-methylenepent-4-en-1-ol (11l): To a solution of dendralene **11k** (151 mg, 0.43 mmol) in dichloromethane (10 mL), DIBAL-H (1.74 mL, 1.0 M in cyclohexane, 1.73 mmol) was added at -78°C under the argon atmosphere and the solution was stirred for 1 h at the same temperature. The temperature of the reaction mixture was raised to 0 ºC, stirred for another 1 h and finally allowed to attain room temperature. The reaction mixture was quenched with dil HCl and extracted with dichloromethane. The organic layer was concentrated under reduced pressure and the residue was purified by column chromatography (petroleum ether-EtOAc; 90:10) to obtain the dendralene **11l** (105 mg, 80%) as colourless liquid. R_f (hexane-EtOAc, 80:20) = 0.4; Found: C, 82.15; H, 7.32. Calc. for $C_{21}H_{22}O_2$: C, 82.32; H, 7.24%; IR ν_{max}: 3426, 3058, 3034, 2951, 2933, 2838, 1607, 1511, 1480, 1441, 1303, 1248, 1177, 1034 cm^{-1}; ^1H NMR (300 MHz, CD_3COCD_3): δ 7.49 (d, J = 7.5 Hz, 2 H, Ph), 7.37-7.25 (m, 5 H, Ar, Ph), 6.90 (d, J = 8.7 Hz, 2 H, Ar), 6.64 (s, 1 H, PhC*H*), 6.53 (s, 1 H, ArC*H*), 5.27 (s, 1 H, C=CH_AH_B), 5.24 (s, 1 H, C=CH_AH_B), 4.36 (d, J = 5.4 Hz, 2 H, CH_2OH), 3.89 (t, J = 5.4 Hz, 1 H,

View Article Online
DOI: 10.1039/C6RA01729K

CH_2OH), 3.78 (s, 3 H, OCH_3), 2.05 (s, 3 H, C=CCH_3); ^{13}C NMR (75 MHz, CD_3COCD_3): δ 155.6, 143.2, 138.3, 136.8, 132.8, 131.6, 130.3, 129.3, 128.3, 114.7, 113.6, 60.3, 55.8, 17.6.

(3aSR,4SR,7aRS)-Ethyl 4-(4-bromophenyl)-2,3,3a,4,7,7a-hexahydro-6-[(E)-1-(4-methoxyphenyl]-3-phenylprop-1-en-2-yl)-2-methyl-1,3-dioxo-1H-isoindole-5-carboxylate (15): A solution of dendralene **11b** (60 mg, 0.12 mmol, 1 equiv) and NMM (15 mg, 0.14 mmol, 1 equiv) in benzene (3 mL) was heated under reflux for 3 d. The reaction mixture was then concentrated on rotary evaporator and the residue was filtered through a small silica gel column to obtain the D-A adducts (57 mg, 78%) which on careful chromatography on silica gel provided the major adduct **15** (50 mg, 69%) as a white solid. R_f (hexane-EtOAc, 70:30) = 0.36; mp 119°C; Found: C, 66.28; H, 5.39; N, 2.05. Calc. for $C_{34}H_{32}BrNO_5$: C, 66.45; H, 5.25; N, 2.28%; IR ν_{max}: 3062, 3023, 2979, 2954, 2932, 2838, 1775, 1702, 1606, 1510, 1488, 1434, 1380, 1281, 1253, 1220, 1178, 1122, 1075, 1025, 1008, 969 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.30 (d, J = 8.5 Hz, 2 H, Ar), 7.29-7.23 (m, 5 H, Ph), 7.19 (d, J = 8.0 Hz, 2 H, Ar), 6.90 (d, 2 H, J = 8.5 Hz, Ar), 6.63 (d, J = 8.5 Hz, 2 H, Ar), 6.45 (s, 1 H, ArCH), 4.46 (d, J = 7.5 Hz, 1 H, ArCHCH), 4.10 (q, J = 7.5 Hz, 1 H, OC$H_AH_BCH_3$), 4.09 (q, J = 7.5 Hz, 1 H, $OCH_AH_BCH_3$), 4.06 (d, J = 15.0 Hz, 1 H, PhCH_AH_B), 3.83 (d, J = 17.0 Hz, 1 H, $PhCH_AH_B$), 3.81 (s, 3 H, OCH_3), 3.07 (t, J = 7.5 Hz, 1 H, ArCHCH), 2.72-2.67 (m, 1 H, COCHCH_AH_B), 2.65 (dd, J = 18.5, 6 Hz, 1 H, COCHC$H_AH_{B)}$, 2.53 (dd, J = 18.5, 10.5 Hz, 1 H, $COCHCH_AH_B$), 2.40 (s, 3 H, NCH_3), 1.16 (t, J = 7.5 Hz, 3 H, OCH_2CH_3); ^{13}C NMR (125 MHz, $CDCl_3$): δ 178.7, 177.0, 167.2, 158.8, 150.1, 140.4, 138.6, 135.1, 131.4, 130.3, 130.1, 129.5, 129.2, 128.4, 127.7, 126.6, 121.5, 113.9, 60.9, 55.3, 45.1, 41.9, 37.6, 37.0, 28.7, 24.0, 14.1. Recrystalization of compound **15** from ethylacetate/hexane gave crystals suitable for single crystal X-ray analysis.

View Article Online
DOI: 10.1039/C6RA01729K

(3aSR,4SR,7aRS)-Ethyl 4-(4-bromophenyl)-6-[(E)-1-(3-chlorophenyl)-3-phenylprop-1-en-2-yl]-2,3,3a,4,7,7a-hexahydro-2-methyl-1,3-dioxo-1H-isoindole-5-carboxylate (16): A solution of dendralene **11g** (155 mg, 0.3 mmol, 1 equiv) and NMM (34 mg, 0.3 mmol, 1 equiv) in toluene (5 mL) was heated under reflux for 2 d. The reaction mixture was then concentrated on rotary evaporator and the residue was filtered through a small silica gel column to obtain the D-A adducts (148 mg, 78%) which on careful chromatography on silica gel provided the major adduct **16** (118 mg, 62%) as a white solid. R_f (hexane-EtOAc, 80:20) = 0.16; mp 140-141°C; Found: C, 64.13; H, 4.77; N, 2.09. Calc. for $C_{33}H_{29}BrClNO_4$: C, 64.04; H, 4.72; N, 2.26%; IR ν_{max}: 3024, 2977, 2929, 2849, 1778, 1703, 1591, 1562, 1486, 1434, 1382, 1276, 1220, 1124, 1074, 1047, 1010 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$): δ 7.37-7.19 (m, 11 H, Ar, Ph), 6.64 (d, J = 8.4 Hz, 2 H, Ar), 6.44 (s, 1H, ArC*H*), 4.49 (d, J = 7.2 Hz, 1 H, ArC*H*CH), 4.14 (q, J = 7.2 Hz, 1H, $OCH_ACH_BCH_3$), 4.13 (q, J = 7.0 Hz, 1H, $OCH_AC*H*_BCH_3$), 4.05 (d, J = 15.4 Hz, 1 H, $PhCH_ACH_B$), 3.84 (d, J = 14.6 Hz, 1 H, $PhCH_AC*H*_B$), 3.08 (t, J = 7.6 Hz, 1 H, ArCHC*H*), 2.75-2.46 (m, 3 H, $COCHCH_2$), 2.42 (s, 3 H, NCH_3), 1.20 (t, J = 7.2 Hz, 3 H, OCH_2C*H*_3); ^{13}C NMR (50 MHz, $CDCl_3$): δ 178.6, 176.9, 166.6, 149.9, 143.6, 138.4, 138.1, 135.0, 134.3, 131.4, 130.2, 129.7, 129.6, 128.8, 128.6, 128.5, 127.3, 126.9, 126.8, 126.2, 121.5, 61.0, 45.0, 41.7, 37.4, 37.1, 28.9, 24.0, 14.1. Recrystalization of compound **16** from ethanol gave crystals suitable for single crystal X-ray analysis.

(2Z)-Ethyl 2-((3aRS,4RS,7aSR)-2,3,3a,4,7,7a-hexahydro-4-(4-methoxyphenyl)-2,5-dimethyl-1,3-dioxo-1H-isoindol-6-yl)-3-phenylacrylate (17) and (3aSR,4SR,7aRS)-Ethyl 2,3,3a,4,7,7a-hexahydro-6-[(E)-1-(4-methoxyphenyl)prop-1-en-2-yl]-2-methyl-1,3-dioxo-4-phenyl-1H-isoindole-5-carboxylate (18): A solution of dendralene **11k** (126 mg, 0.36 mmol, 1 equiv) and NMM (41 mg, 0.36 mmol, 1 equiv) in toluene (3 mL) was heated under reflux for 1 d. The

View Article Online
DOI: 10.1039/C6RA01729K

reaction mixture was then concentrated on rotary evaporator and chromatographed to obtain the D-A adducts as an inseparable 54:46 mixture of **17**/**18** (149 mg, 89%). R_f (hexane-EtOAc, 70:30) = 0.3; Found: C, 73.07; H, 6.56; N, 3.07. Calc. for $C_{28}H_{29}NO_5$: C, 73.18; H, 6.36; N, 3.05%; IR ν_{max}: 3023, 2981, 2940, 2906, 2837, 1780, 1713, 1696, 1610, 1511, 1437, 1382, 1255, 1175, 1035, 760,697 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$): δ 7.40-7.31 (m, 5 H, Ph, **17**), 7.30-7.18 (m, 5 H, Ar, Ph, **18**), 7.09 (d, J = 7.0 Hz, 2 H, Ph, **18**), 7.08 (d, J = 8.5 Hz, 2 H, Ar, **17**), 6.92 (d, J = 8.5 Hz, 2 H, Ar, **18**), 6.81 (d, J = 9.0 Hz, 2 H, Ar, **17**), 6.77 (s, 1 H, PhC*H*, **17**), 6.27 (s, 1 H, ArC*H*, **18**), 4.56 (d, J = 7.5 Hz, 1 H, PhC*H*, **18**), 4.21 (q, J = 7.0 Hz, 2 H, OCH_2CH$_3$, **17**), 4.03 (q, J = 7.0 Hz, 1 H, OCH_2CH$_3$, **18**), 3.85 (d, J = 5.0 Hz, 1 H, ArC*H*, **17**), 3.85 (s, 3 H, OCH$_3$, **18**), 3.79 (s, 3 H, OCH$_3$, **17**), 3.39 (t, J = 8.0 Hz, 1 H, PhCHC*H*, **18**), 3.33 (t, J = 9.0 Hz, 1 H, ArCHC*H*, **17**), 3.23-3.15 (m, 3 H, COC*H*CH_AH$_B$, **18**, COC*H*CH$_2$, **17**), 3.08-2.98 (m, 1 H, COCHCH_AH$_B$, **17**), 2.82 (dd, J = 20.0, 12.0 Hz, 1 H, COCHCH$_A$$H_B$, **18**), 2.73 (dd, J = 18.0, 11.5 Hz, 1 H, COCHCH$_A$$H_B$, **17**), 2.47 (s, NCH$_3$, 3 H, **17**), 2.40 (s, 3 H, NCH$_3$, **18**), 2.15 (d, J = 0.5 Hz, 3 H, C=CCH$_3$, **18**), 1.81 (s, 3 H, C=CCH$_3$, **17**), 1.19 (t, J = 7.0 Hz, 3 H, OCH$_2$CH_3, **17**), 1.09 (t, J = 7.0 Hz, 3 H, OCH$_2$CH_3, **18**); ^{13}C NMR (50 MHz, $CDCl_3$): δ 179.5 (**17**), 179.0 (**18**), 178.0 (**17**), 177.2 (**18**), 168.1 (**17**), 167.7 (**18**), 158.9 (**17**), 158.4 (**18**), 150.6 (**18**), 137.6 (**17**), 136.8 (**18**), 136.6 (**17**), 135.5 (**17**), 134.6 (**17**), 134.3 (**17**), 130.1, 130.0, 129.9, 129.8, 128.6, 128.4, 128.3, 128.2, 127.6, 127.0, 125.9, 113.7 (**17**), 113.6 (**18**), 61.0 (**17**) , 60.6 (**18**), 55.2 (**18**), 55.1 (**17**), 46.2 (**18**), 45.2 (**17**), 45.1 (**17**), 42.0 (**18**), 37.5 (**18**), 37.4 (**17**), 29.7 (**18**), 26.6 (**18**), 25.9 (**17**), 23.9 (**17**), 23.8 (**18**), 20.3 (**17**), 17.4 (**18**), 13.8 (**17**). Structures were confirmed from the mixture by COSY and ROESY NMR (for details, see the SI).

Synthesis of compounds 19, 20 and 21: A solution of dendralene **6l** (48 mg, 0.16 mmol, 1 equiv) and NMM (21 mg, 0.19 mmol, 1 equiv) in toluene (3 mL) was heated under reflux for 1

View Article Online
DOI: 10.1039/C6RA01729K

d. The reaction mixture was then concentrated on rotary evaporator and the residue on careful chromatography on silica gel provided D-A adducts **19** (52 mg, 65%) as white solid, **20** (8 mg, 10%) as foam and **21** (3 mg, 4%) as gummy solid (Combined yield: 79%).

(3aRS,4RS,7aSR)-3a,4,7,7a-Tetrahydro-6-[(Z)-1-hydroxy-3-phenylprop-2-en-2-yl]-4-(4-methoxyphenyl)-2,5-dimethyl-2H-isoindole-1,3-dione (19): R_f (hexane-EtOAc, 60:40) = 0.21; mp 117-118°C; IR ν_{max}: 3443, 3059, 3021, 2936, 2906, 2853, 2840, 1777, 1694, 1610, 1507, 1434, 1386, 1249, 1178, 1135, 1034 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$): δ 7.39-7.36 (m, 2 H, Ph), 7.30-7.28 (m, 3 H, Ph), 7.07 (d, J = 8.5 Hz, 2 H, Ar), 6.78 (d, J = 8.5 Hz, 2 H, Ar), 6.48 (s, 1 H, PhC*H*), 4.53 (d, J = 12.5 Hz, 1 H, CH_AH$_B$OH), 4.49 (d, J = 12.5 Hz, 1 H, CH$_A$$H_B$OH), 3.82 (d, J = 7.0 Hz, 1 H, ArC*H*CH), 3.75 (s, 3 H, OCH_3), 3.31 (t, J = 8.5 Hz, 1 H, ArCHC*H*), 3.19-3.14 (m, 1 H, COC*H*CH_2), 3.02 (d, J = 18.0 Hz, 1 H, COCHCH_AH$_B$), 2.73 (dd, J = 18.0, 11.5 Hz, 2 H, COCHCH$_A$$H_B$), 2.45 (s, 3 H, NCH_3), 1.80 (s, 3H, C=CCH_3); ^{13}C NMR (125 MHz, $CDCl_3$): δ 179.9, 178.2, 158.8, 141.3, 136.3, 132.4, 132.0, 130.6, 130.0, 129.0, 128.7, 128.3, 127.2, 113.7, 60.3, 55.1, 46.0, 45.2, 37.3, 25.7, 23.8, 20.2. Recrystalization of compound **19** from ethylacetate/hexane gave crystals suitable for single crystal X-ray analysis.

(3aRS,4SR,7aSR)-3a,4,7,7a-Tetrahydro-5-(hydroxymethyl)-6-[(E)-1-(4-methoxyphenyl)prop-1-en-2-yl]-2-methyl-4-phenyl-2H-isoindole-1,3-dione (20): R_f (hexane-EtOAc, 60:40) = 0.17; Found: C, 74.60; H, 6.67; N, 3.26. Calc. for $C_{26}H_{27}NO_4$: C, 74.80; H, 6.52; N, 3.35%; IR ν_{max}: 3457, 3035, 2925, 2854, 1700, 1510, 1434, 1251, 1034 cm^{-1}; ^1H NMR (500 MHz, C_6D_6): δ 7.36 (d, J = 7.5 Hz, 2 H, Ph), 7.28 (d, J = 8.5 Hz, 2 H, Ar), 7.17 (t, J = 7.5 Hz, 2 H, Ph), 7.07 (t, J = 7.5 Hz, 1 H, Ph), 6.94 (d, J = 8.5, 2 H, Ar), 6.48 (s, 1 H, ArC*H*), 4.47 (d, J = 7 Hz, 1 H, PhC*H*), 4.35 (d, J = 12 Hz, 1 H, CH_ACH$_B$OH), 3.79 (dd, J = 12, 2 Hz, 1 H, CH$_A$CH_BOH), 3.46 (s, 3 H,

View Article Online
DOI: 10.1039/C6RA01729K

OCH_3), 3.18 (m, 2 H, COCHCH_AH_B, CH_2OH), 3.02 (t, J = 7.5 Hz, 1 H, PhCHCH), 2.53-2.45 (m, 2 H, COCHCH_AH_B), 2.39 (s, 3 H, NCH_3), 1.96 (s, 3 H, C=CCH_3); ^{13}C NMR (125 MHz, $CDCl_3$): δ 179.6, 177.9, 158.3, 140.3, 137.4, 135.6, 132.1, 130.1, 129.6, 128.9, 128.4, 127.8, 127.5, 113.6, 62.2, 55.2, 45.4, 41.8, 37.4, 25.3, 23.7, 17.8.

(3aSR,4RS,7aRS)-3a,4,7,7a-Tetrahydro-6-[(Z)-1-hydroxy-3-phenylprop-2-en-2-yl]-4-(4-methoxyphenyl)-2,5-dimethyl-2H-isoindole-1,3-dione (21): R_f (hexane-EtOAc, 60:40) = 0.4; IR ν_{max}: 3498, 3019, 2932, 1774, 1697, 1610, 1510, 1441, 1250, 1034, 755 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.37-7.25 (m, 7 H, Ar, Ph), 6.91 (d, J = 8.5 Hz, 2 H, Ar), 6.34 (s, 1 H, PhCH), 4.39 (d, J = 13.5 Hz, 1 H, CH_AH_BOH), 4.37 (d, J = 13.0 Hz, 1 H, CH_AH_BOH), 4.13 (s, 1 H, ArCH), 3.81 (s, 3 H, OCH_3), 3.40 (d, J = 8.5 Hz, 1 H, ArCHCH), 3.12 (t, J = 8.0 Hz, 1 H, COCHCH_AH_B), 3.01 (s, 3 H, NCH_3), 2.70 (d, J = 15.5 Hz, 1 H, COCHCH_AH_B), 2.44-2.39 (m, 1 H, COCHCH_2), 1.92 (d, J = 2.0 Hz, 3 H, C=CCH_3); ^{13}C NMR (125 MHz, $CDCl_3$): δ 180.8, 179.4, 158.3, 140.7, 136.2, 134.1, 133.5, 131.3, 130.7, 128.8, 128.3, 128.2, 127.2, 114.3, 59.7, 55.2, 47.1, 45.7, 39.6, 28.1, 25.1, 21.0.

Acknowledgments

Mr. Gonna Somu Naidu is thankful to Council of Scientific and Industrial Research (CSIR), New Delhi for a research fellowship. X-ray crystallographic data for compound **16** was collected at the X-ray diffraction facility, IIT, Indore.

Supporting Information. Copies of the ^{1}H NMR spectra for compounds **10**-**21**, ^{13}C NMR spectra for **11**-**21**, ^{31}P NMR of **12a-c**, COSY and ROESY for compounds (**17**&**18**) , **20,** and X-ray crystallographic data for compounds **11a**, **15**, **16** and **19** are available.

View Article Online
DOI: 10.1039/C6RA01729K

References:

(1) H. Hopf, in *Classics in Hydrocarbon Chemistry: Syntheses, Concepts, Perspectives*, Wiley-VCH, Weinheim, 2000, chap. 7, pp. 103.

(2) H. Hopf, *Angew. Chem. Int. Ed.*, 2001, **40**, 705.

(3) H. Hopf, *Nature*, 2009, **460**, 183.

(4) H. Hopf and M. S. Sherburn, *Angew. Chem. Int. Ed.*, 2012, **51**, 2298.

(5) E. G. Mackay and M. S. Sherburn, *Pure Appl. Chem.*, 2013, **85**, 1227.

(6) M. S. Sherburn, *Acc. Chem. Res.*, 2015, **48**, 1961.

(7) W. J. Bailey, J. Economy and M. E. Hermes, *J. Org. Chem.*, 1962, **27**, 3295.

(8) R. C. Blume, *U.S. Pat.* 3,860,669, 1973.

(9) C. D. Diakoumakos and J. A. Mikroyannidis, *J. Appl. Polym. Sci.*, 1994, **53**, 201.

(10) K. Tekenaka, S. Amamoto, H. Kishi, H. Takeshita, M. Miya and T. Shiomi, *Macromolecules*, 2013, **46**, 7282.

(11) A. L. Kanibolotsky, J.C. Forgie, G. J. McEntee, M. M. A. Talpur, P. J. Skabara, T. D. J. Westgate, J. J. W. McDouall, M. Auinger, S. J. Coles and M. B. Hursthouse, *Chem. Eur. J.*, 2009, **15**, 11581.

View Article Online
DOI: 10.1039/C6RA01729K

(12) R. R. Amaresh, D. Liu, T. Konovalova, M. V. Lakshmikantham, M. P. Cava, and L. D. Kispert, *J. Org. Chem.*, 2001, **66**, 7757.

(13) M. R. Bryce, M. A. Coffin, P. J. Skabara, A. J. Moore,; A. S. Batsanov and J. A. K. Howard, *Chem. Eur. J.*, 2000, **6**, 1955.

(14) Y. Kajiwara, S. Hino and Y. Misaki, *Bull. Chem. Soc. Jpn.*, 2012, **85**, 830.

(15) M. Hasegawa, M. Watanabe and Y. Misaki, *J. Synth. Org. Chem. Jpn.*, 2013, **71**, 1268.

(16) U. Fleischer, W. Kutzelnigg, P. Lazzeretti and V. Muhlenkamp, *J. Am. Chem. Soc.*, 1994, **116**, 5298.

(17) O. Tsuge, E. Wada and S. Kanemasa, *Chem. Lett.*, 1983, **12**, 1525.

(18) B. S. Radovic, M. Careri, A. Mangia, M. Musci and M. Gerboles, Anklam, E. *Food Chem.*, 2001, **72**, 511.

(19) M. Rahman, M. Yusaf, J. U. Chowdhury, and M. A. Wahab, *Bangladesh J. Sci. Ind. Res.*, 1987, **22**, 152.

(20) M. A. Sefton, I. L. Francis, and P. J. Williams, *J. Food Sci.*, 1994, **59**, 142.

(21) A. Arnone, R. Cardillo, V. Dimodugno and G. Nasini, *J. Chem. Soc. Perkin Trans. 1*, 1989, 1995.

(22) W. J. Bailey and J. Economy, *J. Am. Chem. Soc.*, 1955, **77**, 1133.

(23) A. T. Blomquist, and J. A. Verdol, *J. Am. Chem. Soc.*, 1955, **77**, 1806.

(24) H. Priebe and H. Hopf, *Angew. Chem., Int. Ed. Engl.*, 1982, **21**, 286.

View Article Online
DOI: 10.1039/C6RA01729K

(25) S. Woo, N. Squires and A. G. Fallis, *Org. Lett.*, 1999, **1**, 573.

(26) T. A. Bradford, A. D. Payne, A. C. Willis, M. N. Paddon-Row and M. S. Sherburn, *J. Org. Chem.*, 2010, **75**, 491.

(27) S. Fielder, D. D. Rowan and M. S. Sherburn, *Angew. Chem. Int. Ed.*, 2000, **39**, 4331.

(28) J. I. G Cadogan, S. Cradock, S. Gillam and I. Gosney, *J. Chem. Soc.,Chem. Commun.*, 1991, 114.

(29) A. D. Payne, G. Bojase, M. N. Paddon-Row and M. S. Sherburn, *Angew. Chem. Int. Ed.*, 2009, **48**, 4836.

(30) T. A. Bradford, A. D. Payne, A. C. Willis, M. N. Paddon-Row and M. S. Sherburn, *Org. Lett.*, 2007, 9, 4861.

(31) N. A. Miller, A. C. Willis, M. N. Paddon-Row and M. S. Sherburn, *Angew. Chem. Int. Ed.*, 2007, **46**, 937.

(32) G. Bojase, A. D. Payne, A. C. Willis and M. S. Sherburn, *Angew. Chem. Int. Ed.*, 2008, **47**, 910.

(33) A. D. Payne, A. C. Willis and M. S. Sherburn, *J. Am. Chem. Soc.*, 2005, **127**, 12188.

(34) N. Thies and E. Haak, *Angew. Chem. Int. Ed*., 2015, **54**, 4097.

(35) K. M. Brummondo, H. Chen, P. Sill and L. You, *J. Chem. Soc*., 2002, **124**, 15186.

(36) S. Brase, H. Wertal, D. Frank, D. Vidovic and A. Meijere, *Eur. J. Org. Chem.*, 2005, 4167.

View Article Online
DOI: 10.1039/C6RA01729K

(37) M. Arisawa, T. Sugihara and M. Yamaguchi, *Chem. Commun.*, 1998, 2615.

(38) T. Miura, T. Biyajima, T. Toyoshima and M. Murakami, *Beilstein. J. Org. Chem.*, 2011, **7**, 578.

(39) K. Beydoun, H.-J. Zhang, B. Sundararaju, B. Demerseman, M. Achard, Z. Xi and C. Bruneau, *Chem. Commun.*, 2009, 6580.

(40) H. Srour, K. Abidi, Z. Sahli, B. Sundararaju, N. Hamdi, M. Achard and C. Bruneau, *ChemCatChem*, 2011, **3**, 1876.

(41) J. L. Notre, A. A. Martinez, P. H. Dixneuf and C. Bruneau, *Tetrahedron*, 2003, **59**, 9425.

(42) B. K. D. Kim, Y. Do and S. Chang, *Org. Lett.*, 2003, **5**, 3041.

(43) H. Wang, B. Beiring, D-G. Yu, K. D. Collins and F. Glorius, *Angew. Chem. Int. Ed.*, 2013, **52**, 12430.

(44) C. J. Reider, K. J. Winberg and F. G. West, *J.Org. Chem.*, 2011, **76**, 50.

(45) H. L. Shimp, A. Hare, M. McLaughlin and G. C. Micalizio, *Tetrahedron*, 2008, **64**, 3437.

(46) S. Kim, D. Seomoon and P. H. Lee, *Chem. Commun.*, 2009, 1873.

(47) C. S. Chin, H. Lee, H. Park and M. Kim, *Organomatallics*, 2002, **21**, 3889.

(48) S. K. Ghosh, R. Singh and S. M. Date, *Chem. Commun.*, 2003, 636.

(49) E. J. Corey and M. Chaykovsky, *J. Am. Chem. Soc.*, 1965, **87**, 1353.

(50) S. M. Date, R. Singh and S. K. Ghosh, *Org. Biomol. Chem.*, 2005, **3**, 3369.

View Article Online
DOI: 10.1039/C6RA01729K

(51) S. M. Date and S. K. Ghosh, *Angew. Chem. Int. Ed.*, 2007, **46**, 386.

(52) S. M. Date and S. K. Ghosh, *Bull. Chem. Soc. Jpn.*, 2004, **77**, 2099.

(53) R. Singh and S. K. Ghosh, *Org. Lett.*, 2007, **9**, 5071.

(54) R. Singh and S. K. Ghosh, *Tetrahedron*, 2010, **66**, 2284.

(55) R. Singh, G. C. Singh and S. K. Ghosh, *Tetrahedron Lett.*, 2005, **46**, 4719.

(56) R. Singh, G. C. Singh and S. K. Ghosh, *Eur. J. Org. Chem.*, 2007, 5376.

(57) S. K. Ghosh, R. Singh and G. C. Singh, *Eur. J.Org. Chem.*, 2004, 4141.

(58) R. Singh and S. K. Ghosh, *Chem. Commun.*, 2011, **47**, 10809.

(59) R. Singh and S. K. Ghosh, *Tetrahedron:Asymmetry*, 2014, **25**, 57.

(60) M. N. Paddon-Row and M. S. Sherburn, *Chem. Commun.*, 2012, **48**, 832.

(61) H. Toombs-Ruane, E. L. Pearson, M. N. Paddon-Row and M. S. Sherburn, *Chem. Commun.*, 2012, **48**, 6639.

(62) A. Erkkila and P. M. Pihko, *J. Org. Chem.*, 2006, **71**, 2538.

(63) K. Speck and T. Magauer, *Beilstein J. Org. Chem.*, 2013, **9**, 2048.

(64) S. Kiyooka H. Fujimoto, M. Mishima, S. Kobayashi, K. M. Uddin and M. Fujio, *Tetrahedron Lett.*, 2003, **44**, 927.

(65) N. Lahmar, J. Aatar, T. B. Ayed, H. Amri and M. Bellassoued, *J. Organometal. Chem.*, 2006, **691**, 3018.

View Article Online
DOI: 10.1039/C6RA01729K

Graphical Abstract

Synthesis of highly functionalized [3]dendralenes and their Diels-Alder reaction displaying unexpected regioselectivity

Gonna Somu Naidu[a], Rekha Singh[a], Mukesh Kumar[b] and Sunil K. Ghosh*[a]

[a] Bio-Organic Division

[b]Solid State Physics Division

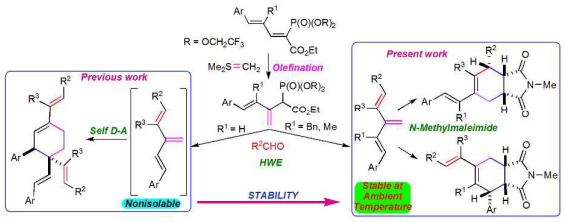
Bhabha Atomic Research Centre, Trombay, Mumbai 400085, India

*Corresponding author

Tel: +91-22-25595012; Fax: +91-22-25505151

E-mail: ghsunil@barc.gov.in

Graphical abstract



Sequential olefinations applied for the synthesis of acyclic tetrasubstituted [3]dendralenes which didn't cyclodimerize and displayed unusual regioselectivity in Diels-Alder reaction.