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Computational Study Potency of Eugenol and Safrole Derivatives as Active Sunscreen Material

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ABSTRACT. Computational studies have been carried out on eugenol and safrole derivatives as active sunscreen materials. The calculations were using Density Functional Theory (DFT) with the B3LYP functional and basis set 6-31G (d). The calculated eugenol derivative i.e. 3,4-dimethoxy isobutyl cinnamate; 3,4-dimethoxy isoamyl cinnamate; 3,4-dimethoxy isohexyl cinnamate; 3,4 dimethoxy isoheptyl cinnamate; 3,4-dimethoxy isoctyl cinnamate. The calculated safrole i.e. 3,4-methylenedioxy isobutyl cinnamate; 3,4-methylenedioxy isoamyl cinnamate; 3,4-methylenedioxy isohexyl cinnamate; 3,4-methylenedioxy isoheptyl cinnamate; and 3,4-methylenedioxy isooctyl cinnamate. The main parameter in determining the potential of sunscreen compounds is energy gap. The results of computational calculations show that the 3,4-methylenedioxy isohexyl cinnamate has the smallest energy gap (HOMO-LUMO) of 0.15021 eV. This shows that 3,4-methylenedioxy isohexyl cinnamate has a better potential as an active sunscreen material. In addition, the elongation of the alkyl chain does not significantly affect the HOMO-LUMO energy difference

Keywords: Computational, DFT, B3LYP, Eugenol, Safrole, Sunscreen

INTRODUCTION

Maluku Islands is one of the areas that has considerable potential for development of essential oils. Essential oil is one of the secondary metabolites produced by higher plants and has an important role for the plants and also for human life. The compounds from essential oil been reported to have bioactive properties, which can be used as ingredients in medicines and cosmetics (He et al., 2021; Sarkic & Stappen, 2018; Tongnuanchan & Benjakul, 2014).. The certain characteristics for cosmetics and health used that are known to have the characteristic of being able to absorb ultraviolet (UV) rays from sunlight (sunscreen compound). Research on the development of sunscreen compound products is currently being carried out. One of the essential oils that can be used to make SPF is a chalcone derivatives (Barbulova, Colucci, & Apone, 2015; Cefali, Ataide, Moriel, Foglio, & Mazzola, 2016; Ikhtiarudin, Agistia, Harlianti, & Zamri, 2019).

As far as we know, not much research has been done to synthesize sunscreen compounds from cinnamate derivatives. The research to synthesis sunscreen compounds derived from cinnamate was conducted from eugenol which obtained from clove oil and produced a sunscreen compound of 3,4-dimethoxy isoamyl cinnamate. This result provides maximum SPF (Sun Protection Factor) protection at concentration of 10.25µg/mL (He et al., 2021; Wahyuningsih, Raharjo, & Tahir, 2010). Safrole has a similar structure to eugenol, which has an allyl group. With the same method, the cinnamic derivative sunscreen compound of 3,4-methylenedioxy isoamyl cinnamate was synthesized from safrole which isolated from cullilawang (*Cinnamomun cullilawang*) oil. The results of this study resulted in the optimal SPF concentration for 3,4-methylenedioxy isoamyl was 5.31µg /mL (Shamsah & Owolabi, 2020; Sohilait, Sohilait, & Fransina, 2013).

The development of sunscreen compounds can be done both experimentally and in a modeling method. Experimental results will provide accurate results but require a relatively greater time and cost when compared to modeling using computational chemistry methods. With modeling can be obtained estimates of the nature of the compound of the model with low cost and short time, but to be able to provide accurate data will depend very much on the theoretical approach taken (Cramer, 2004).

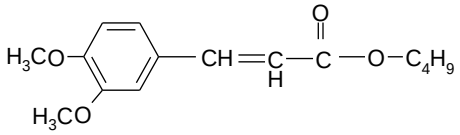
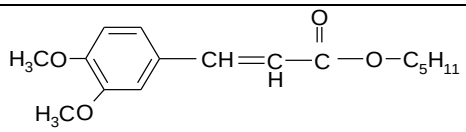
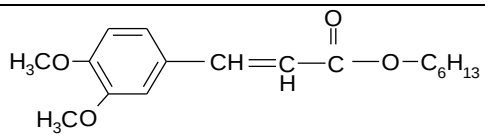
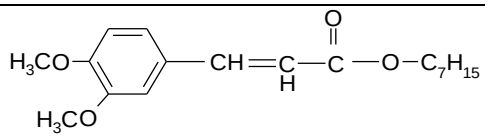
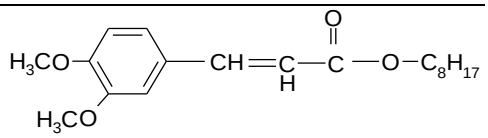
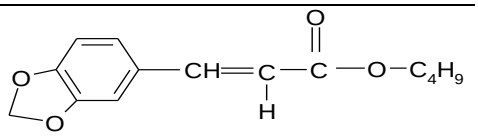
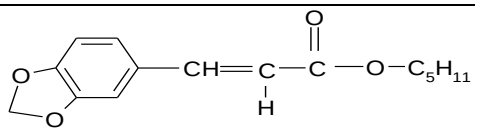
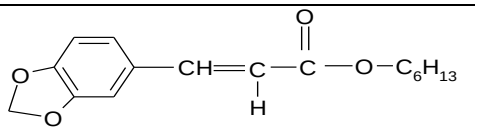
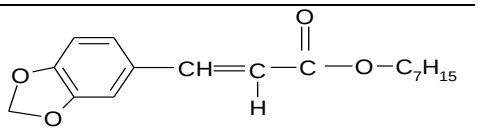
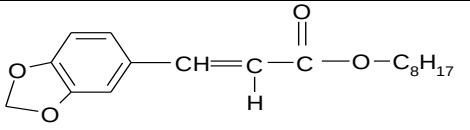
Computational methods allow the structural design of new compounds and determination of their properties prior to synthesis. The design of sunscreen compounds using computational chemistry has more advantages because new compounds can be obtained with relatively low cost and very efficient.

EXPERIMENTAL SECTION

Computational calculation using Density Functional Theory for geometry optimization. The calculations were using basis set 6-31G(d) and

functional B3LYP. The calculation for geometry optimization in gas phase. The materials of this research are 3,4-methylenedioxy isoamyl cinnamate obtained from the experimental literature (Sohilait, Sohilait, & Fransina, 2013), and the structure of 3,4-dimethoxy isoamyl sinamate from other research (Wahyuningsih, Raharjo, & Tahir, 2010). The structure of eugenol and safrole can be seen in **Table 1**. The accurate properties of a molecule can be predicted if the structure of a molecule is optimized with the lowest energy (Maahury, Male, & Martoprawiro, 2020). The properties to be obtained include structural parameters, dipole moment, atomic charge, HOMO-LUMO, energy gap, and orbital population.

Table 1. Structure of the eugenol and safrole derivative compounds

No	Compound	*	Structure
1	3,4-dimethoxy isobutyl cinnamate	E_1	
2	3,4-dimethoxy isoamyl cinnamate	E_2	
3	3,4-dimethoxy isohexyl cinnamate	E_3	
4	3,4 dimethoxy isoheptyl cinnamate	E_4	
5	3,4-dimethoxy isoctyl cinnamate	E_5	
6	3,4-methylenedioxy isobutyl cinnamate	S_1	
7	3,4- methylenedioxy isoamyl cinnamate	S_2	
8	3,4- methylenedioxy isohexyl cinnamate	S_3	
9	3,4- methylenedioxy isoheptyl cinnamate	S_4	
10	3,4- methylenedioxy isoctyl cinnamate	S_5	

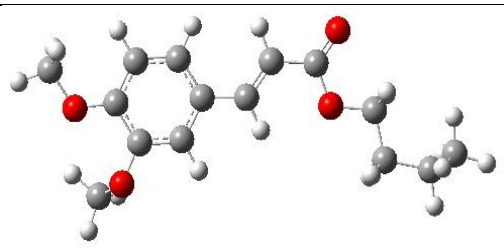
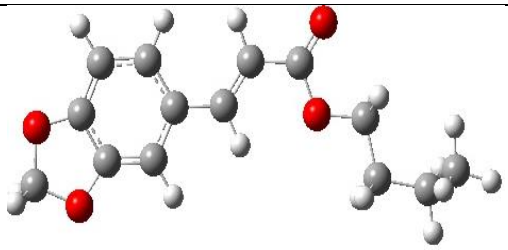
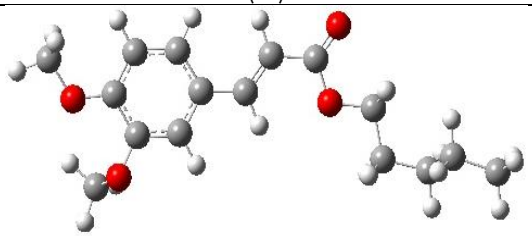
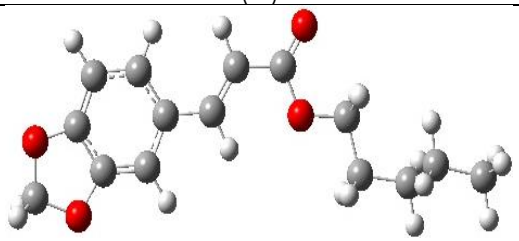
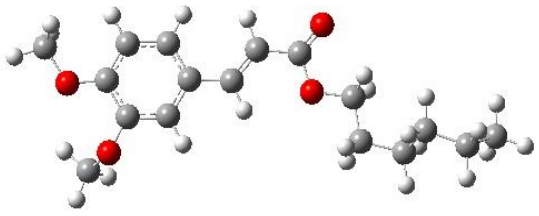
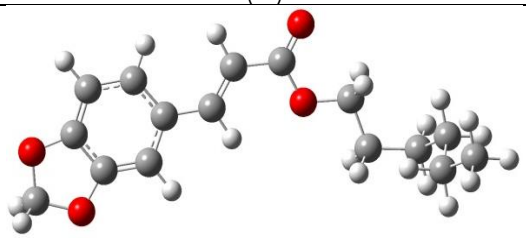
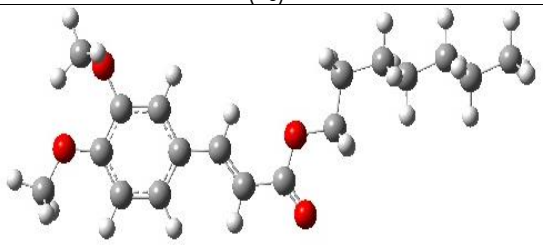
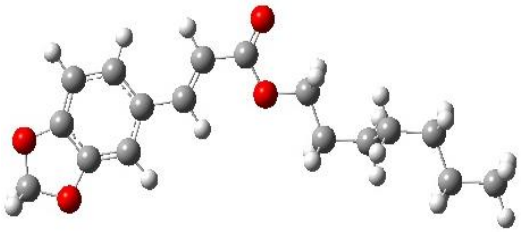
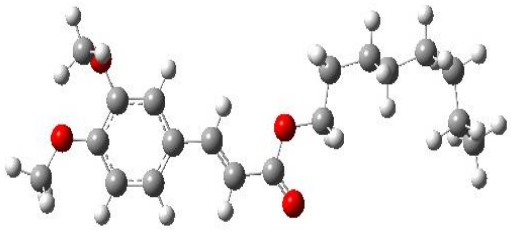
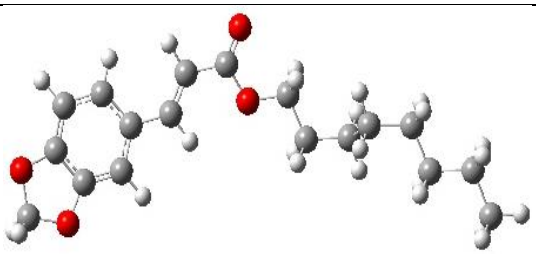
*: *The name used in the study* (**E** for Eugenol and **S** for Safrole)

RESULTS AND DISCUSSION

Geometry Optimization for Structure

The eugenol and safrole structure has almost the same structure, which is built by a phenyl ring and an alkyl group linked to a ketone (RCOR') group. The structure of the eugenol derivative, two methoxy (CH_3O) groups are added to the phenyl ring, while the methylenedioxy (CH_2O_2) group is added to the phenyl ring. The following is the three-dimensional structure of the optimized eugenol and safrolee derivatives as presented in **Table 2**.

Table 2. Three-dimensional structure of the optimized eugenol and safrole derivatives

Eugenol Derivative Structure	Safrolee Derivative Structure
 (E_1)	 (S_1)
 (E_2)	 (S_2)
 (E_3)	 (S_3)
 (E_4)	 (S_4)
 (E_5)	 (S_5)

Atomic dot symbols : (Hydrogen, H), (Carbon, C) and (Oxygen, O)

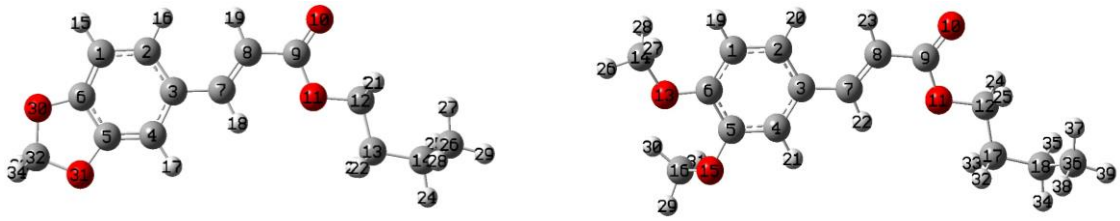


Figure 1. The structure of eugenol and safrole with numbering

Geometry Optimization for Structure Parameters

Geometry optimization can determine the stability of a molecule so that the model or description of the molecular structure is closer to the actual molecular structure. Determine the effect of the substituents on bond length, dihedral angle, and bond angle, the initial structure of the eugenol and safrole derivatives must marked with the atomic numbering for comparing the values of the initial structure parameters with the optimized structure parameters. The structure with numbering for eugenol and safrole can be seen in **Figure 1** while the data on the effect of the substituents on structural parameters are presented in **Table 3**.

Structural parameters such as bond length, bond angle, and dihedral of the eugenol derivative do not change significantly in the presence of an alkyl group in the main structure (**Table 4**). The bond angle <10,11,12 and <11,12,13 get smaller due to the extension of the alkyl group which causes repulsion so that the bond angle shrinks. The dihedral angles $D_{6,5,4,3}$, $D_{1,7,8,9}$ and $D_{10,11,12,13}$ have almost the same degree scale for each derivative structure. The substitution of the alkyl group in the eugenol derivative structure has a less significant effect on the dihedral angle. The same results were obtained by Harno et al (2018) with the platinum(II) porphyrin that substituents do not give any significant effect on the structure of complexes.

For safrole derivatives structural parameters such as bond length and bond angle of the safrole derivative do not change significantly in the presence of an alkyl group in the main structure but substitution with an alkyl group and the presence of a methoxy group gives a considerable influence on the dihedral angle.

Table 3. Structural parameter of eugenol (E) and safrole (S) derivatives

Optimized Geometry		Compound									
		E_1	E_2	E_3	E_4	E_5	S_1	S_1	S_3	S_4	S_5
Bond Length (Å)	$r_{6,5}$	1.39	1.39	1.39	1.39	1.39	1.38	1.38	1.38	1.38	1.38
	$r_{5,4}$	1.41	1.41	1.41	1.41	1.41	1.39	1.39	1.39	1.39	1.39
	$r_{4,3}$	1.40	1.40	1.40	1.40	1.40	1.38	1.38	1.38	1.38	1.38
	$r_{1,7}$	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46
	$r_{7,8}$	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
	$r_{8,9}$	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47
	$r_{10,11}$	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52
	$r_{11,12}$	1.54	1.54	1.54	1.54	1.54	1.53	1.54	1.54	1.54	1.54
	$r_{12\text{-}13}$	1.53	1.54	1.54	1.54	1.54	1.53	1.54	1.54	1.54	1.54
Bond Angle (°)	$<_{6,5,4}$	119.48	119.49	119.49	119.49	119.49	121.96	121.96	121.96	121.95	121.96
	$<_{5,4,3}$	119.03	119.03	119.03	119.02	119.03	121.66	121.65	121.66	121.67	121.66
	$<_{1,7,8}$	127.43	127.44	127.43	127.44	127.43	127.65	127.69	127.71	127.73	127.71
	$<_{7,8,9}$	124.44	124.41	124.43	124.42	124.45	124.39	124.35	124.32	124.30	124.29
	$<_{10,11,12}$	113.39	113.49	113.42	113.42	113.40	113.35	113.40	113.34	113.57	113.68
	$<_{11,12,13}$	114.52	114.91	114.56	114.48	114.43	114.51	114.92	116.16	114.57	114.60
Dihedral (°)	$D_{6,5,4,3}$	0.83	0.90	0.91	0.91	0.89	-0.03	-0.01	-0.06	0.02	0.04
	$D_{1,7,8,9}$	179.74	179.70	179.60	179.67	179.62	179.82	179.89	179.75	179.97	179.97
	$D_{10,11,12,13}$	65.87	66.51	66.22	66.41	65.99	65.96	66.36	63.18	66.97	66.73

Geometry Optimization for Moment dipole

Molecular dipole moment is a primary quantity providing essential insight into the distribution of electron charge within a molecule and measures the amount of a molecule's polarity. The electronegativity of the atoms involved determines polarity. Data on **Table 3** shows that the presence of methylenedioxy, methoxy, and alkyl groups causes the 3,4-dimethoxy isobutyl cinnamate compound to have a higher dipole moment value of 3,4-methylenedioxy isoamyl cinnamate and 3,4-dimethoxy isoamyl cinnamate. The presence of oxygen atoms in the methylenedioxy and dimethoxy groups can attract electrons (electronegativity) greater than carbon atoms. Thus, polarized bonds are formed when oxygen atoms bind to carbon atoms. The overall polarity value results from the polarity of the bond and the influence of lone pair electrons in the molecule. Oxygen contains lone pair electrons, which can increase the dipole moment. The dipole moment of eugenol and safrole derivatives are shown in **Table 4**.

Atomic Charge

The method to calculate atomic charge is density functional theory (DFT). This method is chosen because it sees electrons as a density unit, not individuals. So, after optimization, the atomic charge number gives a stable number, not fluctuating. The reactivity of a molecule is related to the charge of each atom. Reactivity refers to how the molecule can interact with another molecule. Atomic charge analysis was carried out to determine the effect of substituents on the atomic charge distribution patterns of eugenol and safrole compounds. The atomic charge of eugenol and safrole derivatives is shown in **Table 5**.

For eugenol compounds, the data in **Table 5** shows that the atomic charges on C6 and C3 atoms are negatively charged. In contrast, C5 and C4 are positively charged due to methoxy groups on the eugenol derivative compounds. The C1 and C7 atoms show an induction effect between the alkyl group substituents on the cinnamic chain and the phenyl ring. The C1 and C7 values are negative for all eugenol derivative compounds. At C8 and C9 atoms of the eugenol derivative compounds with values that are not different from their respective derivatives, C8 atoms are negatively charged, and C9 atoms are positively charged. This is because the strength of the delocalized electrons in the phenyl ring is greater, affecting the C8 atom than the C9, which is bound as a ketone carbonyl group. For safrole compounds, it shows that the substitution of (CH_2O_2) and the extension of the alkyl group cause an induction effect that is both attractive and electron-donating attached to the atom so that the electron-attracting groups will result in the net charge of the atom being electropositive. In contrast, the presence of electron-donating groups will result in a charge. Overall, net atoms will become more electronegative.

Table 4. The dipole moment of eugenol and safrole derivatives

Compound	Dipole Moment (Debye)	Compound	Dipole Moment (Debye)
E_1	3.71	S_1	3.59
E_2	3.68	S_2	3.56
E_3	3.63	S_3	3.60
E_4	3.66	S_4	3.59
E_5	3.63	S_5	3.51

Table 5. Atomic charge of eugenol and safrole derivatives

Atomic Position	Compound/Atomic Charge									
	E_1	E_2	E_3	E_4	E_5	S_1	S_2	S_3	S_4	S_5
C6	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25
C5	0.32	0.32	0.32	0.32	0.32	0.33	0.33	0.33	0.33	0.33
C4	0.35	0.35	0.35	0.35	0.35	0.34	0.34	0.34	0.34	0.34
C3	-0.20	-0.20	-0.20	-0.20	-0.20	-0.18	-0.18	-0.18	-0.18	-0.18
C1	0.17	0.17	0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.16
C7	-0.15	-0.15	-0.15	-0.15	-0.15	-0.15	-0.15	-0.15	-0.15	-0.15
C8	-0.22	-0.22	-0.22	-0.22	-0.22	-0.22	-0.22	-0.22	-0.22	-0.22
C9	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63
C10	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03
C11	-0.27	-0.28	-0.28	-0.28	-0.28	-0.27	-0.28	-0.28	-0.28	-0.28
C12	-0.26	-0.26	-0.27	-0.27	-0.27	-0.26	-0.27	-0.27	-0.27	-0.27
C13	-0.45	-0.25	-0.25	-0.26	-0.26	-0.45	-0.26	-0.25	-0.26	-0.26
O1	-0.51	-0.51	-0.51	-0.51	-0.51	-0.50	-0.50	-0.50	-0.50	-0.50
O2	-0.49	-0.49	-0.49	-0.49	-0.49	-0.49	-0.49	-0.49	-0.49	-0.49

HOMO-LUMO Display

The load density contours display HOMO LUMO shows how molecular orbital distribution for each molecule (Maahury, Male, & Martoprawiro, 2020). The load density contours display HOMO LUMO of eugenol and safrole derivatives can be seen in **Figure 2** and **Figure 3**. The red and green color distribution indicates electrons in the *p* orbital region. The color distribution indicates the delocalization of the molecule.

The difference in delocalization in the eugenol and safrole derivative molecules where the HOMO charge density contour shows delocalization in all the main chains and the groups that are attached to the benzene ring. Meanwhile, the LUMO charge density contour is also delocalized on the main chain but not on the bonding group and tends to be delocalized towards the alkyl group. Chain elongation of alkyl groups in all compounds, both eugenol, and safrole derivatives, has significant effect on the conformational structure and surface density (Djunaidi, Astuti, & Siahaan, 2019; Kohay, Bilkis, & Mishael, 2019; Niquini et al., 2020; Sherin & Manojkumar, 2020).

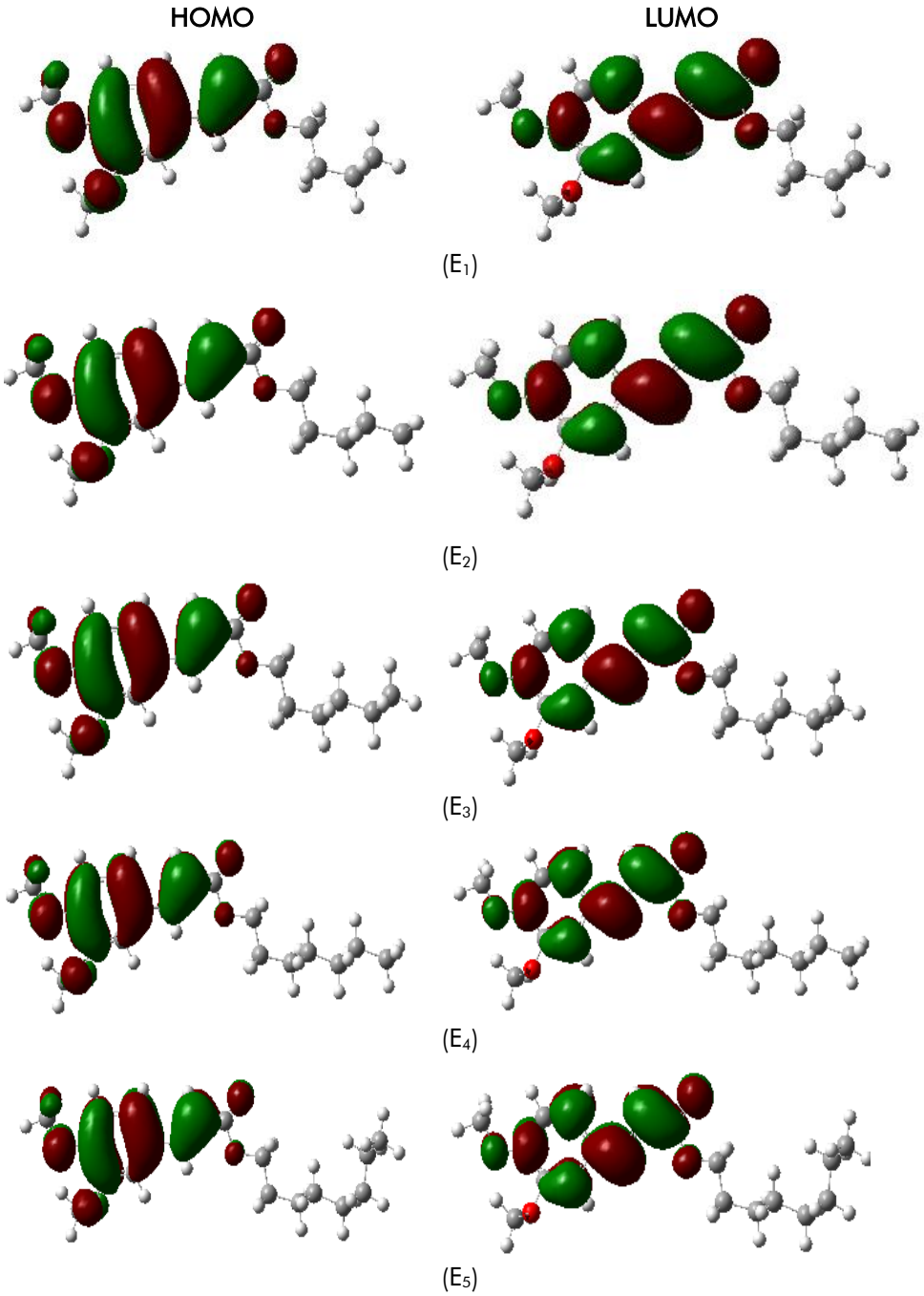


Figure 2. The load density contours display HOMO LUMO of eugenol derivatives

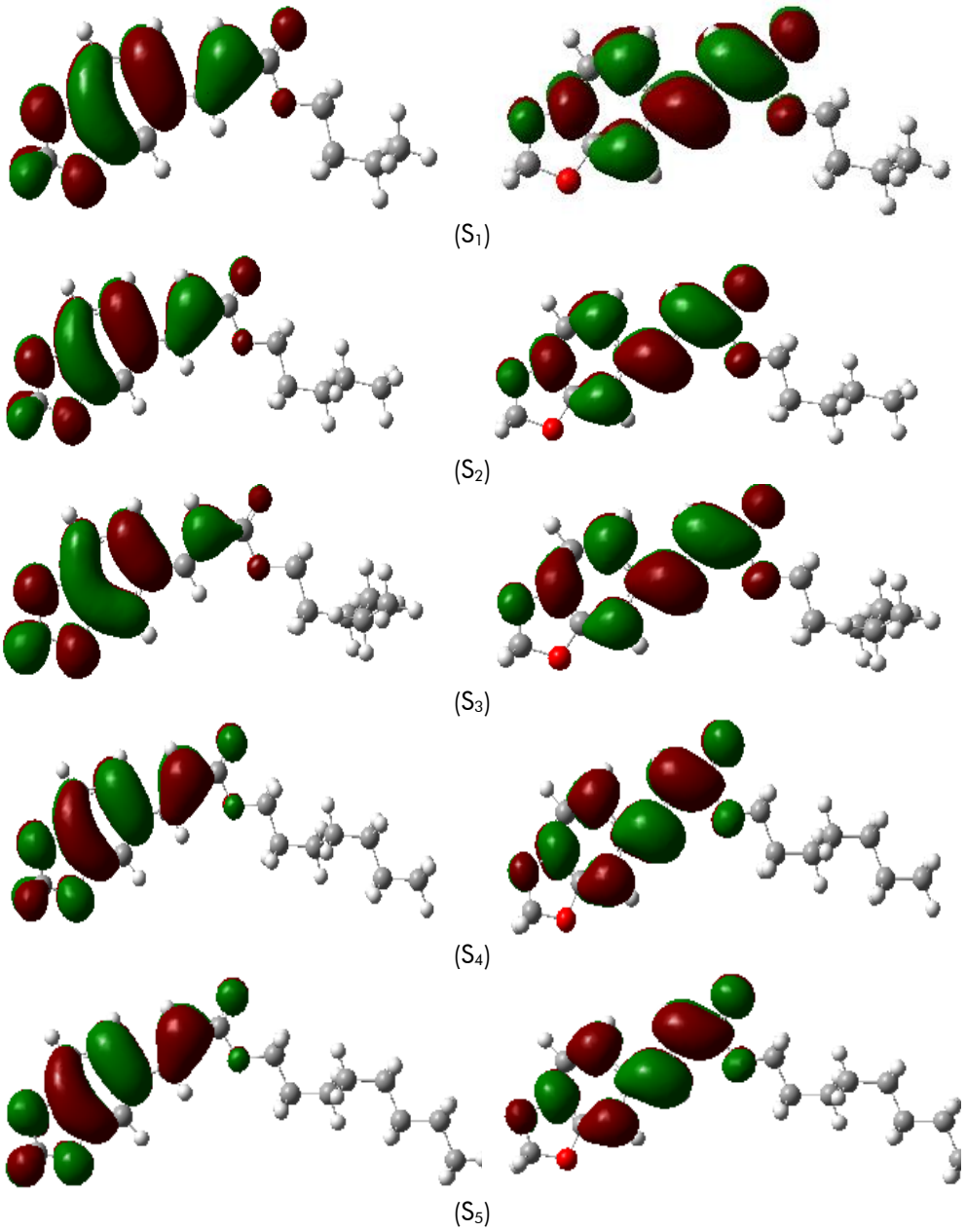


Figure 3. The load density contours display HOMO LUMO of safrole derivatives

If HOMO-LUMO densities are spread across the molecule and overlap, the transferred electron from HOMO to LUMO can easily happen (Maahury et al., 2020). HOMO and LUMO of derivatives eugenol and safrole are not dispersed throughout the molecule. The LUMO density of eugenol and safrole derivatives overlap with HOMO, which causes easy excitation from HOMO to LUMO. This condition shows the properties as a good sunscreen of these compounds

Orbital population

Analysis of orbital population can explain which orbital contributes to HOMO-LUMO spreading quantitatively (Maahury et al., 2020d). The percentage of the orbital population of the safrole and eugenol molecules is shown in **Table 6**.

From **Table 6**, it can be seen that the main components of NHOMO, NLUMO and HOMO of all the structures of eugenol and safrole derivatives are derived from *p* atomic orbitals of C6, C3 atoms in the phenyl ring and C7 atom in the middle chain, while the main components of LUMO for all eugenol derivatives come from *p* atomic orbital of C8 atom in the chain. In contrast to the main element of LUMO, all safrole derivatives come from the C4 orbital in the phenyl ring. Overall, the structure of the eugenol derivative compounds shows the transfer of charge only in the middle chain. In contrast, the safrole derivatives' structure shows the transfer of charge from the phenyl ring to the middle chain.

Table 6. Percentage of the orbital population of the eugenol and safrole compounds

		C3		C1		C6		C5		C4		C7		C8		C9		C10		C11		C12		C13	
Molecule	Orbital	*s*	*p*	*s*	*p*	*s*	*p*	*s*	*p*	*s*	*p*	*s*	*p*	*s*	*p*	*s*	*p*	*s*	*p*	*s*	*p*	*s*	*p*	*s*	*p*
E_1	NHOMO	0.09	23.10	0.24	1.93	1.03	44.68	0.12	18.33	0.62	0.50	0.05	2.75	0.01	6.44	0.01	0.04	0.00	0.06	0.00	0.01	0.00	0.00	0.00	0.00
	HOMO	0.00	5.49	0.07	23.76	0.37	1.04	0.02	16.32	0.04	22.61	0.00	4.53	0.01	25.42	0.00	0.14	0.00	0.12	0.00	0.03	0.00	0.01	0.00	0.01
	LUMO	0.01	0.01	0.00	6.77	0.03	8.06	0.00	1.57	0.00	15.45	0.00	31.85	0.00	25.24	0.00	10.70	0.00	0.11	0.01	0.15	0.00	0.02	0.02	0.01
	NLUMO	0.00	35.07	0.02	0.31	0.10	33.71	0.06	28.80	0.02	1.27	0.02	0.09	0.00	0.14	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E_2	NHOMO	0.09	23.10	0.24	1.91	1.03	44.67	0.12	18.40	0.62	0.49	0.05	2.74	0.01	6.41	0.01	0.03	0.00	0.06	0.00	0.01	0.00	0.00	0.00	0.00
	HOMO	0.00	5.50	0.06	23.75	0.37	1.05	0.02	16.29	0.04	22.58	0.00	4.54	0.01	25.44	0.00	0.14	0.00	0.12	0.00	0.03	0.00	0.01	0.00	0.01
	LUMO	0.01	0.01	0.00	6.77	0.03	8.06	0.00	1.57	0.00	15.46	0.00	31.83	0.00	25.24	0.00	10.68	0.00	0.10	0.01	0.15	0.00	0.02	0.04	0.01
	NLUMO	0.00	35.06	0.02	0.31	0.10	33.72	0.06	28.80	0.02	1.27	0.01	0.09	0.00	0.13	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E_3	NHOMO	0.09	23.09	0.24	1.91	1.03	44.67	0.12	18.41	0.62	0.49	0.04	2.74	0.01	6.42	0.01	0.04	0.00	0.06	0.00	0.01	0.00	0.00	0.00	0.00
	HOMO	0.00	5.50	0.07	23.75	0.37	1.06	0.02	16.28	0.04	22.58	0.00	4.55	0.01	25.45	0.00	0.14	0.00	0.12	0.00	0.03	0.00	0.01	0.00	0.01
	LUMO	0.01	0.01	0.00	6.78	0.02	8.06	0.00	1.58	0.00	15.47	0.00	31.82	0.00	25.26	0.00	10.67	0.00	0.10	0.01	0.14	0.00	0.02	0.02	0.01
	NLUMO	0.00	35.07	0.02	0.31	0.10	33.72	0.06	28.80	0.02	1.27	0.01	0.09	0.00	0.13	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E_4	NHOMO	0.08	23.08	0.22	1.90	1.02	44.66	0.12	18.46	0.62	0.49	0.04	2.75	0.01	6.41	0.01	0.04	0.00	0.06	0.00	0.01	0.00	0.00	0.00	0.00
	HOMO	0.00	5.51	0.07	23.75	0.37	1.06	0.02	16.27	0.04	22.57	0.00	4.55	0.00	25.46	0.00	0.14	0.00	0.12	0.00	0.03	0.00	0.01	0.00	0.01
	LUMO	0.01	0.01	0.01	6.79	0.02	8.06	0.00	1.58	0.00	15.47	0.00	31.81	0.00	25.25	0.00	10.67	0.00	0.10	0.01	0.14	0.00	0.02	0.04	0.01
	NLUMO	0.00	35.06	0.03	0.31	0.10	33.73	0.06	28.81	0.02	1.27	0.00	0.09	0.00	0.13	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E_5	NHOMO	0.09	23.10	0.25	1.92	1.03	44.67	0.12	18.35	0.62	0.50	0.05	2.74	0.01	6.43	0.01	0.04	0.00	0.06	0.00	0.01	0.00	0.00	0.00	0.00
	HOMO	0.00	5.49	0.06	23.75	0.37	1.04	0.02	16.31	0.04	22.60	0.00	4.54	0.01	25.42	0.00	0.14	0.00	0.13	0.00	0.03	0.00	0.01	0.00	0.01
	LUMO	0.01	0.01	0.00	6.77	0.03	8.06	0.00	1.57	0.00	15.45	0.00	31.83	0.00	25.24	0.00	10.69	0.00	0.10	0.01	0.14	0.00	0.02	0.04	0.01
	NLUMO	0.00	35.06	0.02	0.32	0.10	33.70	0.06	28.78	0.02	1.27	0.03	0.10	0.00	0.15	0.01	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S_1	NHOMO	0.04	13.90	0.00	2.57	22.67	35.93	0.00	8.84	0.00	0.63	0.00	5.02	0.00	10.25	0.00	0.02	0.00	0.10	0.00	0.01	0.00	0.00	0.00	0.00
	HOMO	0.01	4.62	0.00	27.12	0.01	0.15	0.00	21.71	0.00	30.69	0.00	3.77	0.00	11.52	0.00	0.20	0.00	0.12	0.00	0.03	0.00	0.01	0.00	0.01
	LUMO	0.00	0.16	0.00	9.03	0.00	11.14	0.00	1.44	0.01	19.99	0.00	38.26	0.00	6.88	0.00	12.72	0.00	0.12	0.01	0.18	0.00	0.02	0.03	0.01
	NLUMO	0.00	36.13	0.00	1.04	0.00	29.81	0.01	23.21	0.00	2.70	0.01	0.79	0.00	6.27	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S_2	NHOMO	0.01	16.63	0.00	3.07	0.00	42.99	0.00	10.60	0.01	0.75	0.00	6.01	0.00	19.77	0.00	0.03	0.00	0.11	0.00	0.01	0.00	0.01	0.00	0.01
	HOMO	0.00	4.04	0.00	23.69	0.01	0.13	0.00	18.95	0.00	26.82	0.00	3.31	0.00	22.70	0.00	0.18	0.00	0.10	0.00	0.03	0.00	0.01	0.00	0.01
	LUMO	0.00	0.13	0.00	7.27	0.00	8.95	0.00	1.16	0.01	16.08	0.00	30.73	0.00	25.15	0.00	10.21	0.00	0.10	0.01	0.14	0.00	0.02	0.03	0.01
	NLUMO	0.00	38.43	0.00	1.10	0.00	31.71	0.01	24.68	0.00	2.87	0.01	0.83	0.00	0.31	0.00	7.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S_3	NHOMO	0.00	17.93	0.00	3.35	0.00	46.47	0.00	11.38	0.00	0.82	0.00	6.53	0.00	13.35	0.00	0.03	0.00	0.12	0.00	0.01	0.00	0.01	0.00	0.01
	HOMO	0.00	4.07	0.00	23.71	0.00	0.14	0.00	19.01	0.00	26.82	0.00	3.26	0.00	22.65	0.00	0.18	0.00	0.10	0.00	0.03	0.00	0.01	0.00	0.01
	LUMO	0.00	0.12	0.00	7.24	0.00	8.96	0.00	1.16	0.00	16.06	0.00	30.50	0.26	25.15	0.00	10.24	0.00	0.10	0.01	0.14	0.00	0.02	0.01	0.01
	NLUMO	0.00	38.45	0.00	1.11	0.00	31.67	0.00	24.66	0.00	2.91	0.00	0.84	0.00	0.31	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S_4	NHOMO	0.00	17.91	0.00	3.34	0.00	46.46	0.00	11.39	0.00	0.81	0.00	6.55	0.00	13.36	0.00	0.03	0.00	0.13	0.00	0.01	0.00	0.01	0.00	0.01
	HOMO	0.00	4.07	0.00	23.71	0.00	0.14	0.00	19.00	0.00	26.82	0.00	3.27	0.00	22.66	0.00	0.18	0.00	0.10	0.00	0.03	0.00	0.01	0.00	0.01
	LUMO	0.00	0.12	0.00	7.26	0.00	8.95	0.00	1.16	0.00	16.07	0.00	30.75	0.00	25.15	0.00	10.22	0.00	0.10	0.00	0.14	0.00	0.02	0.04	0.01
	NLUMO	0.00	38.44	0.00	1.11	0.00	31.66	0.00	24.65	0.00	2.91	0.02	0.84	0.00	0.32	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S_5	NHOMO	0.01	17.97	0.01	3.30	0.00	46.45	0.00	11.49	0.01	0.81	0.01	6.51	0.00	13.26	0.00	0.03	0.00	0.13	0.00	0.01	0.00	0.01	0.00	0.01
	HOMO	0.01	4.03	0.00	23.68	0.02	0.12	0.00	18.93	0.00	26.82	0.00	3.32	0.01	22.71	0.00	0.18	0.00	0.10	0.00	0.03	0.00	0.01	0.00	0.01
	LUMO	0.00	0.13	0.01	7.29	0.01	8.95	0.00	1.17	0.01	16.09	0.00	30.69	0.00	25.15	0.00	10.19	0.00	0.10	0.00	0.14	0.00	0.02	0.04	0.01
	NLUMO	0.00	38.40	0.00	1.10	0.00	31.70	0.01	24.67	0.00	2.86	0.05	0.84	0.00	0.33	0.01	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 7. Energy gap of eugenol and safrole derivatives

Energy	Compound									
	E_1	E_2	E_3	E_4	E_5	S_1	S_2	S_3	S_4	S_5
E_{HOMO} (eV)	-0.21155	-0.21152	-0.21145	-0.21146	-0.21148	-0.20886	-0.20887	-0.20860	-0.20851	-0.20882
E_{LUMO} (eV)	-0.05511	-0.05507	-0.05498	-0.05498	-0.05502	-0.05854	-0.05851	-0.05839	-0.05824	-0.05834
ΔE (eV)	0.15644	0.15645	0.15647	0.15648	0.15646	0.15032	0.15036	0.15021	0.15027	0.15048

Energy gap

The optimization calculations' results can also be determined the difference in the energy levels of the HOMO and LUMO orbitals (energy gap) of all the molecules of the eugenol and safrole derivatives presented in **Table 7**. The HOMO-LUMO energy difference or energy gap describes the ease with which a molecular system can experience excitation to a higher electronic state. The lower energy difference of the HOMO-LUMO orbitals will give a picture of a relatively more stable molecular system. A large HOMO-LUMO energy difference means that the molecule has high stability, so it has low reactivity in chemical reactions (Peymanfar, Yektaei, Javanshir, & Selseleh-Zakerin, 2020; Shamsah & Owolabi, 2020).

Based on Table 6, it can be seen that the chain elongation of alkyl groups affects changes in the energy values of the HOMO and LUMO orbitals even though the changes are small, about $1x10^{-5}$ - $3x10^{-5}$ eV for eugenol derivative cinnamic compounds and $6x10^{-5}$ – $2,7x10^{-4}$ eV for the cinnamon derivative of safrole. The substituents that tend to attract and push electrons will cause changes to the energy of HOMO and LUMO. Based on atomic charge analysis (**Table 5**), 3,4-methylenedioxy isoheptyl cinnamate compound has the smallest HOMO-LUMO energy difference. The energy difference between the HOMO-LUMO orbitals with the smallest value reflects the ease in the process of electron excitation so that their sensitivity to light (photosensitivity) tends to be stronger (Sherin & Manojkumar, 2020; Vu, Le Phuc Nhi, Vu, & Tung Ngo, 2020).

CONCLUSIONS

Based on the computational results of the eugenol derivatives and the safrole derivatives, it can be concluded that the structure of the compound 3,4-methylenedioxy isohexyl cinnamate has the smallest HOMO-LUMO energy difference, that is 0.15021 eV. So it can be said that the 3,4-methylenedioxy isohexyl cinnamate molecule from the safrole compound derivative is more potential as a sunscreen compound. It can be concluded that the elongation of the alkyl chain does not significantly affect the HOMO-LUMO energy difference.

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