International Journal of
Life Science
International Peer Reviewed Open Access Refereed Journal

Int. J. of Life Science, 2019; 7 (2):151-160
ISSN:2320-7817(p) | 2320-964X(o)

Original Article Open Access

Effect of vitamin B_{12} supplementation on the reproduction of *Daphnia magna* (Straus 1820) under sudden turbidity change

Nadia Istiqomah[1*], Novi Arisman[1], Takao Yoshimatsu

Graduate School of Bioresources, Mie University, Tsu, Mie 514-8507
Corresponding author – Email – nad.istiqomah@yahoo.com

Manuscript details:

Received: 16.05.2019
Accepted: 16.06.2019
Published: 20.06.2019

Editor: Dr. Arvind Chavhan

Cite this article as:
Istiqomah Nadia, Novi Arisman, Takao Yoshimatsu (2019) Effect of vitamin B_{12} supplementation on the reproduction of *Daphnia magna* (Straus 1820) under sudden turbidity change, *Int. J. of Life Science*, Volume 7(2): 151-160

Available online on
http://www.ijlsci.in
ISSN: 2320-964X (Online)
ISSN: 2320-7817 (Print)

ABSTRACT

Sediment loading related to heavy rainfall has become an issue to aquatic animals. Here, we reported a study revealing how vitamin B_{12}, as an important nutrient exclusively produced by bacteria, can minimize damage caused by sudden turbidity changed in Cladocera zooplankton, *Daphnia magna*. The animals were exposed individually during its lifespan to various turbidity levels (0, 15, 50, 100, 600, 1200 NTU (Nephelometric Turbidity Unit)) using kaolin clay and fed by *Chlorella vulgaris* with different level of vitamin B_{12} supplementation (0, 5, 15, 30 µg L^{-1}) in the grown media. Exposing *Daphnia* to the turbidity had no effect to the lifespan and the survivorship, but the fecundity. In addition, supplementation of vitamin B_{12} showed positive effect to the quality of offspring. Although it is found very subtle, the ratio of total malformation (ranged from 0.002 – 0.022) and male offspring (0.025 for 0 µg L^{-1} and 0.014 for 5 µg L^{-1}) produced by exposed *Daphnia* were lessen recorded in proportional with the increasing dose of vitamin B_{12}. Collectively our data indicate that pulse turbidity exposure to *D. magna* had affected the offspring condition and presence of vitamin B_{12} can contribute to normal development offspring of *D. magna* in the changing environment.

Keywords: *Daphnia magna*, Cladocera, kaolin, turbidity, vitamin B_{12}

INTRODUCTION

Turbidity is one of the important water quality factors in the aquatic ecosystem, which can be contributed by both organic and inorganic particles, but sediment loading (clay, silt particles) often tops of the list of material causing turbidity (Gilbert 1990; Kirk 1991). Increasing sediment loading to the aquatic ecosystem was well correlated with rainfall events and intensity (Gelda *et al*. 2013; Lee *et al*. 2016). The problem will be aggravated with more frequent and intense runoff related to ongoing climate change (Pendergrass *et al*. 2017), albeit anthropogenic factors have a major contribution (IPCC 2014; Häder and Gao 2015). The negative impacts of suspended sediment have been well documented for a wide variety of aquatic organism, start from the producer to the higher consumer in the aquatic food chain. Firstly, it will limit the light attenuation of autotroph taxa to carried out photosynthesis (Bilotta & Brazier 2008; Häder and Gao 2015). Lastly, filter and deposit feeder organisms, such as daphniids, can also be affected indirectly due to particles ingestion possibility that may clog the gut and result in suboptimum food intake, causing stress, or further may even death (Bilotta and Brazier 2008; Chen *et al*. 2012; Hasenbein *et al*. 2013; Maisanaba *et al*. 2015).

There is an increasing concern in the interaction between bacteria, zooplankton and their environment, and how those interactions affect zooplankton performance in the fluctuating environment and stressful condition (Peerakietkhajorn *et al*. 2015; Sison-Mangus *et al*. 2015; Mushegian *et al*. 2016; Manakul *et al*. 2017). The presence of bacteria is reported to play nutritional role for daphniids by producing certain enzymes or nutrients that beneficial for their reproduction and growth (Peerakietkhajorn *et al*. 2015). One of the nutrients that exclusively produced by bacteria and readily available in the aquatic environment is vitamin B_{12} (Yu *et al*. 1989; Croft *et al*. 2005; Tang *et al*. 2010; Fang *et al*. 2017; Helliwell 2017). It is well-known for decreasing stress (Ghemrawi *et al*. 2013; Ferrer *et al*. 2016) and plays a role as an antioxidant (Bito *et al*. 2017). Vitamin B_{12} also reported have a protective effect on the cells from nutritional stress (Ghemrawi *et al*. 2013). Research has consistently found that this vitamin plays an important role, especially for phytoplankton dynamics since most of algae are vitamin B_{12} auxotroph (Yu *et al*. 1989; Croft *et al*. 2005; Helliwell *et al*. 2016). However, there is still little information about its role for zooplankton in the natural environment. Previous studies have reported in the laboratory scale that supplementation of vitamin B_{12} both in the media and/or food have beneficial for improving growth and fecundity for *Daphnia pulex* (Keating 1985), marine rotifer *Branchionus plicatilis* (Hirayama *et al*. 1989; Yu *et al*. 1989; Hayashi *et al*. 2007), and *Daphnia magna* (Kusari *et al*. 2017). Thus, the aim of present study is to examine vitamin B_{12}, that exclusively produced by bacteria, to obtain a better understanding in respect of bacteria-zooplankton relationship. *Daphnia magna* (Straus 1820), herbivorous freshwater zooplankton and a key species in the aquatic food web, was chosen because of its sensitivity to changing the abiotic environment and widely used as a standard test organism (OECD 2012). The short-time life cycle and parthenogenetic reproduction allow the animal to be observed for its response in the life-history change. It is also passive filter-feeder that susceptible to turbidity change caused by sediment loading exposure. We assumed that the presence of vitamin B_{12} have a contribution to minimizing damage caused by turbidity change in *Daphnia*.

MATERIALS AND METHODS

Experimental design

D. magna which is obtained from Gene Bank, National Institute for Environmental Studies, Ibaraki Prefecture, Japan, was grown for many generations in our laboratory at 20±1°C using commercial mineral water. They were cultured in several 1 L jars of commercial mineral water with the density ~10 ind L^{-1} and fed by commercial Chlorella (Chlorella V-12, Chlorella Industry Inc., Fukuoka, Japan) for maintaining a healthy culture.

For experimental purposes, *Chlorella vulgaris* (Beijerinck 1890) (Gene Bank of National Research Institute of Aquaculture, Mie, Japan) was cultured in 3 L of modified f/2 medium (Andersen *et al*. 2005) and used as the sole diet for experiment. Vitamin B_{12} content was not included in the algal media culture. Food stock preparation was carried out by centrifuged the 5 days harvested algal culture at 4000 rpm for 30 minutes and remove the supernatant. The algal suspension was diluted using 200 ml distilled water and stored at 4±1°C until use for feeding. The final cells density was measured using hemocytometer Thoma under a light microscope with an estimated amount of 300 × 10^3 cells ml^{-1}.

A commercial kaolin clay ($Al_2Si_2O_5(OH)_4$) (approximately 0.4 μm particle size in diameter) was used as turbidity material. Kaolin has been prevalently utilized as standard solution for turbidity measurement, with 1 NTU = ~1 mg L^{-1} of kaolin clay (JWRC, 2008). Kaolin were diluted with commercial mineral water used for culture until the desired turbidity applied. Turbidity concentration was measured using handheld colorimeter for water quality measurement (HACH DR890, HACH Co., Ltd., USA) with commercial water as a blank. Kaolin solution was prepared daily, and the turbidity was maintained during the exposure time to prevent suspension.

For the animal test and experimental procedure, the selection was applied to maintain parthenogenetically reproduction before the experimental start. The 5th brood neonates were gained from 30 mothers. The experiment was performed in the six-well microplates, where each well contains one neonate (at age < 24 hours old). The neonates were exposed daily during their lifespan by different turbidity levels (15, 50, 100, 600, 1200 NTU) for 3 hours. After turbidity exposure, the animals were moved to a new medium and fed by *C. vulgaris* with 3 different doses of vitamin B_{12} (5, 15, 30 μg L^{-1}). Crystalline Cyanocobalamin (Wako Pure Chemical Industry, Co. Ltd, Japan) was used and diluted in the distilled water until the desired doses applied. The control treatment consists of pure medium, fed by only *C. vulgaris* in clear water without the addition of vitamin B_{12}. In total there are 144 neonates (6 turbidity level × 4 vitamin B_{12} × 6 neonates in microplates) used for experiment and observation was carried out until the animals are dead. All the animals were fed by the similar amount of food, approximately 300 × 10^3 cells ml^{-1} of *C. vulgaris* and kept at incubator with the temperature set up 20 ± 1°C and photoperiod 12:12 L: D cycle.

A daily observation was performed to record the mortality and the day when the onset of reproduction occurred. Once reproduction started, we separated the neonates from the mothers and neonates are fixed by 5% formalin for further body size measurement. The neonates were counted, and the sex of neonates was observed under a dissecting microscope with × 40 magnification. For body size measurement, light microscope equipped by eyepiece micrometer was used with ×40 magnification.

Data analysis

The following reproductive parameters were calculated during the treatment: total number of offspring per female until the 5th reproduction, male appearance/total female offspring per group treatment, offspring malformation/total normal offspring per group treatment, each offspring size per female, time to first brood per female, and frequency of reproduction occurred per female during lifespan.

Total lifespan, offspring number per female, and frequency of reproduction occurred per female were compared between group treatments using two-way ANOVA with significant value $P < 0.05$, followed by Tukey post hoc test to gain differences between treatments. Levene Test was also performed prior data analysis to meet ANOVA assumption. In the case of offspring size, we use Kruskal Wallis non-parametric test followed by Dunn Test because each individual produces a different number of offspring that result in unequal sample size in group treatments. Time to first brood per female was calculated as a mean difference of the time to first brood per female in treated animals and the mean of the time to first brood per female in control ± standard deviation. The malformation offspring were defined as the ratio of malformation offspring to the total normal offspring observed in each vitamin B_{12} doses group. The male offspring was defined as the ratio of male offspring to the total normal female offspring observed in each vitamin B_{12} doses group.

RESULTS

Lifespan

Exposing *D. magna* with kaolin clay for 3 hours with or without vitamin B_{12} supplementation in the grown media did not affect the lifespan in all vitamin B_{12} treatment groups as shown in Figure 1. However, 2-way ANOVA followed by Tukey post-hoc test confirmed that the treatment group without supplementation of vitamin B_{12} showed significantly longer lifespan ($P < 0.05$;

Table 1; Table 2) compare to that receive vitamin B_{12} supplementation (ranged from 42.33 ± 1.03 to 43.00 ± 0.00 days).

Age at first reproduction

The time to start the first reproduction of *D. magna* were significantly different in the clear water and low turbidity exposure (15 NTU) without vitamin B_{12} supplementation. The mothers start their reproduction at the day 10th of the experiment. However, the higher turbidity exposure without supplementation of vitamin B_{12} and other groups with supplementation of vitamin B_{12} respond similarly, most of them were starting their reproduction earlier, at the day 9th of the experiment (Figure 2).

Total offspring number and frequency of reproduction

In the case of offspring number, we observed the offspring number both in each reproduction and continuously recording during the lifespan. The offspring number was significantly higher ($P < 0.05$) in the treatment with supplementation of 30 μg L^{-1} of

vitamin B_{12} until the 5th reproduction (approximately for 20-22 days experiments, when the viability of animal test was 100%). Although the offspring number were not turbidity-dependent in every vitamin B_{12} treatment groups, it is shown the fewest offspring number was attained in the highest turbidity value (1200 NTU) as depicted in
Figure **3** and

Table 2. None of the differences measured were statistically significant for total offspring number during the lifespan.

Two-way ANOVA confirmed that each factor, turbidity exposure and the presence of vitamin B_{12}, were significantly affected the frequency of reproduction of *D. magna*. The animals tend to reproduce more often when exposed at the highest turbidity (1200 NTU), 8.00 ± 0.63 – 9.33 ± 1.21 times during lifespan, compared to the animal grown in the clear water, ranged from 6.00 ± 1.09 to 7.50 ± 1.76 times during lifespan. Turbidity level ranged from 15 to 600 NTU did not differ significantly in the frequency of reproduction as shown in

Table 2. When compared among the vitamin B_{12} group treatments, supplementation of 15 and 30 μ L^{-1} of vitamin B_{12} showed lesser frequency of reproduction than the treatment group supplemented by the lower dose of vitamin B_{12} as summarized in Figure 4.

Offspring size

With respect to the offspring body size of *D. magna* exposed to the combination of turbidity and vitamin B_{12}, all the mothers produced nearly similar offspring in size. Each factor, kaolin clay exposure and supplementation of vitamin B_{12}, did not significantly affected the offspring size produced by *D. magna*. The offspring size ranged from 0.56 ± 0.05 to 0.59 ± 0.04 mm in size (Figure 5).

Table 1. Summary of the subsequent univariate analyses (2-way ANOVA) for lifespan, offspring number, and number of reproductions of *D. magna*

Dependent variables	Source of variation	df	SS	*F*	*P*
Lifespan	VB_{12}	3	488	5.247	0.00195*
	Turbidity	5	225	1.452	0.21083
	VB_{12} × Turbidity	15	137	0.294	0.99521
	Residuals	120	3722		
Offspring number	VB_{12}	3	689.9	10.221	4.81×10^{-16}*
	Turbidity	5	100.3	0.892	0.4890
	VB_{12} × Turbidity	15	800.6	2.372	0.00501
	Residuals	120	2700		
Offspring number (1st-5th reproduction)	VB_{12}	3	172.1	8.506	3.61×10^{-5}*
	Turbidity	5	370.1	10.978	1.02×10^{-8}*
	VB_{12} × Turbidity	15	291.5	2.882	0.000677*
	Residuals	120	809.2		
Number of reproductions	VB_{12}	3	76.30	17.935	1.11×10^{-9}*
	Turbidity	5	25.90	5.179	0.00412*
	VB_{12} × Turbidity	15	32.08	1.508	0.11270
	Residuals	120	170.17		

Table 2. Summary of Tukey post hoc test for differentiate among treatment groups relative to parameters observed.

Response variable	Vitamin B_{12} (μg L^{-1})	Turbidity (NTU)
Lifespan	$30^a < 5^a < 15^a < 0^b$	$0^a < 600^a < 100^a < 50^a < 1200^a < 15^a$
Offspring number (all)	$15^a < 30^b < 0^b < 5^b$	$100^a < 50^a < 600^a < 15^a < 0^a < 1200^a$
Offspring number (1st -5th)	$5^a < 0^a < 15^a < 30^b$	$1200^a < 100^{ab} < 600^{ab} < 50^{ab} < 15^b < 0^c$
Number of reproductions	$15^a < 30^a < 5^b < 0^b$	$0^a < 100^{ab} < 15^{ab} < 600^{ab} < 50^{ab} < 1200^b$

Table 3. Total normal and malformation offspring recorded in *D. magna* supplemented by different vitamin B_{12} doses under turbidity exposure using kaolin clay.

Turbidity (NTU)	0 µg L^{-1}			5 µg L^{-1}			15 µg L^{-1}			30 µg L^{-1}		
	NO	MO	Ratio	NO	MO	Ratio	NO	MO	Ratio	NO	MO	Ratio
0	147	0	0	161	0	0	143	0	0	158	0	0
15	108	3	0.027	155	0	0	117	0	0	187	0	0
50	125	3	0.024	154	8	0.052	130	6	0.046	150	0	0
100	157	1	0.006	136	3	0.022	147	1	0.006	147	1	0.006
600	136	1	0.007	161	1	0.006	121	2	0.016	151	0	0
1200	136	4	0.029	155	6	0.038	132	2	0.015	157	1	0.006
Total	**809**	**18**	**0.022**	**922**	**18**	**0.019**	**790**	**11**	**0.014**	**950**	**2**	**0.002**

NO = normal offspring, MO = malformation offspring

Table 4. Total female and male offspring recorded in *D. magna* supplemented by different vitamin B_{12} doses under turbidity exposure using kaolin clay.

Turbidity (NTU)	0 µg L^{-1}			5 µg L^{-1}			15 µg L^{-1}			30 µg L^{-1}		
	F	M	Ratio	F	M	Ratio	F	M	Ratio	F	M	Ratio
0	147	0	0	161	0	0	143	0	0	158	0	0
15	108	0	0	155	0	0	117	0	0	187	0	0
50	125	12	0.096	154	0	0	130	0	0	150	0	0
100	157	2	0.013	136	1	0.007	147	0	0	147	0	0
600	136	6	0.044	161	7	0.043	121	0	0	151	0	0
1200	136	0	0	155	5	0.035	132	0	0	157	0	0
Total	**809**	**20**	**0.025**	**922**	**13**	**0.014**	**790**	**0**	**0**	**950**	**0**	**0**

F = female offspring, M = male offspring

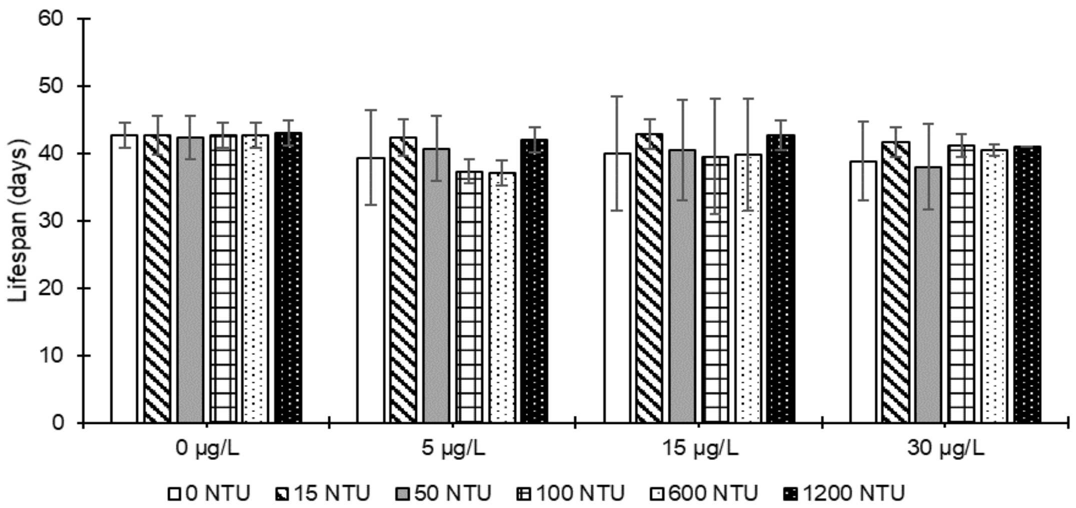

Figure 1. Mean lifespan of *D. magna* when exposed by various turbidity and supplemented by different level of vitamin B_{12}. Bars denote mean value ± SD.

Sex and malformation ratio

Male neonates and malformation offspring were recorded in *D. magna* after short-time turbidity exposure using kaolin clay during their lifespan in very small quantities. Malformation offspring were lessen recorded in the group treated with a higher dose of vitamin B_{12} supplementation as depicted in Table 3. Observed malformation included malformed tail (curved) and stunted body (dwarf-like) (Figure 6). A similar pattern also recorded in the male offspring

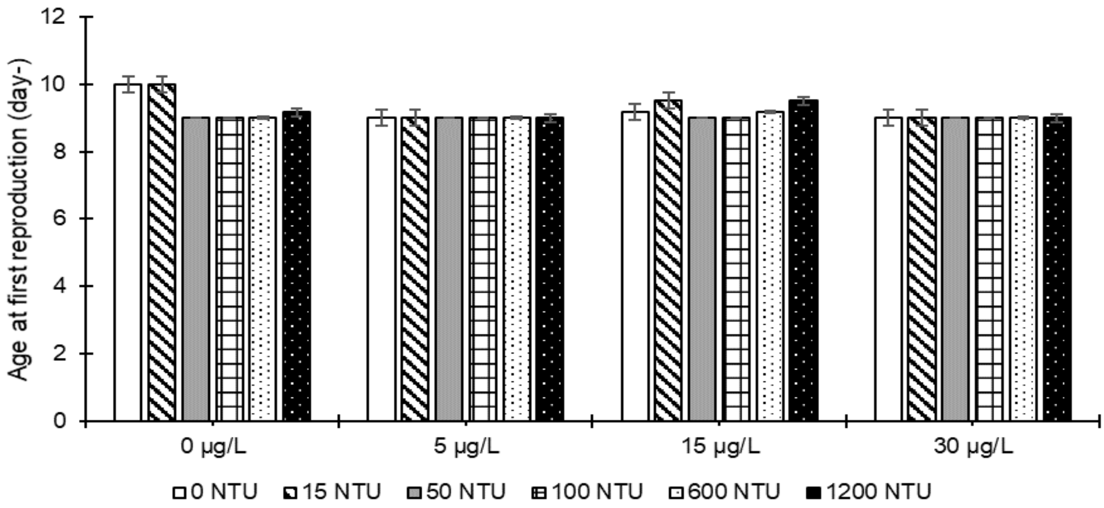

Figure 2. Mean of days of maturity of *D. magna* exposed by various turbidity and supplemented by different level of vitamin B_{12}. Bars denote mean value ± SD.

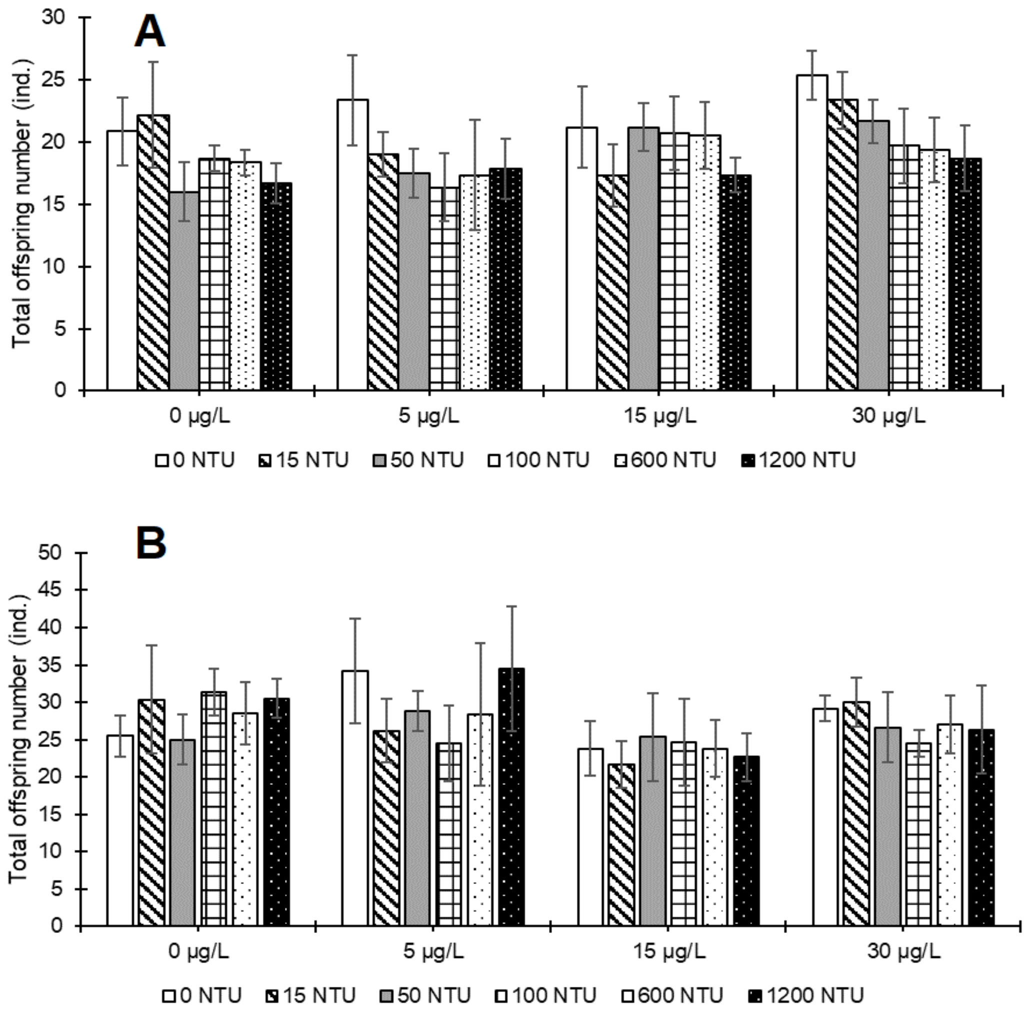

Figure 3 Mean of offspring number of *D. magna* supplemented by different level of vitamin B_{12} under various turbidity with kaolin clay (A) from the 1^{st} – 5^{th} reproduction (20-22 days of experiments) and (B) during lifespan. Bars denote mean value ± SD. Significance level against the control treatment (0 NTU) in each vitamin B_{12} group is indicated by *P < 0.05, **P < 0.01.

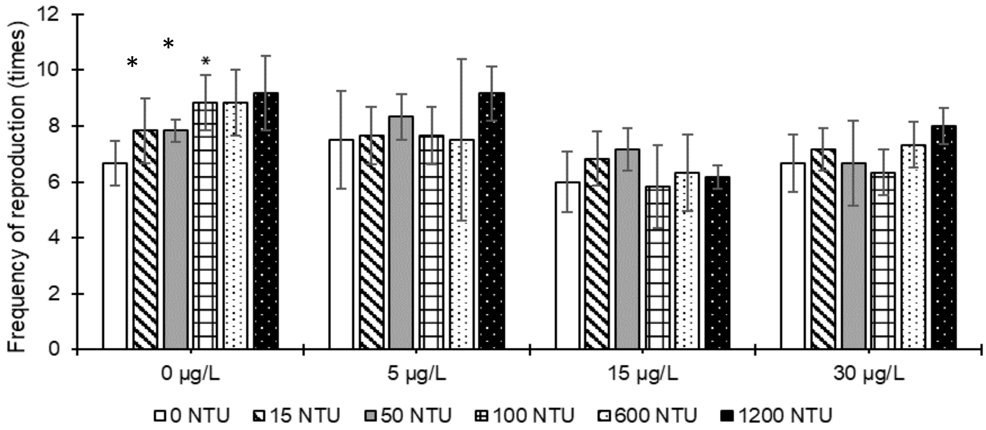

Figure 4. Average frequency of reproduction during lifespan of *D. magna* under various turbidity with kaolin clay and supplemented by different level of vitamin B_{12}. Significance level against the control treatment (0 NTU) in each vitamin B_{12} group is indicated by *$P < 0.05$, **$P < 0.01$.

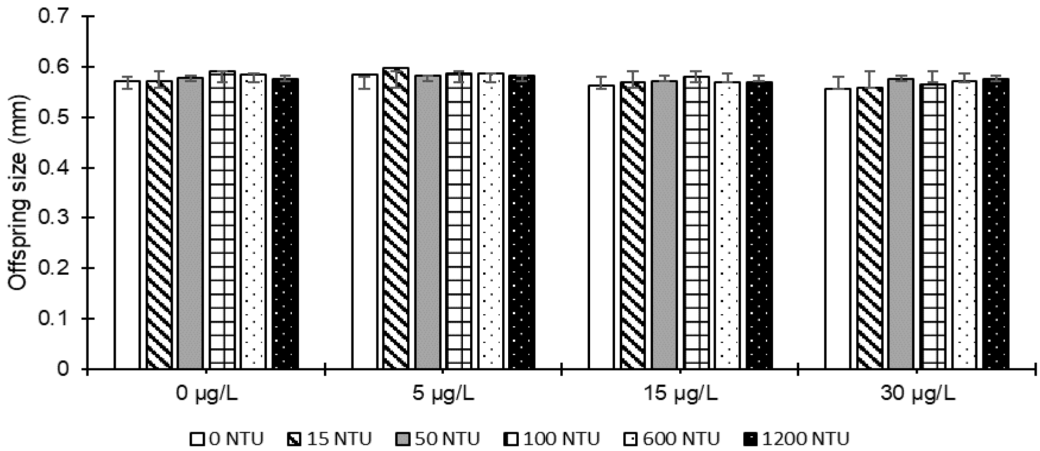

Figure 5. Mean of offspring size of *D. magna* under various turbidity using kaolin clay and supplemented by vitamin B_{12}. Bars denoted mean value ± SD.

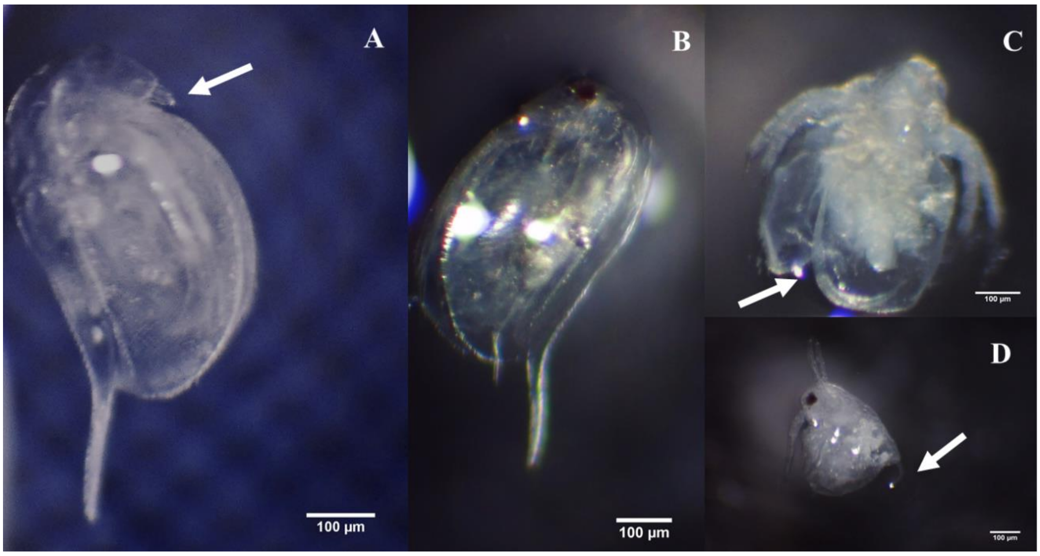

Figure 6. Example of male and malformation offspring found in mother *D. magna* exposed by various turbidity using kaolin clay. (A) normal-male offspring, indicated by the appearance of long antennules (B) normal female offspring (C) curve-tailed offspring (D) stunted-body (dwarf) offspring.

appearance that randomly found in the group treatments without vitamin B_{12} supplementation and 5 μg L^{-1} of vitamin B_{12}. The ratio values were not in accordance with the level of turbidity. However, it was found especially in the 50 – 1200 NTU (Table 4). The mother lived in the clear water and very low turbidity (0 and 15 NTU), as well as the mothers that lived in the higher doses of vitamin B_{12} (15 and 30 μg L^{-1}) in the media produced entirely female offspring. Although the ratios of both the deformities and male offspring were subtle, the total ratio was vitamin B_{12} dose-dependent.

DISCUSSION

The aim of this study was to observe the role of vitamin B_{12} in ambient water, which is exclusively produced by bacteria, on freshwater Cladocera *D. magna* at the morphological and life history when exposed to turbidity changed by kaolin clay. The results suggested that in general, *D. magna* was able to tolerate short-time turbidity changed, no significant difference in the lifespan and no mortality was observed until their 5th reproduction (day 20-22), as the standard experimental period by OECD (2012) for reproduction test on *D. magna*. However, the reproduction of *D. magna* as well as quality offspring shown disrupted in the turbid water together with the absence of vitamin B_{12} in the grown media.

The presence of considerable amount of inorganic clay in the ambient water were suggested can inhibit optimum food uptake for zooplankton, such as Daphniids, as reported in the previous studies (Hart 1992; Rellstab & Spaak 2007; Pietrzak *et al*. 2010; Robinson *et al*. 2010). However, the present study showed the survivorship of *D. magna* was not disrupted by turbid water condition. This result was supported by a study carried out by Robinson *et al*. (2010) that exposing *D. magna* using 800 mg L^{-1} of kaolin clay, with longer exposure time (24 hours) and at least 48 hours for recovery period did not result in any mortality. Despite of that, exposing *D. magna* in the highest turbidity (1200 NTU), even only short-time periods, led to increasing number of reproduction but fewer offspring (both in each and total reproduction) compare to that exposed by lower turbidity.

Our result demonstrated that supplementation of vitamin B_{12} efficiently increase the fecundity of *D. magna* and offspring condition (minimize the malformation and male offspring appearance). The positive effect of vitamin B_{12} supplementation is in concordance with previous study with higher dose (0.75, 1.5, and 3 mg L^{-1}) of vitamin B_{12} supplementation in ambient water can increase *D. magna*'s fitness (Kusari *et al*. 2017). Bioavailability of vitamin B_{12} was suggested to increase DNA methylation level that is susceptible to external environmental cues, especially it linked to nutritional deficit, and may change the phenotype response. Kleiven *et al*. (1992) stated that *D. magna* required, at least, simultaneously three stimuli for their sexual reproduction: crowding, photoperiod, and food limitation. Since this study was using an identical amount of food for all group treatments and using optimum photoperiod as well as crowding were not accountable to the reason, we assumed that kaolin clay presences were reduced optimum food uptake for *Daphnia*. In addition, the exposure of this study was conducted in the 1st instar juvenile and continuously during the lifespan, it is assumed that normal development of embryo was failed to be delivered due to kaolin exposure in the critical stage of *Daphnia*, in a long time before maturity. Vitamin B_{12} in the ambient water might help *Daphnia* to maintain the fitness under such condition. However, the molecular mechanisms in this early investigation were unexplored due to the experiment was carried out in individual basis.

The presence of kaolin clay together with insufficient nutritional uptake (vitamin B_{12} – deficient) decrease the energy of *Daphnia* for reproduction under environmental change. The limited energy is spent on physiological reaction, including repairing damage and impact to the fecundity failure. The strong effect of food quality suggests that the mothers *Daphnia*'s energy has a role to produce certain offspring with normal development (Sarpe *et al*. 2014; Choi *et al*. 2016). This study revealed that vitamin B_{12} has a role to maintain fitness caused by nutritional stress in *D. magna,* and this function also found when symbiotic bacteria present in the *D. magna* culture (Sison-Mangus *et al*. 2015). Since bacteria is vitamin B_{12} producer, it is become clearly proved that *D. magna* requires bacteria to maintain its performance during fluctuating environmental change. The cellular availability of vitamin B_{12} was reported as a key vitamin for DNA methylation process, that is susceptible to external environment cues (Ducker and Rabinowitz 2017).

Even though this study was performed in the laboratory scale, the results may be interpreted from an ecological point of view. It is assumed that despite the experimental design is somewhat artificial, the present study may explain the role of bacteria for *D. magna* resilience under environmental change, as discussed below. Since vitamin B_{12} presence in the aquatic ecosystem is exclusively produced by bacteria and archaea (Fang *et al*. 2017; Obeid 2017), and consumed largely by algae (Croft *et al*. 2005; Kazamia *et al*. 2012; Sañudo-Wilhelmy *et al*. 2014; Wells *et al*. 2017), the content of dissolved vitamin B_{12} in nature will depend on the production-consumption between algae and bacteria. Seasonal dynamics, however, have a contribution to establishing bacterial production in the aquatic ecosystem. During heavy rainfall and flood, primary production of phytoplankton is limited due to insufficient light penetration in turbid water.

Consequently, the organic carbon content in the water as major countershaft for bacterial production (Cole *et al*. 1988; Farjalla *et al*. 2006) is also limited. This condition will indirectly effect the amount of vitamin B_{12} in the water, and shifting in high-demand of vitamin B_{12} phytoplankton auxotroph (Gobler *et al*. 2007; Hou 2018). *Daphnia*, that negatively affected by turbid water and/or flood will be helped by the nutritional role of bacteria present. It is assumed, somehow, has a contribution for the resilience of filter-feeding zooplankton due to changing an environment (Häder & Gao 2015).

CONCLUSION

Overall, the observations outlined in the present study, showing a beneficial effect of vitamin B_{12} in the ambient water to maintain *D. magna*'s reproduction under turbid condition. This study provide novel information about the role of vitamin related to the environmental change in the aquatic ecosystem. Further research might explore the molecular metabolism of this vitamin with larger group of individual and other environmental cues.

REFERENCES

Andersen RA, Berges JA, Harrison PJ and Watanabe MM (2005) Recipes for freshwater and seawater media. In: Andersen RA, (ed). *Algal Culturing Technique*. Oxford, UK: Elsevier, pp: 507.

Bilotta GS and Brazier RE (2008) Understanding the influence of suspended solids on water quality and aquatic biota. *Water Research*, 42:2849–2861.

Bito T, Misaki T, Yabuta Y, Ishikawa T, Kawano T and Watanabe F (2017) Vitamin B_{12} deficiency results in severe oxidative stress, leading to memory retention impairment in *Caenorhabditis elegans*. *Redox Biology*, 11:21–29.

Chen L, Fu X, Zhang G, Zeng Y and Ren Z (2012) Influences of temperature, pH and turbidity on the behavioral responses of *Daphnia magna* and Japanese Medaka (*Oryzias latipes*) in the biomonitor. *Procedia Environmental Sciences*, 13:80–86.

Choi JY, Kim SK, La GH, Chang KH, Kim DK, Jeong KY, Park MS, Joo GJ, Kim HW and Jeong KS (2016) Effects of algal food quality on sexual reproduction of *Daphnia magna*. *Ecology and Evolution,* 6:2817–2832.

Cole J, Findlay S and Pace M (1988) Bacterial production in fresh and saltwater ecosystems: a cross-system overview. *Marine Ecology Progress Series*, 43:1–10.

Croft MT, Lawrence AD, Raux-Deery E, Warren MJ and Smith AG (2005) Algae acquire vitamin B_{12} through a symbiotic relationship with bacteria. *Nature*, 438:90–93.

Dao TS, Do-Hong LC and Wiegand C (2010) Chronic effects of cyanobacterial toxins on *Daphnia magna* and their offspring. *Toxicon*, 55:1244–1254.

Ducker GS and Rabinowitz JD (2017) One-Carbon Metabolism in health and disease. *Cell Metabolism*, 25:27–42.

Fang H, Kang J and Zhang D (2017) Microbial production of vitamin B_{12}: A review and future perspectives. *Microbial Cell Factory*. 16:15.

Farjalla VF, Azevedo DA, Esteves FA, Bozelli RL, Roland F and Enrich-Prast A (2006) Influence of hydrological pulse on bacterial growth and DOC uptake in a clear-water Amazonian lake. *Microbiology Ecology,* 52:334–344.

Ferrer A, Rivera J, Zapata C, Norambuena J, Sandoval Á, Chávez R, Orellana O and Levicán G (2016) Cobalamin protection against oxidative stress in the acidophilic iron-oxidizing bacterium *Leptospirillum* group II CF-1. *Frontier Microbiology,* 7:1–11.

Gelda RK, Effler SW, Prestigiacomo AR, Peng F, Effler AJP, Wagner BA, Perkins MG, O'Donnell DM, O'Donnell SM and Pierson DC (2013) Characterizations and modeling of turbidity in a water supply reservoir following an extreme runoff event. *Inland Waters,* 3:377–390.

Ghemrawi R, Pooya S, Lorentz S, Gauchotte G, Arnold C, Gueant J-L and Battaglia-Hsu S-F (2013) Decreased vitamin B_{12} availability induces ER stress through impaired SIRT1-deacetylation of HSF1. *Cell Death Disease*, 4:e553.

Gilbert KLK and JJ.(1990) Suspended clay and the population dynamics of planktonic Rotifers and Cladocerans. *Ecology,* 71:1741–1755.

Gobler CJ, Norman C, Panzeca C, Taylor GT, and Sañudo-Wilhelmy SA (2007) Effect of B-vitamins (B_1, B_{12}) and inorganic nutrients on algal bloom dynamics in a coastal ecosystem. *Aquatic Microbial Ecology,* 49:181–194.

Häder D-P and Gao K (2015) Interactions of anthropogenic stress factors on marine phytoplankton. *Frontiers in Environmental Sciences,* 3:1–14.

Hasenbein M, Komoroske LM, Connon RE, Geist J and Fangue NA (2013) Turbidity and salinity affect feeding performance and physiological stress in the endangered delta smelt. *Integrative Comparative Biology,* 53:620–634.

Hayashi M, Yukino T, Watanabe F, Miyamoto E and Nakano Y (2007) Effect of vitamin B_{12}-enriched thraustochytrids on the population growth of rotifers. *Bioscience, Biotechnology, and Biochemistry,* 71:222–225.

Helliwell KE (2017) The roles of B vitamins in phytoplankton nutrition: New perspectives and prospects. *New Phytologist,* 216:62-68.

Helliwell KE, Lawrence AD, Holzer A, Kudahl UJ, Sasso S, Kräutler B, Scanlan DJ, Warren MJ and Smith AG (2016) Cyanobacteria and eukaryotic algae use different chemical variants of vitamin B_{12}. *Current Biology,* 26:999–1008.

Hirayama K, Maruyama I and Maeda T (1989) Nutritional effect of freshwater *Chlorella* on growth of the rotifer *Brachionus plicatilis*. *Hydrobiologia,* 186–187:39–42.

Hou Z (2018) Impacts of environmental variables on a phytoplankton community : A case study of the tributaries of a subtropical river , Southern China. *Water,* 10:152.

IPCC (2014) Climate Change 2014: Synthesis Report. Contribution of Working Groups I,II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. Geneva, Switzerland, pp:151.

Japan Water Research Center (JWRC) (2008) Research on water purification system. *www.jwrc-net.or.jp/ aswin/projects-activities/ trainee_files/ 20080410_03.pdf*

Kazamia E, Czesnick H, Nguyen TT Van, Croft MT, Sherwood E, Sasso S, Hodson SJ, Warren MJ and Smith AG (2012) Mutualistic interactions between vitamin B_{12}-dependent algae and heterotrophic bacteria exhibit regulation. *Environmental Microbiology,* 14:1466–1476.

Keating KI (1985) The influence of vitamin B_{12} deficiency on the reproduction of *Daphnia pulex* Leydig. *Journal of Crustacean Biology,* 5:130–136.

Kirk KL (1991) Suspended clay reduces *Daphnia* feeding rate : behavioural mechanisms. *Freshwater Biology,* 25:357–365.

Kleiven OT, Larsson P and Hobek A (1992) Sexual reproduction in *Daphnia magna* requires three stimuli. *Oikos,* 65:197–206.

Kusari F, O 'doherty AM, Hodges NJ and Wojewodzic MW (2017) Bi-directional effects of vitamin B $_{12}$ and methotrexate on *Daphnia magna* fitness and genomic methylation. *Scientific Reports*, 1–9.

Lee CS, Lee YC and Chiang HM (2016) Abrupt state change of river water quality (turbidity): Effect of extreme rainfalls and typhoons. *Science Total Environment,* 557–558:91–101.

Maisanaba S, Pichardo S, Puerto M, Gutiérrez-Praena D, Cameán AM and Jos A (2015) Toxicological evaluation of clay minerals and derived nanocomposites: A review. *Environmental Research*, 138:233–254.

Manakul P, Peerakietkhajorn S, Matsuura T, Kato Y and Watanabe H (2017) Effects of symbiotic bacteria on chemical sensitivity of *Daphnia magna*. *Marine Environmental Research,* 128:70–75.

Mushegian AA, Burcklen E and Scha TMM (2016) Temperature-dependent benefits of bacterial exposure in embryonic development of *Daphnia magna* resting eggs. *Journal of Experimental Biology,* 897–904.

Obeid R (2017) Cobalamin deficiency. In : JR. Harris, BB. Biswas and P. Quin (eds.) *Vitamin B_{12} : Advances and insights*. CRC Press : Boca Raton, FL, pp: 301-313.

OECD (2012) OECD Guideline for the testing of chemicals: *Daphnia magna* Reproduction Test No. 211. Paris. pp: 25.

Ogonowski M, Schür C, Jarsén Å and Gorokhova E (2016) The effects of natural and anthropogenic microparticles on individual fitness in *Daphnia magna*. *PLoS One,* 11:1–20.

Peerakietkhajorn S, Tsukada K, Kato Y, Matsuura T and Watanabe H (2015) Symbiotic bacteria contribute to increasing the population size of a freshwater crustacean, *Daphnia magna*. *Environmental Microbiology Reports,* 7:364–372.

Pendergrass AG, Knutti R, Lehner F, Deser C and Sanderson BM (2017) Precipitation variability increases in a warmer climate. *Scientific Reports,* 7:1–9.

Pietrzak B, Bednarska A and Grzesiuk M (2010) Longevity of *Daphnia magna* males and females. *Hydrobiologia,* 643:71–75.

Robinson SE, Capper NA and Klaine SJ (2010) The effects of continuous and pulsed exposures of suspended clay on the survival, growth, and reproduction of *Daphnia magna*. *Environmental Toxicology and Chemistry,* 29:168–175.

Sañudo-Wilhelmy SA, Gómez-Consarnau L, Suffridge C and Webb EA (2014) The role of B vitamins in marine biogeochemistry. *Annual Review of Marine Science,* 6:339–367.

Sarpe D, de Senerpont Domis LN, Declerck SAJ, van Donk E and Ibelings BW (2014) Food quality dominates the impact of food quantity on *Daphnia* life history: Possible implications for re-oligotrophication. *Inland Waters,* 4:363–368.

Sison-Mangus MP, Mushegian AA and Ebert D (2015) Water fleas require microbiota for survival, growth and reproduction. *ISME J,* 9:59–67.

Tang YZ, Koch F and Gobler CJ (2010) Most harmful algal bloom species are vitamin B_1 and B_{12} auxotrophs. *Proceeding of the National Academy Sciences,* 107:20756–20761.

Wells ML, Potin P, Craigie JS, Raven JA, Merchant SS, Helliwell KE, Smith AG, Camire ME and Brawley SH (2017) Algae as nutritional and functional food sources: revisiting our understanding. *Journal of Applied Phycology,* 29:949–982.

Yu J-P, Hino A, Ushiro M and Maeda M (1989) Function of bacteria as vitamin B_{12} producers during mass culture of the rotifer *Brachionus plicatilis*. *Nippon Suisan Gakkaishi,* 55:1799–1806.