

INFLUENCE OF DIFFERENT FEEDING REGIMES ON THE SURVIVAL AND GROWTH OF *ACROPORA DIGITIFERA* IN HUSBANDRY

PUTERI NURSHAZMIMI ZAIDI¹, FARAH AMIRAH AHMAD MUSTAFFA¹ AND TAN CHUN HONG^{1,2*}

¹Research and Education on the Environment for Future Sustainability (REEFS) Research Interest Group, Faculty of Science and Marine Environment (FSSM), Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia. ²Institute of Oceanography and Environment (INOS), Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia.

*Corresponding author: tanchunhong@umt.edu.my

Submitted final draft: 6 July 2022

Accepted: 9 October 2022

<http://doi.org/10.46754/jssm.2023.01.008>

Abstract: Scleractinian corals rely on autotrophy and heterotrophy feeding to maintain their daily energy requirements. In the wild, there are plenty of food sources in their surroundings. But in closed *ex-situ* systems, one of the biggest challenges for corals is to meet their nutrient requirements. This study aims to determine the survivorship and growth of *Acropora digitifera* in *ex-situ* systems with different feeding treatments. Three colonies were placed in different treatment tanks, and then three branches per colony were tagged. Two tanks were fed with *Artemia* and *budu* (fermented anchovy sauce), while one tank remains unfed throughout the experiment. The mortality and linear growth rate of the corals were quantified monthly for three months. The results showed that feeding had a significant influence on coral growth. Between the fed corals, *budu* promoted the highest mean growth rate (0.045 ± 0.005 mm/day), while corals in the *Artemia*-fed tank showed a growth rate that is 50% lower. However, corals in the *Artemia*-fed tank had the highest (89%) survival rate. The unfed corals were recorded to have the lowest growth rate (0.004 ± 0.005 mm/day). This showed that *A. digitifera* better utilised dissolved particulate food (i.e., *budu*) compared with zooplanktons. Correspondingly, further studies on *budu* as a potential alternative coral feed are needed in future.

Keywords: *Acropora digitifera*, mesocosm, growth rate, coral feeding, *budu*, *Artemia*.

Introduction

Coral reefs are highly productive marine ecosystems, hosting a high biodiversity of marine flora and fauna that thrive in an oligotrophic environment. Uniquely, corals are able to survive and thrive in nutrient-poor conditions due to their symbiosis with unicellular dinoflagellates, commonly known as zooxanthellae (Davies, 1984). These endosymbiotic zooxanthellae (genus *Symbiodinium*) channel high amounts (>99%) of their photosynthetic products to the coral (Muscatine & Cernichiaro, 1969). Through photosynthetic activities, corals receive oxygen and carbohydrates for their nutritional needs. In return, the corals provide phosphorus, nitrogen, and carbon dioxide to the zooxanthellae (Barnes & Hughes, 1982; Trench, 1993; Baker, 2003; Furla *et al.*, 2011). However, although corals may get up to 95% of their carbon requirements from the zooxanthellae (Muscatine *et al.*, 1981;

1990), there is still a lack of important elements, such as phosphorus and nitrogen (Battey & Patton, 1987), which are vital for the growth of corals (Falkowski *et al.*, 1984; Rinkevitch, 1989; Davies, 1991). Consequently, corals are still dependent on heterotrophic feeding for additional nutrients and energy not obtainable from the symbionts (Houlbrèque *et al.*, 2004; Crabbe & Smith, 2006; Hii *et al.*, 2008).

In nature, corals acquire energy from various food sources. For example, from bacteria (Ferrier-Pages *et al.*, 1998), dissolved (Sorokin, 1973; Al-Moghrabi *et al.*, 1993) and particulate organic matter (Anthony, 1999; Anthony & Fabricius, 2000), sediment (Rosenfeld *et al.*, 1999), as well as absorbing the dissolved nutrients (Titlyanov *et al.*, 2000a; 2000b; Ferrier-Pages *et al.*, 2003). However, corals could not ingest all ranges of particles because of the physical constraints or their feeding selectivity

(Sorokin, 1991; Sebens *et al.*, 1996; Leal *et al.*, 2014b). Moreover, there is no ideal prey to nourish corals as feeding preferences vary with coral species and prey capture rates (Leal *et al.*, 2014b). Furthermore, Scleractinian corals are polytrophic, which means that they obtain food in more than one way (Goreau *et al.*, 1971). They can be voracious predators (Sebens *et al.*, 1996), exhibiting several modes of feeding. For example, they combined tentacle movement with cnidocyte firing and then use mucociliary feeding to ingest immobilised prey (Sorokin, 1990; Ferrier-Pagès *et al.*, 2003; Palardy *et al.*, 2006), as well as by mucus entanglement to trap food (Lewis & Price, 1975).

One of the biggest challenges in the aquaculture industry or closed *ex-situ* system is to satisfy the nutrient requirements for corals (Arvedlund *et al.*, 2003; Wabnitz *et al.*, 2003; Houlbrèque & Ferrier-Pagès, 2009; Leal *et al.*, 2014a; 2014b; Toh *et al.*, 2014). The lack of data on coral feeding and their nutritional requirements is one of the barriers of successful coral maintenance in *ex-situ* cultivation (Arvedlund *et al.*, 2003). Usually, to fulfil coral's growth requirements, they are routinely supplied with commercial dry food, microalgae, and zooplanktons (Petersen *et al.*, 2008). The most popular live feed used for coral feeding is *Artemia salina* nauplii. It can provide corals with the essential source of nitrogen, phosphorous and amino acids (Sorgeloos *et al.*, 2001; Houlbrèque *et al.*, 2004; Hii *et al.*, 2008). Researchers found that corals fed with *Artemia* have higher growth rates compared with other species (Petersen *et al.*, 2008; Toh *et al.*, 2014). Besides, *Artemia* is easier to cultivate compared with other marine zooplankton species, producing high nutrient value in a considerably small size of about 500 µm in length (Helland *et al.*, 2003; Reynaud *et al.*, 2004). The organisms can be fed with nutrients enriched *Artemia* as food to meet specific nutrient requirements (Dhert *et al.*, 1990; Olsen *et al.*, 1999; Hanaee *et al.*, 2005; Monroig *et al.*, 2006). Thus, *Artemia* is undeniably convenient for corals husbandry in *ex-situ* sites as a source of energy supply.

Scleractinian corals that were fed (*ex-situ*) experienced a significant increase in tissue thickness, skeletal growth and survivorship compared with those that were not (Anthony & Fabricius, 2000; Houlbrèque *et al.*, 2004; Grotolli *et al.*, 2006; Sawall *et al.*, 2011). Furthermore, feeding would also increase the zooxanthellae density, as well as the rates of areal photosynthesis (Ferrier-Pagès *et al.*, 2000; 2003; Houlbrèque *et al.*, 2003; 2004; Davy *et al.*, 2006). However, there were also debates on the need for heterotrophic feeding for corals. Studies showed that heterotrophy feeding was found to give only a minimal effect on the skeletal growth of scleractinian corals (Johannes, 1974; Wellington, 1982). A study also found that there were similar amounts of photosynthates translocated by the zooxanthellae between starved and fed animals (Davy & Cook, 2001).

Besides that, there is limited knowledge of artificial feed as an alternative food source, which is potentially less costly and labour-intensive than live feed. For example, the usage of honey and anchovy sauce for corals was something that has been explored among coral hobbyists in this industry (Sebastian, 2017). Anchovy sauce, also known as *budu*, is a traditional fermented fish sauce in Malaysia, commonly consumed as flavouring additives and as a dipping sauce (Huda & Rosma, 2006). It was used by hobbyists to help promote coral growth in aquariums, but there has been no scientific evidence. The product has a high protein content in terms of nutrition for humans (Sanceda *et al.*, 1996), which presumably affect coral growth rate, hence providing an interesting research opportunity. This can be potentially less costly and labour-intensive than live feed. Further study is needed to find a specific feeding requirement for corals, especially for the *Acropora* species in a mesocosm system. Hence, this study aims to evaluate the effects of live, artificial, and non-feeding treatment on the survival and growth rate of branching *A. digitifera* in a hatchery setup.

Materials and Methods

Sampling Site and Feeding Treatment

Nine healthy colonies (size ~10 cm²) of branching *A. digitifera* were collected from Pulau Bidong, Terengganu at a depth of approximately 5 m. They were acclimated for two weeks without being fed before the experiments. The coral colonies were randomly divided into three treatments containing three colonies each: (1) Corals that were fed with newly hatched *Artemia*; (2) corals that were fed with *budu* (i.e., liquid fermented anchovy sauce) and, (3) unfed corals (as control). Corals in the two feeding treatments were fed every 72 hours, due to a rhythmic trend (Hii et al., 2008). Feeding was set between 7 pm and 8 pm for an hour. This was to simulate the natural environment, where corals actively feed during sunset due to the zooplankton density being highest at the time (Heidelberg et al., 2004; Yahel et al., 2005; Nakajima et al., 2008). Furthermore, feeding efficiency also increased when polyps are fully expanded at night (Borneman, 2001).

Experimental Tank Set-up

Three recirculating closed systems were set up for this experiment, each consisting of 100 L water volume with return water into a sump. The sump contained three mesh sizes of filter sponges at the outlet to filter particulate matter from being circulated in the system, a protein skimmer, and a biofiltration media consisting of live rock, bio balls and ceramics. The systems were left to run for one month to mature the biological bacteria in the water. Led light (AI Hydra 32HD Led Light) of blue, white, and red was used with an intensity of 350 $\mu\text{mol m}^{-2} \text{s}^{-1}$ photoperiod 12:12 hours (light:dark). Water temperature was maintained at 27°C to 28°C with the aid of chillers connected to the pump before the water is returned to the tank. Salinity was maintained at 33-34 ppt, with a 10% water change weekly. Water quality parameters were maintained as follows: Alkalinity, 8-9 dkH; calcium, 430-440 mg/L; magnesium, 1330-1350 mg/L; nitrate, <5 mg/L; ammonia, 0 mg/L; and

phosphate < 0.05 mg/L using the Salifert test kit. In the natural marine environment, the calcium content is around 420 mg/l (Spotte, 1979). Thus, it is suggested that the calcium concentration be maintained in the aquarium system at above 360 mg/l as it has enhancing effects on coral calcification rates (Tambutté et al., 1996). Since water flow is also one of the important environmental parameters for sessile corals to transport dissolved and particulate nutrients (Kaandorp & Kubler, 2001), a medium-strong water flow that passes through the coral colonies were also provided.

Feeding Regimes

For the live feeding treatment, newly hatched *Artemia* nauplii were used because it is commonly used as live feed in aquaculture facilities (Dhont & Sorgeloos, 2002). *Artemia* nauplii is been well accepted by several coral species such as *Galaxea* sp. and *Pocillopora* sp. (Houlbrèque et al., 2003; Hii et al., 2008; Osinga et al., 2012) and could enhance coral growth and survival (Petersen et al., 2008). The *Artemia* stock for the feeding treatment was prepared 24 hours before the feeding time, following the methods described by Dhont and Stappen (2003). Briefly, about 3 g of *Artemia salina* cysts (Great Salt Lake Brine Shrimp Eggs, Premium Quality, GSL-INT) were prepared at a salinity of 34 ppt at room temperature (~28°C) in a 5 L container with vigorous aeration. The average nauplii size was 400-500 μm length when freshly hatched (Naceur et al., 2008). During feeding, the water pump was shut off and the *Artemia* were pipetted directly over the whole coral colonies at the surface of the polyps. After one hour, the water pump was turned back and the uneaten floating *Artemia* were removed by the filtration system. Meanwhile, the *budu* feeding treatment was given 2 ml of *budu* that was readily prepared in a bottle, then diluted with 100 ml of seawater (2% concentration) directly on top of coral polyps. Lastly, the non-feeding treatment corals were left to rely on only autotrophy through aquarium lighting.

Coral Survival and Growth Rates

The linear extension rate was measured monthly for three months to examine the growth rate of corals in response to different feeding regimes. Linear extension growth rate was expressed in mm/day. Three nubbins per colony (a total of nine nubbins per treatment) were used for the measurement. Direct measurements of nubbins length were taken from the cable tie up to the axial polyp (Okubo *et al.*, 2005; Johnson *et al.*, 2011) using an underwater camera with a ruler as the scale bar. Then, the photos were analysed using the image analysis software ImageJ version 1.52a (<https://imagej.nih.gov/ij/download.html>). Meanwhile, the number of nubbins still alive at the end compared with the number of nubbins at the beginning of the experiment was examined to obtain the coral survival rate.

Proximate Analysis Sample Preparation

A proximate analysis was conducted to determine the nutritional value of different food types used for these experiments (i.e., *budu* and *A. salina* nauplii), along with the additional commercial coral feed. This is to quantify the nutritional value of the protein, lipid, and ash following guidelines from the AOAC method (2000).

In this experiment, *budu* and *Artemia* nauplii were considered as a wet samples, which is defined as a sample with a high water content of more than 20%. Therefore, the wet samples were frozen and dried using the freeze-drying method and kept in a freezer at -80°C for three days. Then, the samples were ground into smaller pieces and then homogenised. On the other hand, the commercial coral feed was directly grinded and filtered by 1 mm size filters as it was already in a powder form (which is classified as a dry sample, with a low water content of only 8-11% or lower). This was to ensure the homogeneity of the samples and increase the surface area for optimum and effective extraction during the analysis. All the samples were kept in closed containers to avoid

direct exposure to surrounding moisture and high temperature.

Crude protein content was determined according to the Kjeldhal (1883) method, calculated from the nitrogen content of the food sample. Meanwhile, crude lipid was determined with the low boiling of organic solvent through the Soxhlet extraction method. For ash content, it is determined by the remaining inorganic residue after complete oxidation of organic content in a food sample by ignition at 600°C in a muffle furnace.

Statistical Analyses

The collected data (i.e., growth rates) was first tested for normality and homogeneity of variance using the Shapiro-Wilk and Lavené's tests. Then, Welch's test was used to examine the significant difference between samples with a significant level of $\alpha = 0.05$. The Welch's test was used to compare two mean groups because the data violates the assumption of homogeneity of variances. Due to the survivorship factors, sample sizes were unequal (unequal variance). The statistical analysis was conducted with the Statistic Package for Social Science (SPSS) software version 20.

Results and Discussion

During the feeding, it can be seen that feeding does stimulate *A. digitifera* to extend their tentacles, excrete mucus, and also extrude the mesenterial filament (Figure 1). Lewis and Price (1975) observed *A. millepora* as a small polyp species that extend their tentacle and excrete mucus prior to feeding. This is due to the presence of food chemical signs (Lehman & Porter, 1973). All these mechanisms were carried out to maximise their feeding strategy. Once after *Artemia* and *budu* were pipetted around the corals, the *Artemia* nauplii were found clumped together near the tip of the polyps (Figure 1). The *Artemia* nauplii appeared to be immobilised or dead in a mucus net, most likely due to the cnidocyte firing, thus causing mortality before

being consumed. The same was observed by Hii et al. (2008) and van Os et al. (2012).

One of the major mechanisms to enhance coral heterotrophy feeding was mucus production to facilitate the ingestion of prey from loss to the water column (Ferrier-Pages et al., 1998; van Os et al., 2012). The mucus produced is a source of energy for corals. It contains fatty acids, triglycerides, wax esters, and other energy-rich substances with high nutritional value (Coffroth, 1984). Besides that, there were also reports of the extrusion of mesenterial filaments for extracoelenteric digestion (Lang & Chornesky, 1990; Goldberg, 2002), of which the digestion process happened outside the body. This extracoelenteric digestion may be an energetically favourable feeding

strategy because the corals do not have to move all the prey into the coelenteron by mucociliary feeding and muscle action (Wijgerde et al., 2011).

Food Proximate Analysis

The food proximate analysis showed that *Artemia* and *budu* varied in composition in terms of crude protein, crude lipid, and ash (Figure 2). Coral feed was added to the analysis as a comparison with the commercialised product that is made especially for corals. Both *Artemia* (34.06%±1.15) and coral feed (34.18%±1.02) had similar crude protein contents, while *budu* had only 21.13%±0.48. The percentage of crude lipid was highest in *Artemia* (39.43%±1.93), followed by coral feed (9.48%±0.01), and *budu*

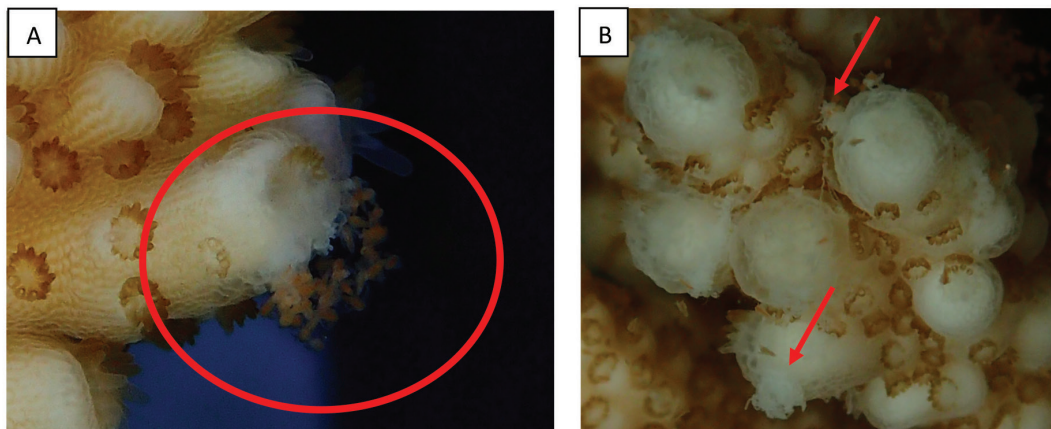


Figure 1: *Acropora digitifera* preying on *Artemia salina* nauplii by (A) mucus entrapment, inside the red circle and (B) extrusion of mesenterial filament, red arrow

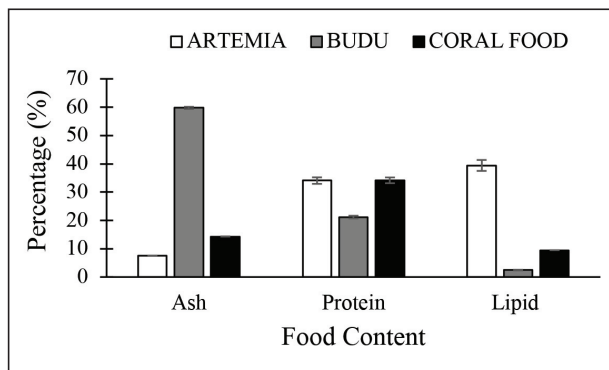


Figure 2: The percentage of proximate nutritional chemical compositions of ash, crude protein and crude lipid in three different food types (n=3)

(2.47%±0.13). Lastly, the percentage of ash was the highest in *budu* (59.75%±0.38), followed by coral feed (14.33%±0.04), and *Artemia* (7.57%±0.04).

Variation in Coral Survival Rates

The survival rates of *A. digitifera* varied between feeding treatments. The mortality rate recorded for the *Artemia*-fed treatment was the lowest, with 87% surviving at the third month of the experiment. The *budu* and unfed treatments saw survival rates of only 22% and 67%, respectively. An outbreak of cyanobacteria or the “red slime algae” outbreak was recorded in the *budu* treatment tank in the second month and potentially led to higher mortality. A similar high algae outbreak was reported in the use of commercial coral feed (i.e., Reef-Roids and Reef Chili) (Forsman *et al.*, 2012). All coral colonies started to develop tissue lesions (also known as tissue necrosis) in the second month (Luna *et al.*, 2010). This phenomenon, defines as “slow tissue necrosis” (STN) is a condition where tissue starts to tear off from the skeleton (Petersen, 2005) but no specific rate was recorded, especially in aquarium systems (Sweet *et al.*, 2011).

There are number of factors contributing to the low survivorship of the *budu* treatment. *Budu* is in a liquid form, which easily dissolves as particulate matter in the water compared with live zooplanktons. Those uneaten food particles will decay and contribute to bacteria and algae (Stambler *et al.*, 1991; Larned, 1998). It causes nitrogen and -phosphorous buildup in the water column, which then deteriorates the quality of water, negatively affecting growth and survival (Petersen *et al.*, 2008; Ali *et al.*, 2010; Forsman *et al.*, 2011). An optimum amount of food will give a balance of nutrient loading in the water, while adding excessive feed will deteriorate coral performance. Deterioration of water quality is particularly problematic for closed recirculation systems, compared with the flow through systems where seawater is constantly refreshed (Sheridan *et al.*, 2013). Thus, there is likely to be a fine line between feeding and

overfeeding for dissolved feed. Compared with the *Artemia* treatment, live feed was given, which did not leave any excess feed that may cause water quality deterioration.

Variation in Types of Coral Feed and Growth Rates

As for the growth rate, *budu* experienced the highest mean total growth rate attained for three-month period, with 0.045±0.024 mm/day, followed by corals fed with newly hatched *Artemia* (0.010±0.0019 mm/day), and those unfed (0.004±0.015 mm/day), respectively. A Shapiro-Wilk test showed all feeding treatments were normally distributed; *budu* $W(20) = 0.968$, $p = 0.707$, *Artemia* $W(26) = 0.960$, $p = 0.392$, and unfed $W(23) = 0.979$, $p = 0.890$. However, the Lavene homogeneity test showed that the variances were not equal $t(2) = 4.877$, $p = 0.011$. The Welch test showed there was no significant difference between all feeding treatments $t(2) = 1.930$, $p = 0.159$. The coral growth rate in *budu* treatment was higher compared with the *Artemia* and unfed treatments (Figure 3). But, statistically, the results were the opposite, which may be due to the high variation of standard error from small sample sizes and survivorship of corals. These results further confirmed that *A. digitifera* corals do possess the distinctive heterotrophic ability to thrive. Compared with the unfed treatment, corals that only depend on photosynthesis to thrive had a very minimum or almost no growth at all.

Two different types of food: *Artemia* (commercialised aquaculture industrial feed) versus the liquid fermented anchovy sauce (i.e., *budu*) as an alternative were tested on their effects on coral growth. Even though *budu*-fed corals had the lowest survival rate, the increase in growth rate indicated that this alternative feed had a positive impact on the corals. The nutrient contents in *budu* that are readily dissolved in water presumably contributed to the high growth rate of the corals. *Budu* is a fish sauce based on fermented anchovies. *Budu* is made by mixing fish, mainly *Stolephorus* sp. (*ikan bilis* in Malay), with salt in the ratio of 3:2,

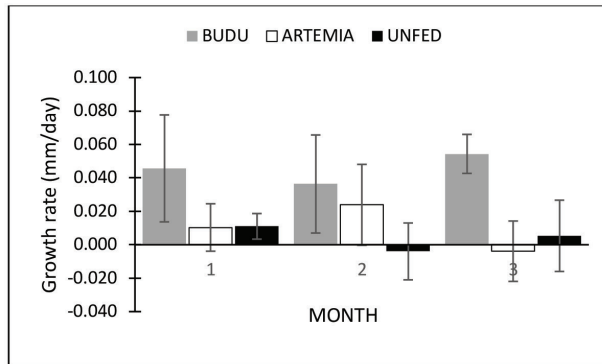


Figure 3: Growth rates of three different feeding treatments of *budu*, newly hatched *Artemia* and unfed (n=27)

and kept in a big earthenware jar underneath sunlight to undergo fermentation for six to 12 months (Klamkiao *et al.*, 2006; Rosma *et al.*, 2009). As such, it has been identified to have a high amount of glutamic acid (16.65 to 30.53 mg/g) compared with some other species of fish (Mohanty *et al.*, 2014; Nadiah *et al.*, 2014; Ahmad *et al.*, 2019). Interestingly, glutamic acid was found to be a chemical feeding activator for corals (Lehman & Porter, 1973). The presence of this chemical compound in the water stimulates extended tentacle feeding behaviour, which then will maximise feeding capture efficiency.

Based on the proximate analysis (Figure 2), the protein content in *budu* was quite high compared with other reported data reported at an average of 9.69% to 15.02% for crude protein and 51.41 to 88.80 mg/g for amino acids (Ghazali *et al.*, 2011; Nadiah *et al.*, 2014; Ahmad *et al.*, 2019). The differences in protein content between the samples were due to the raw materials used, such as fish and salt ration, and fermentation time (Nadiah *et al.*, 2014; Ahmad *et al.*, 2019). Both protein and amino acid are crucial for numerous physiological processes and physical activities, such as growth and maintenance, and their insufficiency will disrupt the whole process (Wilson *et al.*, 2003). The ash content from the *budu* sample has the highest nutritional value compared with protein. Ash represents inorganic nutrients (e.g., mineral and trace elements), such as phosphorus and nitrogen (Pomeranz & Meloan, 1994), which are important building blocks for coral biomass

production (Leal *et al.*, 2017). Thus, it was suggested that the combination of all protein, mineral and trace element contents in *budu* can aid in coral growth. However, the digestibility of *budu* for corals as potential alternative coral feed needs to be further investigated.

Compared to the *budu*-fed treatment, the *Artemia*-fed corals have the second highest growth rate. Based on the results of the proximate analysis, *Artemia* has high crude protein and lipid contents. Conlan *et al.* (2018) indeed suggested that *Acropora* sp. grows rapidly with high-energy materials, such as saturated and monounsaturated fatty acids, and storage lipids. However, due to morphologically having small polyps, *A. digitifera* may have the disadvantage of preferring live moving zooplanktons compared with food that is readily dissolved in water. The same results were found by Anthony (1999) and Conlan *et al.* (2017), where *Acropora* spp. recruits had low consumption of zooplanktons compared with the intakes of other feeding treatments (i.e., SPM, filtered seawater). Kuanui *et al.* (2016) found that *Acropora* sp. was only able to catch a limited number (i.e., 0.44 to 2.39 individuals/polyp/day) of *Artemia*. The coral feeding capability depends on the feeding mechanism, prey size and density, polyp size, number of tentacles, light, flow rate, and temperature (Lasker, 1981; Fabricius & Klumpp, 1995; Sebens *et al.*, 1998; Anthony, 1999; Piniak, 2002; Houlbrèque & Ferrier-Pagès, 2009; Toh *et al.*, 2014). As recommended by Conlan *et al.* (2018), *Acropora* sp. do prefer

smaller and less motile prey. Thus, regardless of the diet with higher nutrients, the capture efficiency of the corals is one of the limiting factors for coral growth.

Small polyp corals depend less on tentacles than on mucus strands or filaments for the capture of zooplanktons (Lewis & Price, 1975). Mucus strands with the extrusion of mesenterial filaments to immobilise *Artemia* can be observed in this study (Figure 1). Thus, it can be undeniably agreed that extracoelenteric digestion might also happen for *A. digitifera*, which contributes to coral growth. Reports of cnidarian mesenterial filaments of a digestive structure (Logan, 1984; Lang & Chornesky, 1990; Goldberg, 2002), that may comprise both digestive zymogen cells and absorptive cells (Yonge, 1930; Abe, 1938; Van Praët, 1980) supported the assumption in this study.

This study provides further evidence that heterotrophy plays an important role in coral growth, especially in the importance of different types of feed used. As previously found, fed corals exhibited twofold faster organic matrix synthesis with significantly higher levels of protein (Houlbreque & Ferrier-Pages, 2009; Hoogenboom *et al.*, 2015) and lipid content (Ferrier-Pages *et al.*, 2003; Treignier *et al.*, 2008; Lim *et al.*, 2017). Then, heterotrophy also increased zooxanthellae (Titlyanov *et al.*, 2000a; 2000b; 2001; Houlbreque *et al.*, 2003; 2004) and chlorophyll *a* and *c2* per unit surface area (Ferrier-Pages *et al.*, 2003; Houlbreque *et al.*, 2003), while indirectly enhancing tissue growth by two to eight times (Ferrier-Pages *et al.*, 2003; Houlbreque *et al.*, 2003; 2004), tissue thickening (Barnes & Lough, 1993), and calcification rates that are 30% higher (Jacques & Pilson, 1980; Sebens, 1991; Witting, 1999) when fed and unfed corals are compared. Toh *et al.* (2014) discovered that even after transplantation to the reef, fed corals from the *ex-situ* feeding regime will continue to develop greater than unfed corals.

In this study, the unfed treatment proved that photoautotroph itself is not enough to satisfy the daily energy and nutrient requirements for

branching *A. digitifera*. They had very minimum or almost no growth at all. Although unfed corals may experience a rapid increase in skeleton extension, their tissues grow at a slower rate due to the non-carbon nutrient from zooplanktons, which are still a limiting factor for tissue growth (Ferrier-Pages *et al.*, 2003). This suggested that coral growth encompassed of both the building of the calcium carbonate skeleton (e.g., linear extension) and the increase of tissue thickness and composition, and food availability is the limiting factor of growth performance, which needs to be further investigated.

Accordingly, corals that relies on autotrophy is undoubtedly capable of growing and surviving. However, this is inadequate for corals to thrive. Thus, it is highly recommended to feed corals in *ex-situ* systems for their health. This is to ensure greater longevity of the corals and did not interfere with the results of the ongoing experiment. Depending on the types of coral, it is suggested that small polyp corals, such as *Acropora* and *Montipora*, be fed with non-live moving zooplanktons. Dissolved feed might optimise their feeding routine to support their daily metabolic activity. However, overfeeding must be avoided as it triggers algae growth that will later cause unfavourable water conditions.

Conclusion

Feeding is indeed important for Scleractinian corals to thrive in enclosed systems as they need food from their surroundings to have a complete nutrient supply for their daily metabolic activity. But corals need to be fed the right choice of food according to the species. Each species of coral have its strategy that follows its morphology to adapt to their surroundings. Corals with small polyps, like *Acropora* would prefer food that is readily available for them to consume by either using mucus, mesenterial filament, or tentacles. Live feed, such as *Artemia* spp. Nauplii, which is widely used in the aquaculture industry, is not advisable due to it being inefficient as prey. Thus, in this study, *budu* (anchovy sauce) was tested as an alternative coral feed, which had promising results in terms of coral growth. Furthermore,

based on the nutrient contents of *budu*, future studies are needed to discover alternative coral feed that is cost-effective and ensures the growth and survival of corals in aquariums.

Acknowledgements

We would like to acknowledge Liew Hon Jung for helping to offset the experiment. We express our gratitude to the Institute of Tropical Aquaculture Hatchery (AKUATROP) UMT for providing the space for the experiment set-up, and to the General Analytical Lab, Faculty of Fisheries and Food Science UMT for its help in sample analysis.

References

- Abe, N. (1938). Feeding behaviour and the nematocyst of *Fungia* and 15 other species of corals. *Palao Tropical Biological Station Studies, 1*, 469-521.
- Ahmad, F., Mahmud, M. F., Ali, N. S. C., Ayub, M. N. A., Mohamad, S. N., Ismail, N., Chilek, T. Z. T, Zamri, A. I., & Khalid, M. I. (2019). Determination of proximate composition and amino acid profile of *Budu* from Setiu, Terengganu and Tumpat, Kelantan. *Asian Journal of Agriculture and Biology. Special Issue*, 61-68.
- Ali, M., Hayward, R. S., Bajer, P. G., & Whitledge, G. W. (2010). Maintenance/submaximum feeding schedules for reducing solid wastes and improving feed conversion in aquaculture. *Journal of the World Aquaculture Society, 41*, 319-331.
- Al-Moghrabi, S., Allemand, D., Jaubert, J. (1993). Valine uptake by the scleractinian coral *Galaxea fascicularis*: Characterization and effect of light and nutritional status. *Journal of Comparative Physiology B, 163*, 355-362. <https://doi.org/10.1007/BF00265638>
- Anthony, K. R. N. (1999). Coral suspension feeding on fine particulate matter. *Journal of Experimental Marine Biology and Ecology, 232*(1), 85-106. [https://doi.org/10.1016/S0022-0981\(98\)00099-9](https://doi.org/10.1016/S0022-0981(98)00099-9)
- Anthony, K. R. N. & Fabricius, K. (2000). Shifting roles of heterotrophy and autotrophy in coral energetics under varying turbidity. *Journal of Experimental Marine Biology and Ecology, 252*, 221-253.
- AOAC (2000). *Official Methods of Analysis* (17th ed.). Gaithersburg, M.D., AOAC International.
- Arvedlund, M., Craggs, J., & Pecoerlli, J. (2003). Coral culture-possible future trends and directions. In Cato J. C., & Brown C.L., (Eds.), *Marine ornamental species: Collection, culture and conservation*. Ames: Iowa State Press.
- Baker, A. C. (2003). Flexibility and specificity in coral-algal symbiosis: Diversity, ecology, and biogeography of *Symbiodinium*. *Annual Review of Ecology, Evolution, and Systematics, 34*, 661-689.
- Barnes, R. S. K., & Hughes, R. N. (1982). *An introduction to marine ecology*. Oxford: Blackwell Scientific Publications.
- Barnes, D. J., & Lough, J. M. (1993). On the nature and causes of density banding in massive coral skeletons. *Journal of Experimental Marine Biology and Ecology, 167*(1), 91-108.
- Batthey, J. F., & Patton, J. S., (1987). Glycerol translocation in *Condylactis gigantea*. *Marine Biology, 95*, 37-46. <https://doi.org/10.1007/BF00447483>
- Borneman, E. H., (2001). *Aquarium corals: Selection, husbandry, and natural history*. Neptune City, New Jersey: T.F.H. Publ., Inc.
- Coffroth, M. A. (1984). Ingestion and incorporation of coral mucus aggregates by a gorgonian soft coral. *Marine Ecology Progress Series, 17*, 193-199. <https://doi.org/10.3354/meps017193>
- Conlan, J. A., Humphrey, C. A., Severati, A., & Francis, D. S. (2017). Influence of different

- feeding regimes on the survival, growth, and biochemical composition of *Acropora* coral recruits. *PLOS ONE*, *12*(11), e0188568. <https://doi.org/10.1371/journal.pone.0188568>
- Conlan, J. A., Bay, L. K., Severati, A., Humphrey, C., & Francis, D. S. (2018). Comparing the capacity of five different dietary treatments to optimise growth and nutritional composition in two scleractinian corals. *PLOS ONE*, *13*(11), e0207956. <https://doi.org/10.1371/journal.pone.0207956>
- Crabbe, M. J. C., & Smith, D. J. (2006). Modelling variations in corallite morphology of *Galaxea fascicularis* coral colonies with depth and light on coastal fringing reefs in the Wakatobi Marine National Park (S.E. Sulawesi, Indonesia). *Computational Biology and Chemistry*, *30*, 155-159.
- Davies, P. S. (1984). The role of zooxanthellae in the nutritional energy requirements of *Pocillopora eydouxi*. *Coral Reefs*, *2*, 181-186.
- Davies, P. S., (1991). Effects of daylight variations on the energy budgets of shallow water corals. *Marine Biology*, *108*, 137-144.
- Davy, S. K., & Cook, C. B., (2001). The relationship between nutritional status and carbon flux in the zooxanthellae sea anemone *Aiptasia pallida*. *Marine Biology*, *139*, 999- 1005.
- Davy, S. K., Withers, K. J. T., & Hinde, R. (2006). Effects of host nutritional status and seasonality on the nitrogen status of zooxanthellae in the temperate coral *Plesiastrea versipora* (Lamarck). *Journal of Experimental Marine Biology and Ecology*, *335*, 256-265. <https://doi.org/10.1016/j.jembe.2006.03.019>
- Dhert, P., Lavens, P., Duray, M., & Sorgeloos, P. (1990). Improved larval survival at metamorphosis of Asian seabass (*Lates calcarifer*) using x3-HUFA-enriched live food. *Aquaculture*, *90*, 63-74. [https://doi.org/10.1016/0044-8486\(90\)90283-S](https://doi.org/10.1016/0044-8486(90)90283-S)
- Dhont, J., & Sorgeloos, P. (2002). *Artemia: Basic and Applied Biology*. Dordrecht, Netherlands: Springer.
- Dhont, J., & Stappen, G. V. (2003). Biology, tank production and nutritional value of *Artemia* (pp. 65-112). In Stottrup J. G., McEvoy L. A. (Eds.), *Live feeds in marine aquaculture*. Oxford: Blackwell.
- Fabricius, K. E., & Klumpp, D. W. (1995). Wide-spread mixotrophy in reef-inhabiting soft corals: The influence of depth, and colony expansion and contraction on photosynthesis. *Marine Ecology-Progress Series*, *126*, 145-152.
- Falkowski, P. G., Dubinsky, Z., Muscatine, L., & Porter, J. W. (1984). Light and bioenergetics of a symbiotic coral. *Bioscience*, *11*, 705-709.
- Ferrier-Pages, C., Allemand, D., Attuso, J. P., Jaubert, J., & Rassoulzadegan, F. (1998). Microheterotrophy in the zooxanthellae coral *Stylophora pistillata*: Effects of light and ciliate density. *Limnol Oceanography*, *43*(7), 1639-1648.
- Ferrier-Pages, C., Gattuso, J. P., Dallot, S., & Jaubert, J. (2000). Effect of nutrient enrichment on growth and photosynthesis of the zooxanthellate coral *Stylophora pistillata*. *Coral Reefs*, *19*, 103-113. <https://doi.org/10.1007/s003380000078>
- Ferrier-Pages, C., Witting, J., Tambutte, E., & Sebens, K. P. (2003). Effect of natural zooplankton feeding on the tissue and skeletal growth of the scleractinian coral *Stylophora pistillata*. *Coral Reefs*, *22*, 229-240. <https://doi.org/10.1007/s00338-003-0312-7>
- Forsman, Z. H., Kimokeo, B. K., Bird, C. E., Hunter, C. L., & Toonen, R. J. (2011). Coral farming: Effects of light, water motion and artificial foods. *Journal of the Marine Biological Association of the UK*, *92*, 721-729.
- Forsman, Z., Hunter, C. L., Bird, C. E., & Toonen, R. J. (2012). Effects of light, water

- motion, and artificial foods. *Journal of the Marine Biological Association of the United Kingdom*, 92(4), 721-729. <https://doi.org/10.1017/s0025315411001500>
- Furla, P., Richier, S., & Allemand, D. (2011). *Physiological Adaptation to Symbiosis in Cnidarians*. In Dubinsky, Z., Stambler, N. (Eds.), *Coral Reefs: An Ecosystem in Transition*. New York: Springer, pp. 187-195.
- Ghazali, A., & Rajab, N. (2011). Evaluation of the biochemical profile and biological activity of *Budu* (A local fermented fish product) extracts on HepG2 Hepatoblastoma cells. *Australian Journal of Basic and Applied Sciences*, 5(12), 2606-2612.
- Goldberg, W. M. (2002). Feeding behavior, epidermal structure and mucus cytochemistry of the scleractinian *Mycetophyllia reesi*, a coral without tentacles. *Tissue Cell*, 34, 232-245.
- Goreau, T. F., Goreau, N. I., & Yonge, C. M. (1971). Reef corals: Autotrophs or heterotrophs? *The Biological Bulletin*, 141, 247-260. <https://doi.org/10.2307/1540115>
- Grotolli, A. G., Rodriguez L. J., & Palardy, J. E. (2006). Heterotrophic plasticity and resilience in bleached corals. *Nature*, 440, 1186-1189.
- Hanaee, J., Agh, N., Hanaee, M., Delazar, A., & Sarker, S. D. (2005). Studies on the enrichment of *Artemia urmiana* cysts for improving fish food value. *Animal Feed Science and Technology*, 120, 107-112. <https://doi.org/10.1016/j.anifeedsci.2005.01.010>
- Helland, S., Terjesen, B. F., & Berg, L. (2003). Free amino acid and protein content in the planktonic copepod *Temora longicornis* compared to *Artemia franciscana*. *Aquaculture*, 215, 213-228.
- Heidelberg, K. B., Sebens, K. P., & Purcell, J. E. (2004). Composition and sources of near reef zooplankton on a Jamaican foreereef along with implications for coral feeding. *Coral Reefs*, 23, 263-276.
- Hii, Y. S., Soo, C. L., & Liew, H. C. (2008). Feeding of scleractinian coral, *Galaxea fascicularis*, on *Artemia salina* nauplii in captivity. *Aquaculture International*, 17, 363-376.
- Hoogenboom, M., Rottier, C., Sikorski, S., & Ferrier-Pagès, C. (2015). Among-species variation in the energy budgets of reef-building corals: Scaling from coral polyps to communities. *Journal of Experimental Biology*, 218, 3866-3877. <https://doi.org/10.1242/jeb.124396>
- Houlbreque, F., Tambutte, E., & Ferrier-Pages, C. (2003). Effect of zooplankton availability on the rates of photosynthesis, and tissue and skeletal growth in the scleractinian coral *Stylophora pistillata*. *Journal of Experimental Marine Biology and Ecology*, 296(2), 145-166. DOI: 10.1016/S0022-0981(03)00259-4
- Houlbreque, F., Tambutte, E., Allemand, D., & Ferrier-Pages, C. (2004). Interactions between zooplankton feeding, photosynthesis and skeletal growth in scleractinian coral *Stylophora pistillata*. *Journal of Experimental Biology*, 207, 1461-1469. <https://doi.org/10.1242/jeb.00911>
- Houlbrèque, F., & Ferrier-Pagès, C. (2009). Heterotrophy in tropical scleractinian corals. *Biological Reviews of the Cambridge Philosophical Society*, 84, 1-17.
- Jacques, T. G., & Pilson, M. E. Q. (1980). Experimental ecology of the temperate scleractinian coral *Astrangia danae*. I. Partition of respiration, photosynthesis and calcification between host and symbionts. *Marine Biology*, 60, 167-178.
- Johannes, R. E. (1974). Sources of nutritional energy for reef corals. *Proceeding International Coral Reef Symposium*, 1, 133-137.

- Johnson, M. E., Lusic, C., Bartels, E., Baums, I. B., Gilliam, D. S., Larson, E. A., Lirman, D., Miller, M. W., Nedimyer, K., & Schopmeyer, S. (2011). Caribbean Acropora restoration guide: Best practices for propagation and population enhancement. The Nature Conservancy, Arlington. 1-64. https://nsuworks.nova.edu/occ_facereports/71.
- Kaandorp, J., & Kubler, J. (2001). *The Algorithmic Beauty of Seaweeds, Sponges, and Corals* (pp. 193). Berlin Heidelberg, Germany: Springer.
- Kjeldahl, J. Z. (1883). A new method for the determination of nitrogen in organic bodies. *Journal of Analytical Chemistry*, 22, 366. <http://dx.doi.org/10.1007/BF01338151>
- Klamkloa, S., Benjakul, S., Visessanguan, W., Kishimura, H., & Simpson, B. K. (2006). Effects of addition of spleen of skipjack tuna (*Katsuwonus pelamis*) on the liquefaction and characteristics of fish sauce made from sardine (*Sardinella gibbosa*). *Food Chemistry*, 98, 440-452.
- Kuanui, P., Chavanich, S., Viyakarna, V., Park, H., S., & Omori, M. (2016). Feeding behaviours of three tropical scleractinian corals in captivity. *Tropical Zoology*, 29(1), 1-9.
- Lang, J. C. & Chornesky, E. A. (1990). Competition between scleractinian reef corals – A review of mechanisms and effects. *Ecosystems of the World*, 25, 209-252.
- Larned, S. T. (1998). Nitrogen-versus phosphorous-limited growth and sources of nutrients for coral reef macroalgae. *Marine Biology*, 132, 409-421.
- Lasker, H. R. (1981). A comparison of the particulate feeding abilities of three species of gorgonian soft corals. *Marine Ecology Progress Series*, 5, 61-67.
- Leal, M. C., Ferrier-Pages, C., Calado, R., Thompson, M. E., Frischer, M. E., & Nejstgaard, J. C. (2014a) Coral feeding on microalgae assessed with molecular trophic markers. *Molecular Ecology*, 23, 3870-3876.
- Leal, M. C., Nejstgaard, J. C., Calado, R., Thompson, M. E., & Frischer, M. E. (2014b). Molecular assessment of heterotrophy and prey digestion in zooxanthellate cnidarians. *Molecular Ecology* 23, 3838-3848.
- Leal, M. C., Ferrier-Pagès, C., Petersen, D., & Osinga, R. (2017). Corals. In *Marine Ornamental Species Aquaculture* (pp. 406-436). <http://dx.doi.org/10.1002/9781119169147.ch21a>
- Lehman, J. T., & Porter, J. W. (1973). Chemical activation of feeding in the Caribbean reef-building coral *Montastrea cavernosa*. *Biological Bulletin*, 145, 140-149.
- Lewis, J. B., & Price, W. S., (1975). Feeding mechanisms and the feeding strategies of Atlantic reef corals. *Journal of Zoology*, 176, 527-544. <https://doi.org/10.1111/j.1469-7998.1975.tb03219.x>
- Lim, C. S., Bachok, Z., & Hii, Y. S. (2017). Effects of supplementary polyunsaturated fatty acids on the health of the scleractinian coral *Galaxea fascicularis* (Linnaeus, 1767). *Journal of Experimental Marine Biology and Ecology*, 491, 1-8.
- Logan, A. (1984). Interspecific aggression in hermatypic corals from Bermuda. *Coral Reefs*, 3, 131-138.
- Luna, G. M., Bongiorni, L., Gili, C., Biavasco, F. & Danovaro, R. (2010) *Vibrio harveyi* as a causative agent of the white syndrome in tropical stony corals. *Environmental Microbiology Reports*, 2, 120-127.
- Mohanty, B., Asha, K. K., Banerjee, S., Laxmanan, P. T., Ganguly, S., Mathew, S., & Sharma, A. P., (2014). Amino acid compositions of 27 food fishes and their importance in clinical nutrition. *Journal of Amino Acids*, 1-7. <https://doi.org/10.1155/2014/269797>
- Monroig, O., Navarro, J. C., Amat, F., Gonzalez, P., Bermejo, A., & Hontoria, H. (2006). Enrichment of *Artemia* nauplii in essential

- fatty acids with different types of liposomes and their use in the rearing of gilthead sea bream (*Sparus aurata*) larvae. *Aquaculture*, 251, 491-508. <https://doi.org/10.1016/j.aquaculture.2005.06.026>
- Muscatine, L., & Cernichiari, E. (1969). Assimilation of photosynthetic products of zooxanthellae by a reef coral. *Biological Bulletin*, 137, 506-523.
- Muscatine, L., McCloskey, L. R., & Marian, R. E. (1981). Estimating the daily contribution of carbon from zooxanthellae to coral animal respiration. *Limnology Oceanography*, 26, 601-611.
- Muscatine, L., (1990). The role of symbiotic algae in carbon and energy flux in reef corals. *Ecosystems of the World*, 25, 75-87.
- Naceur, H. B., Jenhani, A. B. R., El cabsi, M., & Romdhane, M. S. (2008). Determination of biological characteristics of *Artemia salina* (Crustacea: Anostraca) population from Sabkhet Sijoumi (NE Tunisia). *Transitional Waters Bulletin*, 3, 65-74.
- Nadiah, I. M. K., Huda, N., Nadiah, W. A., & Fadhl, A. M. A. K. (2014). Protein Quality of Fish Fermented Product: *Budu* and *Rusip*. *Asia Pacific Journal Sustainable Agriculture Food and Energy*, 2(2), 17-22.
- Nakajima, R., Yoshida, T., Othman, B. H. R., & Toda, T. (2008). Diel variation in abundance, biomass, and size composition of zooplankton community over a coral-reef in Redang Island, Malaysia. *Plankton and Benthos Research*, 3, 216-226.
- Okubo, N., Taniguchi, H., & Motokawa, T. (2005). Successful methods for transplanting fragments of *Acropora formosa* and *Acropora hyacinthus*. *Coral Reefs*, 24, 333-342.
- Olsen, A. I. B. B., Attramadala, Y., Jensen, A., & Olsen, Y. (1999). Influence of size and nutritional value of *Artemia franciscana* on growth and quality of halibut larvae (*Hippoglossus hippoglossus*) during the live feed period. *Aquaculture*, 179, 475-487. [https://doi.org/10.1016/S0044-8486\(99\)00181-7](https://doi.org/10.1016/S0044-8486(99)00181-7)
- Osinga, R., Schutter, M., Wijgerde, T., Rinkevich, B., Shafir, S., & Shpigel, M. (2012). The CORALZOO project: A synopsis of four years of public aquarium science. *Journal of the Marine Biological Association of the UK*, 92, 753-768.
- Palardy, J. E., Grottoli, A. G., & Matthews, K. A. (2006). Effect of naturally changing zooplankton concentrations on feeding rates of two coral species in the Eastern Pacific. *Journal of Experimental Marine Biology and Ecology*, 331, 99-107.
- Petersen, D. (2005). *Breeding techniques for reef building corals: Towards sustainability in ex situ populations*. [PhD thesis, University of Duisburg-Essen, Germany], p. 165.
- Petersen, D., Wietheger, A., & Laterveer, M. (2008). Influence of different food sources on the initial development of sexual recruits of reef building corals in aquaculture. *Aquaculture*, 277(3), 174-178.
- Piniak, G. A. (2002). Effects of symbiotic status, flow speed, and prey type on prey capture by the facultatively symbiotic temperate coral *Oculina arbuscula*. *Marine Biology*, 141, 449-455. <https://doi.org/10.1007/s00227-002-0825-6>
- Pomeranz, Y. & Meloan, E. C. (1994). *Food Analysis: Theory and Practice* (3rd eds.), USA, New York: Chapman and Hall.
- Reynaud, S., Ferrier-Pages, C., Boisson, F., Allemand, D., & Fairbanks, R. G. (2004). Effect of light and temperature on calcification and strontium uptake in the scleractinian coral *Acropora verweyi*. *Marine Ecology Progress Series*, 279, 105-112.
- Rinkevitch, B., (1989). The contribution of photosynthetic products to coral reproduction. *Marine Biology*, 101, 259-263.

- Rosenfeld, M., Bresler, V., & Abelson, A. (1999). Sediment as a possible source of food for corals. *Ecology Letters*, *2*, 345-348.
- Rosma, A., Afiza, T. S., Wan Nadiah, W. A., Liong, M. T., & Gulam, R. R. A. (2009). Short communication microbiological, histamine and 3-MCPD contents of Malaysian unprocessed 'budu'. *International Food Research Journal*, *16*, 589-594.
- Sawall, Y., Teichberg, M. C., Seemann, J., Litaay, M., Jompa, J., & Richter, C. (2011). Nutritional status and metabolism of the coral *Stylophora subseriata* along a eutrophication gradient in Spermonde Archipelago (Indonesia). *Coral Reefs*, *30*, 841-853. <https://doi.org/10.1007/s00338-011-0764-0>
- Sebastian. (2017, September 1). Tissue loss of LPS – Recovering with honey! *I Love Reefing Salt Water Blog*. Retrieved from <http://ilovereeffing.de/gewebeverlust-bei-lps-korallen-heilung-staerken/?lang=en>
- Sebens, K. P. (1991). Effects of water flow on coral growth and prey capture. *American Zoologist*, *31*(5), 59A.
- Sebens, K. P., Vandersall, K. S., Savina, L. A., & Graham, K. R. (1996). Zooplankton capture by two scleractinian corals, *Madracis mirabilis* and *Montastrea cavernosa*, in a field enclosure. *Marine Biology*, *127*, 303-317.
- Sebens, K. P., Witting, J., & Helmuth, B. (1997). Effects of water flow and branch spacing on particle capture by the reef coral *Madracis mirabilis* (Duchassaing and Michelotti). *Journal of Experimental Marine Biology and Ecology*, *211*, 1-28. [https://doi.org/10.1016/S0022-0981\(96\)02636-6](https://doi.org/10.1016/S0022-0981(96)02636-6)
- Sebens, K. P., Grace, S., Helmuth, B., Maney, E. J., & Miles, J. S. (1998). Water flow and prey capture by three scleractinian corals, *Madracis mirabilis*, *Montastrea cavernosa* and *Porites porites*, in a field enclosure. *Marine Biology*, *131*, 347-360.
- Sheridan, C., Kramarsky-Winter, E., Sweet, M., Kushmaro, A., & Costa, M. (2013). Diseases in coral aquaculture: Causes, implications, and preventions. *Aquaculture*, *396-399*, 124-135.
- Sorgeloos, P., Dhert, P., & Candreva, P., (2001). Use of the brine shrimp, *Artemia* spp., in marine fish larviculture. *Aquaculture*, *200*, 147-159.
- Sorokin, Y. I. (1973) On the feeding of some scleractinian corals with bacteria and dissolved organic matter. *Limnology Oceanography*, *18*, 380-385.
- Sorokin, Y. I. (1990). *Ekosistemy Korallovykh rifov* (Ecosystems of Coral Reefs). Moscow: Nauka.
- Sorokin, Y. (1991). Biomass, metabolic rates and feeding of some common reef zoantharians and octocorals. *Marine and Freshwater Research*, *42*, 729-741.
- Spotte, S., (1979). Seawater aquarium. The captive environment. *Journal of the Marine Biological Association of the United Kingdom*, *60*(3), 839-839. <https://doi.org/10.1017/S0025315400040509>
- Stambler, N., Popper, N., Dubinsky, Z., & Stimson, J. (1991). Effects of nutrient enrichment and water motion on the coral *Pocillopora damicornis*. *Pacific Science*, *45*, 299-307.
- Sweet, M., Jones, R., & Bythell, J. (2012). Coral diseases in aquaria and in nature. *Journal of the Marine Biological Association of the United Kingdom*, *92*(4), 791-801. <https://doi.org/10.1017/S0025315411001688>
- Tambuté, E., Allemand, D., Mueller, E., & Jaubert, J., (1996). A compartmental approach to the mechanism of calcification in hermatypic corals. *Journal of Experimental Biology*, *199*, 1029-1041.
- Titlyanov, E. A., Tsukahara, J., Titlyanova, T. V., Leletkin, V. A., Van Woesik, R., & Yamazato, K., (2000a). Zooxanthellae population density and physiological state

- of the coral *Stylophora pistillata* during starvation and osmotic shock. *Symbiosis*, 28, 303-322.
- Titlyanov, E. A., Bil, K., Fomina, I., Titlyanova, T., Leletkin, V., Eden, N., Malkin, A., & Dubinsky, Z. (2000b). Effects of dissolved ammonium addition and host feeding with *Artemia salina* on photoacclimation of the hermatypic coral *Stylophora pistillata*. *Marine Biology*, 137, 463-472.
- Titlyanov, E. A., Titlyanov, T. V., Yamazato, K., & Woessik, R. V. (2001). Photo-acclimation of the hermatypic coral *Stylophora pistillata* while subjected to either starvation or food provisioning. *Journal of Experimental Marine Biology and Ecology*, 257(2), 163-181. [https://doi.org/10.1016/S0022-0981\(00\)00308-7](https://doi.org/10.1016/S0022-0981(00)00308-7)
- Toh, T. C., Ng, C. S. L., Peh, J. W. K., Toh, K. B., & Chou, L. M. (2014). Augmenting the post-transplantation growth and survivorship of juvenile scleractinian corals via nutritional enhancement. *PLOS ONE*, 9, e98529.
- Treignier, C., Grover, R., Ferrier-Pages, C., & Tolosa, I. (2008). Effect of light and feeding on the fatty acid and sterol composition of zooxanthellae and host tissue isolated from the scleractinian coral *Turbinaria reniformis*. *Limnology Oceanography*, 53, 2702-2710. Retrieve from <https://doi.org/10.4319/lo.2008.53.6.2702>
- Trench, R. K. (1993). Microalgal-invertebrate symbiosis: A review. *Endocytobiosis and Cell Research*, 9(2-3), 135-175. https://zs.thulb.uni-jena.de/receive/jportal_jparticle_00059850
- Van Os, N., Masse, L., Se´re´, M., Sara, J., Schoeman, D., & Smit, A. (2012). Influence of heterotrophic feeding on the survival and tissue growth rates of *Galaxea fascicularis* (Octocorralia: Occulinidae) in aquaria. *Aquaculture*, 330-333, 151-161.
- Van Praët, M. (1980). Absorption des substances dissoutes dans le milieu des particules et des produits de la digestion extracellulaire chez *Actinia equina*. [Absorption of substances dissolved in the environment, particles, and products of extracellular digestion in *Actinia equina* (Cnidaria, Actiniaria)]. *Reproduction Nutrition Développement*, 20, 1393-1399.
- Wabnitz, C., Taylor, M., Green, E., & Razak, T. (2003). *From ocean to aquarium: The global trade in marine ornamental species*. Cambridge: UNEP & WCMC.
- Wellington, G. M., (1982). An experimental analysis of the effects of light and zooplankton on coral zonation. *Oecologia*, 52, 311-320.
- Wijgerde, T., Diantari, R., Lewaru, M. W., Verreth, J. A. J., & Osinga, R. (2011). Extracoelenteric zooplankton feeding is a key mechanism of nutrient acquisition for the scleractinian coral *Galaxea fascicularis*. *Journal of Experimental Biology*, 214, 3351-3357.
- Wilson, R. P. (2003). Amino Acids and Proteins (pp. 143-179). In Halver J, Hardy R, (Eds.). *Fish Nutrition* (3rd eds.). San Diego: Elsevier. <https://doi.org/10.1016/B978-012319652-1/50004-5>
- Witting, J. H. (1999). *Zooplankton capture and coral growth: the role of heterotrophy in Caribbean reef corals*. [PhD dissertation, Northeastern University, Boston, USA].
- Yahel, R., Yahel, G., Berman, T., Jaffe, J. S., & Genin, A. (2005). Diel pattern with abrupt crepuscular changes of zooplankton over a coral reef. *Limnology Oceanography*, 50, 930-944.
- Yonge, C. M. (1930). Studies on the physiology of corals. I. Feeding mechanisms and food. *Scientific Reports/Great Barrier Reef Expedition*, 1, 13-57.