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Research

Changes of Fatty Acid Profiles in Mushroom Corals (*Fungia fungites*) After Short-Term Laboratory Exposure to Anti-Fouling Herbicide Diuron

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ABSTRACT

There is a great concern about the recent use of new anti-fouling chemicals for boats and ships to the coral reef health. Diuron is one of the new anti-fouling paints after the ban of organotin as an anti-fouling system (AFS) compound, but yet to be proven safe for the marine environment. Presently, we demonstrated the effects of Diuron on the fatty acid composition of hard coral species (*Fungia fungites*) in the laboratory. The corals were exposed to different doses of Diuron under short-term exposure (96 hr) and the fatty acid (FA) compositions of the coral tissues were determined using the gas chromatography technique. The fatty acid composition between fresh and control samples of *F. fungites* was significantly similar where both samples were dominated by Saturated FA (SAFA), followed by Polyunsaturated FA (PUFA) and Monounsaturated FA (MUFA). In contrast, the trends for exposed samples (20, 100 & 500 µg/L) of *F. fungites* showed a significant decrease (P<0.05) of SAFA, MUFA, and PUFA with species suffering more as the dose of diuron increased. As the level of dose increased, SAFA such as 16:0 was largely affected while unsaturated FA from ω3 and ω6 series showed a slight decrease in their composition. The decrease in fatty acid composition after Diuron exposure indicates that the anti-fouling chemical can affect corals and may impact their metabolism. The finding that Diuron significantly impacts coral tissue fatty acids and metabolism is crucial evidence for classifying marine water quality in sensitive habitats (Class 1) like coral reefs, which are widespread in Malaysian waters. This finding serves as a basis for incorporating Diuron anti-fouling as a parameter in the Malaysian Marine Water Quality Standard (MMWQS). These key policy reforms to protect coral reef ecosystems have multiple benefits for marine ecosystems and humans.

Key words: Coral reef, diuron, booster biocides, fatty acids composition, water quality

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INTRODUCTION

One of the most significant discussions in ocean health is biological fouling. This is the unwanted accumulation of microorganisms, plants, and animals on natural and artificial surfaces such as ships, fishing nets, fish cages, oil rig supports, and buoyant immersed in seawater. It describes a community of organisms that settle and grow on external surfaces of submerged or semi-submerged objects, both natural and artificial (Lewis, 1998; Dafforn *et al*., 2011). It has long been established that, within hr of a structure's submergence, a slime layer comprised of microscopic organisms (bacteria & algae) bound within an extracellular matrix of polymeric substances (Flemming, 2016; Steinberg *et al*., 2002) develops to facilitate settlement and attachment of macro-organisms, including larvae of invertebrates such as ascidians, serpulids, and barnacles, and provides biochemical cues for settlement and increases their adherence to the substrate (Noufal & Hassan, 2016).

Past studies have shown that biological fouling has been a widespread problem. For instance, Dafforn *et al*. (2011) maintain that bio-fouling is common in marine environments and poses a major problem for the shipping industry, which has approximately 90% of the world and seaborne trade over the past three decades (ICS&ISF, 2009). It has also been shown that the growth of organisms on a vessel hull increases frictional drag which reduces ship speed or requires increased power and fuel consumption to maintain speed (Abbott *et al*., 2000). This was reiterated by IMO (2002) that even a small amount of fouling can lead to an increase in fuel consumption of up to 40%, and possibly as much as 50. Slime films alone can impart powering penalties of 21%, with heavy calcareous bio-fouling increasing this penalty to 86% (Schultz, 2007). Noting that a clean ship can sail faster and with less energy, the economic costs of hull fouling have been a driving force behind the development of anti-fouling technologies, legally known as the anti-fouling system (AFS), which is a global industry that was worth approximately US$ 4 billion annually 20 years ago (Wright, 2009), and is still growing.

The International Maritime Organisation (IMO) adopted the International Convention on the Control of Harmful Anti-fouling Systems on Ships (AFS Convention 2001) in October 2001. This IMO Convention prohibits the use of harmful substances in anti-fouling paints used on ships as well as establishes a mechanism to prevent the potential future use of other harmful substances in AFS (IMO, 2002). Ship owners have been urged to take note of the entry of the IMO's control measures on anti-fouling paints under the AFS Convention 2001 from 1 January 2003. In fact, diuron is considered a priority hazardous substance by the European Commission (Malato *et al*., 2002). Therefore, European countries including the UK, Sweden, Denmark, and France have restricted the use of diuron in antifouling paints. However, diuron also can undergo abiotic degradation such as hydrolysis, photodegradation, as well as biotic degradation (Giacomazzi & Cochet, 2004). The studies by Jones (2005) and Flores *et al*. (2021) have proved that diuron induces a significant impact on corals. As a State Member of the IMO, Malaysia began to take initial steps towards complying with the AFS in 2003. Control measures have been imposed on ships plying Malaysia's waters where all ships were prohibited from re-apply organotin compounds which act as biocides in their AFS. The ban on TBT use was made on 1 January 2008, and shifted to the new anti-fouling completely, where ships are prohibited from bearing such compounds on their hulls or eternal parts or surfaces; or should alternatively bear a coating to form a barrier to such compounds leaching from the underlying non-compliant AFS. This ban, however, does not apply to fixed and floating platforms, FSUs (Floating Storage Units), and FPSOs (floating production storage & offloading vessels) that were constructed before 1 January 2003 and that have not been in dry-dock on or after 1 January 2003. After Malaysia ratified the AFS Convention 2001 on 27 September 2010, the requirements under this IMO Convention have been enforced on Malaysian and foreign ships operating in its waters from 27 December 2010 (Marine Department Malaysia, 2011).

After the ban on TBT and other AFS containing organotin compounds, 17 chemicals including Diuron had been proposed as safe and effective anti-fouling chemicals in Japan (Yonehara, 2000). However, European countries such as the UK, Sweden, Denmark, and France have restricted the use of Diuron as anti-fouling paints (Konstantinou & Albanis, 2004; Giacomazzi & Cochet, 2004; Zhang *et al*., 2008) because of increasing evidence of their deleterious effects. However, the discussion about anti-fouling chemicals from the Malaysian perspective is lacking. Therefore, this study was focused on determining the effects of Diuron as an anti-fouling compound on marine organisms in the waters of Peninsular Malaysia. In this study, the coral reef organisms (Fungia fungites) were acutely exposed (96 hr) to different doses of Diuron, and their tissues were taken to determine fatty acids composition as the measure of bioaccumulation and acute toxicity to the organisms.

MATERIALS AND METHODS

Sample collection and acclimatization

Samples of fresh corals (*Fungia fungites*) in Figure 1 were taken from Pulau Bidong (5°37'12.33"N, 103° 3'39.38"E), Terengganu, on the east coast of Peninsular Malaysia. The corals were acclimatized for 2 weeks in well-aerated holding polyethylene tanks (500 L), containing natural seawater with a salinity of 30 ppt, under a natural photoperiod 12 hr:12 hr (light: dark) cycle. The water in the tank was passed through a 1-mm filter, treated with UV-sterilized, and refilled daily. The corals were not fed at all. Water quality characteristics were measured daily: dissolved oxygen (DO) 7.2±0.5 mg/L, and pH 7.69±0.2 but the temperature was automatically controlled to 27°C using a cooling chiller throughout the whole experiment duration.

Fig. 1. Hard coral *Fungia fungites* collected at Pulau Bidong, Terengganu

Chemical preparation

A stock solution of 1000 mg/L Diuron was prepared by using acetone and the working concentrations were made up by spiking the required concentrations to the sea water.

Experimental procedures

After the two weeks of acclimatization period, the corals were transferred into the experimental tanks (one piece per tank) containing 3 L of water and exposed to test concentrations of 20, 100, and 500 µg/L of Diuron in three replicates for 96 hr (Figure 2). The control tank for *Fungia fungites* followed the same procedures but was not exposed to diuron. After four days (96 hr), the tissues of the corals were removed by using a water pick. The tissues in the form of homogenate were then filtered using a known weight of blank filter paper (Sartorius, Glass-Microfiber Disks, MGC, Ø 47 mm & retention rate of 1.2 µm). The samples retained on the filter paper were then freeze-dried (Labconco FreeZone 4.5-L Benchtop Freeze Dry System) for 12 hr at −40°C to remove the excess water to determine the dried coral tissue biomass. The dried samples were kept in the −20°C freezer before FA analysis.

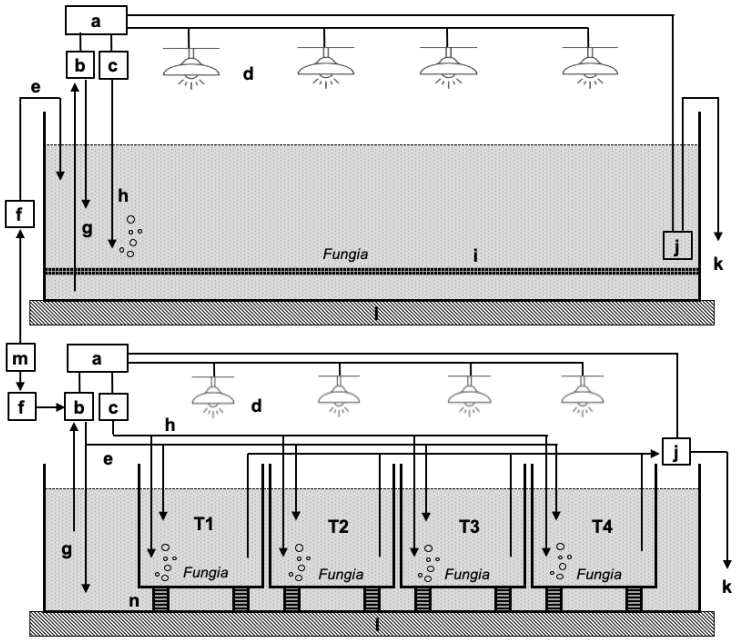

Fig. 2. Schematic diagram of Acclimation Tank (top) and Experiment Tanks (bottom) during exposure experiment of Diuron on the *Fungia Fungites*. a, power supply; b, water chiller; c, aeration compressor; d, lamp; E, treated water input; f, aeration; g, water inflow and outflow for chiller water; h, filter; i, water pump; j, outflow water; k, working bench; l, water sources; m, tank stands and k, T1-T4, treatment tanks. T1 to T4 are Diuron test concentrations of 0, 20, 100, and 500 µg/L, respectively.

Analytical procedures

Dried tissues of *Fungia fungites* coral were taken as samples for fatty acid composition analysis. The one-step method (Abdulkadir & Tsuchiya, 2008) was used in this experiment to combine extraction and esterification processes using a single tube. Three replicates of each tissue sample (200–300 mg) were mixed with 4 mL of hexane and 1 mL of internal standard solution in 50 mL centrifuge tubes. After adding 2 mL of 14% BF_3 in methanol and a magnetic stirring bar, the tubes' head spaces were flushed with nitrogen gas and then closed tightly with a Teflon-lined screw cap. The capped tubes were heated on a hot plate at 100°C for 120 min under continuous stirring. After cooling to room temperature, 1 mL of hexane was added, followed by 2 mL of distilled water. The tubes were then shaken vigorously for 1 min and centrifuged for 3 min at 2500 rpm (650 × g). Of the two phases that formed, the upper phase was the hexane layer containing the FAMEs. Finally, ~1–2 mL of the hexane layer was transferred using a Pasteur pipette into a clean sample vial to be injected into the GC-FID for FAME analysis.

Gas chromatography condition

The FAMEs were separated and quantified using a gas chromatograph (GC 14-B Shimadzu) equipped with a flame ionization detector. Separation was performed with an FFAP-polar capillary column (30 m × 0.32 mm internal diameter, 0.25 µm film thickness). Hydrogen was used as a carrier gas. After injection at 60°C, the oven temperature was raised to 150°C at a rate of 40°C min^{-1}, then to 230°C at 3°C min^{-1}, and finally held constant for 30 min. The flame ionization was held at 240°C. FAME peaks were identified by comparing their retention times with those of authentic standards (Supelco Inc.,). Fatty acids were designated as n:pωx, where n is the number of carbon atoms in the aliphatic chain, p is the number of double bonds and x is the position of the first double bond from the terminal methyl group. The analytical precision for samples was generally <5% for total amounts and major components of FAMEs.

Data analysis

Fatty acid concentrations (CFA, mg/g of dry sample) were calculated by comparing the peak area of fatty acid in the sample with the peak area of internal standard as follows:

$$C_{FA} = \frac{A_s}{A_{IS}} \times \frac{C_{IS}}{W_S}$$

where;
A_S = peak area of fatty acid in the sample in chromatogram
A_{IS}= peak area of internal standard in the chromatogram
C_{IS} = concentration of internal standard (mg)
W_S = weight of sample (g)

Qualitatively (as a percentage), the composition of individual fatty acids was calculated by comparing the peak area of each fatty acid with the total peak area of all fatty acids in the sample.

Statistical analysis

The fatty acid results of *Fungia fungites* were calculated and presented as mean ± standard deviation (Table 1). Significant differences among the mean value of treatments were treated by One-way Analysis of Variance (ANOVA) followed by Least Significant Difference (L.S.D). A two-way Analysis of Variance was used to support a one-way Analysis of Variance to get the F-probability interactions between chemicals, concentrations, and/or species. Duncan's multiple range test (P<0.05) was calculated.

RESULTS

Fatty acid composition

The average concentrations and their standard deviation of saturated fatty acids (SAFA), mono-unsaturated fatty acids (MUFA), and Polyunsaturated fatty acids (PUFA) in the *Fungia fungites* are presented in Table 1. The results show that *Fungia fungites* fatty acids were dominated by SAFA followed by PUFA while MUFA showed little contribution in fresh, control, and those exposed to acetone for monitoring. The average fatty acids for fresh and control samples showed SAFA 27.4±6.17 (54.3%) and 23.8±5.04 (49%) mg/g dry weight, followed by PUFA 20.5±5.48 (40.6%) and 23.2±6.67 (47.8%) mg/g dry weight and last is MUFA 2.25±1.14 (5.06%) and 1.15±0.69 (3.21%) mg/g dry weight respectively (Table 1).

Table 1. Fatty acid composition (mg/g) dry weight of tissue samples of *Fungia fungites* (mushroom) after 96h acute exposure test

Name	Fresh	Control	20µg/L Diuron	100µg/L Diuron	500µg/L Diuron
SAFA					
C14:0	$2.05^{a} \pm 0.58$	$1.57^{b} \pm 0.08$	$1.64^{b} \pm 0.10$	$0.98^{c} \pm 0.10$	$0.98^{c} \pm 0.11$
C16:0	$15.9^{a} \pm 1.39$	$13.2^{bc} \pm 1.53$	$14.1^{ab} \pm 1.29$	$11.4^{c} \pm 1.33$	$7.19^{d} \pm 0.24$
C18:0	$5.27^{a} \pm 0.34$	$5.15^{a} \pm 0.18$	$3.79^{ab} \pm 0.31$	$2.57^{b} \pm 2.23$	$2.27^{b} \pm 0.30$
C20:0	$4.21^{a} \pm 0.15$	$3.89^{ab} \pm 0.61$	$1.24^{d} \pm 1.08$	0.00	0.00
MUFA					
C16:1	$2.55^{a} \pm 0.45$	$1.55^{c} \pm 0.18$	$2.04^{b} \pm 0.17$	$1.74^{bc} \pm 0.10$	$1.84^{bc} \pm 0.13$
C17:1	0.00	0.00	0.00	0.00	0.00
C18:1ω9c	0.00	0.00	0.00	0.00	0.00
C18:1ω9t	0.00	0.00	0.00	0.00	0.00
C20:1	0.00	0.00	0.00	0.00	0.00
PUFA					
C18:3ω6	$3.03^{bc} \pm 0.12$	$3.30^{b} \pm 0.22$	$3.21^{bc} \pm 0.33$	$2.50^{bc} \pm 0.15$	$1.27^{d} \pm 1.10$
C18:3ω3	$13.7^{bc} \pm 1.07$	$16.4^{a} \pm 0.76$	$12.5^{cd} \pm 2.03$	$12.8^{cd} \pm 0.76$	$12.7^{cd} \pm 0.45$
C20:3ω3	$1.24^{cd} \pm 0.30$	$2.04^{a} \pm 0.14$	$1.83^{ab} \pm 0.09$	0.00	$1.54^{bc} \pm 0.64$
C20:5ω3	$2.54^{a} \pm 0.08$	$1.46^{b} \pm 0.25$	0.00	$1.35^{b} \pm 0.12$	0.00
C22:6ω3	0.00	0.00	0.00	0.00	0.00
ΣSAFA	$27.4^{a} \pm 6.17$	$23.8^{ab} \pm 5.04$	$20.8^{b} \pm 6.06$	$14.9^{c} \pm 5.27$	$10.4^{d} \pm 3.19$
ΣMUFA	$2.55^{a} \pm 1.14$	$1.55^{c} \pm 0.69$	$2.04^{b} \pm 0.91$	$1.74^{bc} \pm 0.78$	$1.84^{bc} \pm 0.82$
ΣPUFA	$20.5^{ab} \pm 5.48$	$23.2^{a} \pm 6.67$	$17.5^{b} \pm 5.19$	$16.6^{bc} \pm 5.38$	$15.5^{c} \pm 5.43$
ΣFA	$50.4^{a} \pm 5.04$	$48.5^{a} \pm 5.18$	$40.3^{abc} \pm 4.61$	$33.3^{bc} \pm 4.25$	$27.8^{c} \pm 3.64$

Values are means ± standard deviation (SD) for *n*=3
SAFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids.
Means within rows followed by the same superscript(s) are not significantly different (*P*>0.05).

The *Fungia fungites* samples exposed with 20 µg/L Diuron agreed with the trend of SAFA>PUFA>MUFA as observed in fresh, control, and acetone samples while for the rest of the two groups, the trend was PUFA>SAFA>MUFA (Table 1). However, in both cases, the MUFA groups contributed less in total FA among all exposed tanks of *Fungia fungites* (Figure 3). The behavior of some exposed groups of *Fungia fungites* to show opposite trends as in fresh and control samples can be justified by the fact that the activities in these groups were affected not only by the chemicals but also by the ability of the organism itself to fight the toxic behavior of the used chemical (Diuron).

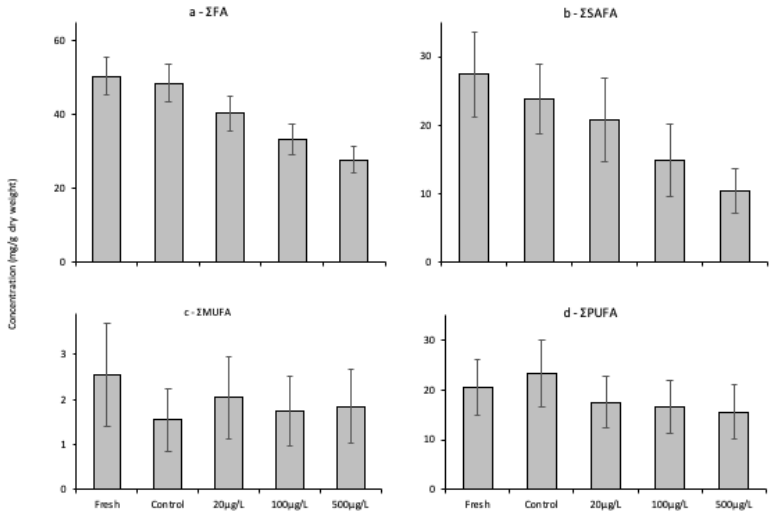

Fig. 3. Fatty acid concentration of different classes and total fatty acid (mg/g) dry weight from tissues of *Fungia Fungites* after exposure at different concentrations Diuron. Figures show the composition of fatty acid classes for total FA (a), SAFA (b), MUFA (c), and PUFA (d). Values are mean ± S.D, *n*=3.

Saturated Fatty Acid (SAFA)

The *Fungia fungites* were relatively enriched in SAFA and the total SAFA is not significantly different (P>0.05) between fresh and control groups. However, the other groups and individual SAFA were significantly different (P<0.05) in this species (Table 1). Of the SAFAs, Palmitic acid (C16:0) was found dominant in all SAFAs of the *Fungia fungites* (Table 1) but significantly different (P<0.05) between the samples. SAFA is pronounced more on average in *Fungia Fungites* (Figure 3).

Monosaturated Fatty Acid (MUFA)

The ΣMUFA for *Fungia fungites* was significantly different in fresh, control, and other exposed concentrations (Table 1). It was observed that MUFA contribution was less in total fatty acids in *Fungia fungites*, because, only Palmitoleic acid (C16:1) was observed in the GC-FID where the rest of MUFA were below the detectable limit (Table 1).

Polyunsaturated Fatty Acid (PUFA)

The ΣPUFA in *Fungia fungites* was not significantly different among fresh and control samples (P>0.05) as seen in Table 1. α-Linolenic acid (C18:3ω3) was dominant PUFA in *Fungia fungit*es (66.8% Fresh sample) (Figure 4b).

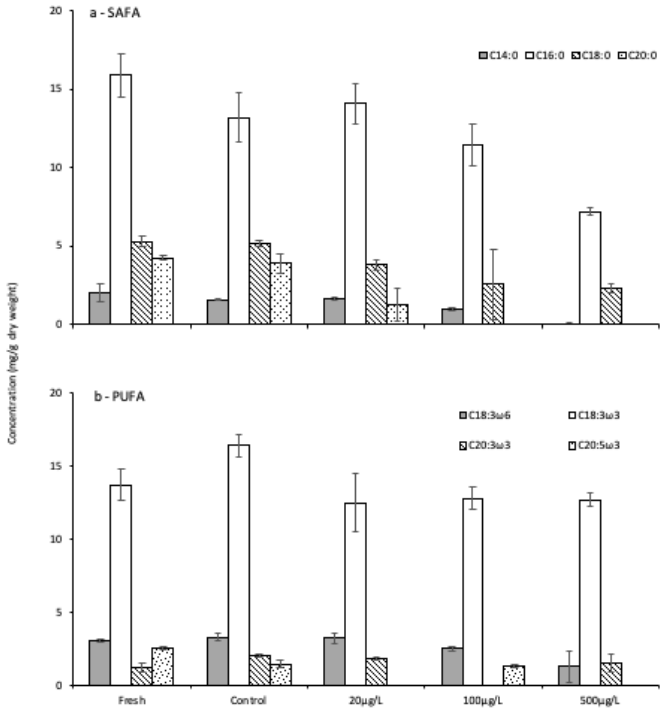

Fig. 4. Individual fatty acid concentrations of *Fungia fungites* exposed at different doses of Diuron. Figures show the composition of fatty acid components for SAFA (a) and PUFA (b). Values are mean ± S.D, n=3.

DISCUSSION

Fatty acid composition

Ali *et al*. (2014) studied Diuron concentration and the levels of diuron contamination in the waters of Peninsular Malaysia. Based on their findings, coastal areas such as Klang, Johor, and Kemaman were contaminated with diuron from various sources such as agricultural, urban uses, and shipping activities while the coral reefs areas such as in Redang and Bidong Islands were mainly contaminated from boating activities. Considering the toxicity of Diuron to aquatic organisms, we present the effect of Diuron on the reef-building corals to seek the toxicity effect on the metabolisms of the coral as indicated by fatty acid composition.

Presently, ΣSAFA was highest in both control and treated samples and significantly affected by the Diuron. In brief, the high composition of ΣSAFA was known to be linked with Palmitic acid which was the predominant fatty acid in the SAFA group as found in other species of hard coral (Imbs *et al*., 2007; Safuan *et al*., 2023). In this experiment, ΣSAFA is largely affected by Diuron and associated with the

lower composition of palmitic acid (16:0) especially when the samples are exposed to higher doses (500 µg/L). A similar trend was also observed in the toxicity test of anti-fouling Irgarol towards coral *Galaxea fascicularis* where the reduction of ΣSAFA as the doses of anti-fouling increase is associated with the reduction of palmitic acid (Ali *et al*., 2022). Reduction in palmitic acid can be due to an active desaturation process of fatty acid for the production of unsaturated fatty acids such as linoleic (18:2ω6) and linolenic acid (18:3ω6) (Kumar *et al*., 2010). This could be the reason why ΣSAFA composition significantly decreased as compared to a slight decrease of unsaturated FA such as PUFA as a reduction in ΣSAFA by the decrement of palmitic acid for the biosynthesis conversion from saturated to unsaturated fatty acid.

The rest of the unsaturated fatty acids such as MUFA and PUFA in this species had significantly been affected by Diuron. MUFA and PUFA are less affected by Diuron possibly due to the active conversion of SAFA to unsaturated fatty acid leading to high content of ΣMUFA and ΣPUFA (Harland *et al*., 1993). Even though the effect is not significant, Diuron is a photosynthetic system II (PSII) inhibitor (Jones & Kerswell, 2003), and these biocides are highly toxic to autotrophic aquatic species such as cyanobacteria, algae, macrophytes, and symbiotic dinoflagellates that live inside the coral's tissues. Diuron could affect the photosynthesis of the symbiotic dinoflagellates in corals at levels of <1 µg/L (Jones & Kerswell, 2003), suggesting that this biocides, at their highest detectable concentrations (>1 µg/L), could cause severe impacts on the growth of microalgae and corals in the marine ecosystem. Moreover, the findings of the current study support the earlier studies conducted by Jones & Kerswell, (2003) and Chesworth *et al*. (2004), which have shown that Diuron was generally toxic for the tested species respectively. Among the PUFAs, the 18:3ω6 and 20:5ω3 are known as a fatty acid biomarker for symbiotic algae (Papina *et al*., 2003; Safuan *et al*., 2021). It is known that symbiotic algae provide up to 90% of photosynthetically fixed carbon to corals including fatty acids which are an important nutrient for the daily energy requirement of their host (Teece *et al*., 2011). Even though PUFAs were not significantly affected, the lower composition of PUFA in the present samples exposed by Diuron can be related to the disruption of the photosynthetically fixed carbon production by the symbiotic algae.

Implication of coral reefs management

Past studies have already proven diuron toxicity to corals and their symbionts (Flores *et al*., 2021). Diuron has also been reported in some islands including Pulau Bidong (25.4 ng/L) and Pulau Redang (42.8 ng/L) in Malaysia (Ali *et al*., 2014). Even though the concentration is significantly lowered than the maximum permissible concentration (430 ng/L), the concentration may increase with the increased number of tourists that come to the islands (Lach *et al*., 2019). Diuron in coral reefs is linked to tourist boats (Ali *et al*., 2014). In Malaysia, the Department of Environment (DOE) enforces the Malaysian Marine Water Quality Standard (MMWQS) to protect the marine ecosystem and ensure the sustainable use of marine resources. This standard supports the DOE's Water Quality Objective and the Environmental Quality Act 1974 (Act 127). The MMWQS aims to protect and sustain marine ecosystems (DOE, 2021). The MMWQS divides marine waters into five classes:

Class 1: Sensitive Marine Habitats
Class 2: Fisheries, including Mariculture
Class 3: Industry, Commercial Activities, and Coastal Settlements
Class 4: Estuaries
Class 5: Recreation

Coral reefs are categorized as sensitive marine habitats and species and are therefore classified under Class I, which includes both gazetted and statutory protected waters (including marine protected areas/ marine parks, fisheries prohibited areas, state parks, and Ramsar sites), and ungazetted waters that are ecologically and biologically sensitive areas (EBSAs) which include coral reefs, sea grass, turtle landing routes and sites, and feeding grounds. However, the classification was limited to several parameters as a reference to determine marine water quality index where anti-fouling biocides or AFS are not included in the parameters for all the classes. This is not in line with the Malaysia Shipping Notice on the Implementation of the International Convention on the Control of Harmful Anti-Fouling Systems on Ships, 2001 (Marine Department Malaysia, 2011), where ships are required to avoid AFS that are harmful to the marine environment.

The findings presented in this study show that Diuron can significantly affect the fatty acid in the coral tissues and have implications on the coral's metabolism. The effect was significant when the corals were exposed to 100 µg/L of Diuron and higher. This finding is important evidence to support

classifying the marine water quality in the Sensitive Marine Habitats (Class 1) like the coral reefs, which are predominant all over the waters surrounding Malaysia. This particular finding can inform policy reform by the DOE, and be used as a basis for revising the parameters in the MMWQS to include the anti-fouling Diuron. This policy reform is crucial to protect coral reefs which have been proven to have multiple benefits to the marine ecosystem and mankind. As noted by NOAA (2019), coral reefs not only serve as habitats to many marine faunas, but they also serve as sources of food and new medicines as well as protect coastlines from storms and erosion, provide jobs for local communities, and offer recreation opportunities, with the estimated net economic value globally to be tens of billions of USD per annum.

This policy reform is predominantly important now that a recent study has shown that future climate change may increase the effect of Diuron on the photosynthesis process of corals which may reduce the calcification of coral (Flores *et al*. 2021). They also suggested that water quality guideline values may need to be adjusted as climate changes can also induce the effect of herbicides Diuron on coral reefs. Therefore, early mitigation measures should be taken to improve the management of the coral reef areas, and addressing Diuron pollution by including this AFS as a parameter in the MMWQS would be able to improve the management of the coral reef ecosystem in Malaysia.

CONCLUSION

This paper explains the toxicological responses and their effects on the fatty acid composition of *Fungia fungites* upon exposure to different concentrations of Diuron in laboratory experiments. The finding indicates that the application of anti-fouling such as diuron can negatively affect reef-building coral. This can be seen that the exposure of diuron significantly affects the fatty acid composition of these organisms. Ensuing from that, it is recommended that since Diuron has been proven to significantly affect the fatty acid in the coral tissues and have implications on metabolisms of the corals, This finding should guide policy reform and serve as a basis for revising the MMWQS parameters to include the anti-fouling agent diuron. This evidence-backed policy reform may be able to increase the protection of the marine water quality in the Sensitive Marine Habitats (Class 1), which is crucial to protect the Malaysian coral reefs which undoubtedly have many ecological roles that benefit the marine environment as well as the mankind.

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ETHICAL STATEMENT

Not applicable.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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