Journal of Marine Science and Technology

Volume 31 | Issue 1 Article 7

# Effects of various dietary carbohydrate sources on the growth performance and body composition of the dog conch, Laevistrombus canarium

Jen-Hong Chu
*Department of Aquatic Biosciences, National Chiayi University, Chiayi, 600, Taiwan*, jhchu@mail.ncyu.edu.tw



Recommended Citation
Chu, Jen-Hong (2023) "Effects of various dietary carbohydrate sources on the growth performance and body composition of the dog conch, Laevistrombus canarium," *Journal of Marine Science and Technology*: Vol. 31: Iss. 1, Article 7.
DOI: 10.51400/2709-6998.2686
Available at: https://jmstt.ntou.edu.tw/journal/vol31/iss1/7

RESEARCH ARTICLE

# Effects of Various Dietary Carbohydrate Sources on the Growth Performance and Body Composition of the Dog Conch, *Laevistrombus canarium*

Jen-Hong Chu

Department of Aquatic Biosciences, National Chiayi University, Chiayi, 600, Taiwan

**Abstract**

**This study investigates the effects of dietary supplementation with various carbohydrate sources on the growth and dietary nutrient utilization efficiency of a 0.72-g dog conch, *Laevistrombus canarium*. Five treatment diets had supplementation with alpha-starch (Sta), dextrin (Dex), pullulan gum (Pg), xanthan gum (Xg), and carboxymethyl cellulose (CMC). At the end of the feeding trial, the best growth performance (weight gain, 442.23%) and diet efficiency (protein efficiency ratio, 1.25, and feed conversion ratio [FCR], 2.04) were exhibited by the dog conch fed the Sta diet, whereas the lowest growth performance was observed in the dog conch fed the Xg and CMC diets. Dog conch fed the Sta (2.04) diet had a lower FCR than dog conch fed the other experimental diets (3.92−5.46). Apparent dietary digestibility (ADD) was significantly higher in dog conch fed the Sta diet than in the dog conch that were fed the other experimental diets. The ADD of protein was significantly lower in the dog conch fed the CMC diet than in those fed the other dietary treatments. The lowest ADD for energy was observed in the dog conch fed the CMC diet, followed by the Xg diet and Pg diet. Moisture, crude protein, and muscle crude lipid were affected by the carbohydrate source. An increase in carbohydrate complexity in the diet led to an enhancement of crude protein content and muscle crude lipid content. Compared with the other diets, the Sta diet yielded a significantly greater improvement in all shell parameters. These findings indicate that dog conch fed a Sta diet demonstrate the best growth parameters, feed efficiency, and ADD; therefore, diets supplemented with Sta are suitable for improving dog conch growth.**

*Keywords: Laevistrombus canarium*, Carbohydrate, Weight gain

## 1. Introduction

Carbohydrates are an energy source and a component of tissues in aquatic animals. Pentose is a component of nucleic acid and provides material for synthesizing body fat. Carbohydrates are a more economical and stable source of energy than proteins or lipids; therefore, many researchers have explored the use of carbohydrate supplementation in aquatic animal feed, although knowledge of carbohydrate use among most aquatic animals is limited compared with that of mammals [45,54].

In the aquafeed industry, various carbohydrates, such as starch and dextrin (Dex), are used as energy sources and feed adhesives that can improve water resistance and enhance the absorb of feed additives. Saccharides in feed can be quickly absorbed by aquatic animals, but a high level of saccharides in an aquatic animal's diet can inhibit their nutrition utilization rate and inhibit growth with respect to various growth parameters [25]. Palmer and Ryman [47] indicated that the use of large quantities of starch as a binder in feed can be detrimental to hepatic metabolism, resulting in negative effects on digestibility. Adhesives used in aquafeeds include wheat gluten; starch; carboxymethyl cellulose (CMC); lignosulfonates; Dex; and various algins, such as alginic acid, carrageenan, agar, xanthan

Received 29 June 2022; revised 07 January 2023; accepted 07 March 2023.
Available online 31 March 2023
E-mail address: jhchu@mail.ncyu.edu.tw.

*https://doi.org/10.51400/2709-6998.2686*

gum (Xg), and pullulan gum (Pg). These adhesives enhance the stability of feed in water [31]. The utilization rate of carbohydrates by fish varies with the food source. Shiau and Huang [55] indicated that tilapia have a lower intestinal absorption rate for sugar when fed a diet supplemented with polysaccharides. In most fish, the utilization of gelatinized starch and Dex is better than that of monosaccharides [63].

The ability to utilize carbohydrates depends on a species' ability to oxidize carbohydrates to glucose and store the glucose as glycogen or fat [28]. Stone et al. [58] indicated that the ability to utilize dietary carbohydrates as an energy source depends on the digestibility, endogenous metabolic enzymes, and assimilation of different types of carbohydrates. Dietary carbohydrate supplements can improve growth parameters in tilapia, *Oreochromis niloticus* [6]; tiger shrimp, *Penaeus monodon* [2]; Atlantic salmon, *Salmo salar* L. [32]; and rainbow trout, *Oncorhynchus mykiss* [49]. Mai et al. [42] found that both dietary carbohydrates and lipids are key energy sources for mollusks such as abalones. In their natural habitat, abalones primarily feed on macroalgae, which have high carbohydrate content; therefore, they can convert carbohydrates into glycogen, which is stored in soft body muscles. Terrestrial carnivores use carbohydrates more than terrestrial herbivores. However, aquatic herbivores can utilize carbohydrates for energy and to achieve a high growth rate [24,42]. Zhang et al. [67] used wheat starch as the carbohydrate source in the diet of spotted babylon, *Babylonia areolata*. When the amount of wheat starch supplement increased, the glycogen content and protein content in the soft muscle tissue were significantly higher. Starch can also enhance the glycolytic and lipogenic pathways in the muscle of *Babylonia areolate*. These results demonstrate that dietary carbohydrates can improve protein utilization for growth, increase enzyme activity, and promote the glycolytic pathway.

Mollusks have a longer feeding time than most fish species; thus, a mollusk's food source must be stable. However, mollusks may not intake food if their food is too difficult to break down [40,65]. Sales and Janssens [53] found that starch is an essential energy source and adhesive in commercial abalone feeds. Carbohydrates can improve the stability of artificial mollusk feeds. Therefore, the digestibility of mollusk food is crucial.

*Laevistrombus canarium*, also known as *Strombus canarium* or the dog conch, is a member of the Order *Littorinimorpha* and the subclass *Caenogastropoda*. The dog conch is an oceanic mollusk with a high market value in many Asian countries [1]. Dog conch is consumed as seafood by humans and is known for its ornamental value and use in fishery tools [15,50]. In Taiwan, dog conch has declined in the wild, although 200,000 dog conch larvae were released into their native natural habitat in 2021 by Penghu Agriculture and Fisheries. Nonetheless, dog conch remains in decline because of overexploitation and overfishing.

To develop dog conch on an economic scale, background studies on the nutritional requirements of dog conch must be conducted. The larval nutrition requirements of dog conch, including protein [13] and lipids [14], have been established in our laboratory. However, the stability of dog conch food in water remains inconsistent, and insufficient knowledge exists regarding the reliable adhesives that allow for an optimal dissolution rate for an extended period. Thus, food stability for dog conch remains difficult to ensure. Therefore, this study identified the optimal dietary carbohydrate source for 0.72-g dog conch *L. canarium* larvae.

## 2. Materials and methods

### 2.1. Experimental diets

The optimal crude protein (46.4%) and crude lipid (5.6%) content of the experimental diets were determined on the basis of our previous laboratory results for dog conch [13,14]. The experimental diets were supplemented with alpha-starch (Sta) (Shimakyu's Pure Chemicals, Japan), dextrin (Dex) (Shimakyu's Pure Chemicals, Japan), pullulan gum (Pg) (Sigma, USA), xanthan gum (Xg, USA) (Sigma, USA), and carboxymethyl cellulose (CMC) (Sigma, USA) (Table 1). Fish meal was the main protein source in the experimental formulae. A 0.25-g fish oil mix containing 0.13-g corn oil was used as the lipid source. Carbohydrates were added to ensure a balanced diet. All experimental raw materials were ground to a particle size smaller than 150 μm by using a grinding machine (Yuan Tai machinery series, D3V-10) before the feed was formulated. After mixing all the raw material until homogeneous, the oil was added. Finally, 300 mL of deionized water was added to form a paste, and an extruder was then used to produce 3 mm pellets. The moist pellets were initially dried in an oven (60 °C) and then stored in a refrigerator at 4 °C until use.

### 2.2. Experimental facility and dog conch husbandry

All animal experimentations conformed to the principles for the use and care of laboratory animals

*Table 1. Formulation and composition of the various experimental diets.*

| Ingredient (%) | Sta | Dex | Pg | Xg | CMC |
|---|---|---|---|---|---|
| Fish meal | 64.46 | 64.46 | 64.46 | 64.46 | 64.46 |
| Oil[a] | 0.38 | 0.38 | 0.38 | 0.38 | 0.38 |
| Lecithin | 1 | 1 | 1 | 1 | 1 |
| Yeast | 1 | 1 | 1 | 1 | 1 |
| Carbohydrate | 25 | 25 | 25 | 25 | 25 |
| Vitamin[b] | 2 | 2 | 2 | 2 | 2 |
| Minerals[c] | 2 | 2 | 2 | 2 | 2 |
| Chromic oxide | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Cellulose | 3.66 | 3.66 | 3.66 | 3.66 | 3.66 |
| Analyzed composition (as fed) | | | | | |
| Moisture | 10.12 | 10.25 | 10.05 | 9.76 | 10.43 |
| Crude protein[d] | 46.08 | 46.12 | 46.08 | 46.10 | 46.09 |
| Crude lipids[d] | 5.58 | 5.69 | 5.58 | 5.62 | 5.53 |
| Ash[d] | 8.4 | 7.9 | 8.8 | 8.8 | 9.2 |
| Gross energy | 336.02 | 336.03 | 336.02 | 336.03 | 336.01 |
| Digestible energy[e] | 257.17 | 250.91 | 235.11 | 235.67 | 188.73 |
| NFE[f]+Fiber | 60.06 | 59.71 | 61.26 | 60.92 | 61.12 |

Sta: alpha-starch; Dex: dextrin; Pg: pullulan gum; Xg: xanthan gum; CMC: carboxymethyl cellulose.

[a] 0.25-g fish oil mix with 0.13-g corn oil.

[b] Modified from Chu et al., [14].

[c] Modified from Bernhart and Tomarell, [8].

[d] Data represents dry weight (in %).

[e] Digestible energies (in kcal per 100 g) = gross energy × apparent digestibility coefficient of energy.

[f] Nitrogen free extract (NFE, in %): The sum of the basic crude protein, crude lipids, and ash are subtracted from 100.

in accordance with the Institutional Animal Care and Use Committee (IACUC) of National Chiayi University (NCYU) (approval no. NCYU-IACUC-11101).

Dog conch cultivation was conducted in an indoor circulating water system comprising 30 fiberglass reinforced plastic aquaria (volume = 90 L). Each plastic aquarium had an independent air supply system. Larval dog conch was obtained from the Aquatic Propagation Center at NCYU and acclimatized at a temperature of 28 °C and with a photoperiod of 12 hours light and 12 hours dark. Larval dog conches were fed a diet of 46% crude protein and 5% crude lipid for 14 days, per the method of Chu et al. [13,14]. Six plastic aquariums were randomly assigned to each experimental diet. Thereafter, the dog conches (10 per aquarium) were fed the experimental diets once per day for 120 days. After each feeding, the uneaten feed was removed and collected to calculate feeding efficiencies such as the feed conversation ratio (FCR) and protein efficiency ratio (PER). Fecal matter was removed through siphoning to maintain high water quality. Data on feeding characteristic, such as the amount of feed consumed and the number of dead dog conches, were recorded daily. During the experiment, the water was maintained at the following levels: temperature: 28 ± 1 °C; pH: 7.3–7.5; ammonia nitrogen ($NH_3$–N): ≤0.05 ppm; and dissolved oxygen (DO): ≥6.0 ppm. The photoperiod remained at 12 hours light and 12 hours dark throughout the experiments.

### *2.3. Sample collection and analysis*

#### *2.3.1. Sample collection*

After the experiments, all surviving *L. canarium* were sacrificed according to IACUC regulations and then weighed, measured, and counted. The shell length, shell width, and shell height were measured using electronic digital calipers according to the method of Guzmán and Viana [29]. The muscle and hepatopancreas were carefully dissected for the composition analysis.

#### *2.3.2. Biochemical analyses*

Analyses of the moisture, ash, fiber, and crude protein of the experimental diets and dog conch muscle tissue were performed per the standard methods of the Association of Analytical Chemists [4]. Crude protein level was measured using the Micro-Kjeldahl method, and nitrogen (N × 6.25) concentration was determined using the crude protein content of the sample. Crude lipid level was measured according to the methods described by Folch et al. [22]; the extraction solution comprised a chloroform and methanol (2:1, v/v) mixture, and a 0.5-g sample was extracted using a homogenizer (IKA Ultra Turax T25 Basic) and 40-mL extraction solution. Crude fiber was evaluated using acid

($H_2SO_4$), and the base (NaOH) solution reagents were analyzed using a Fibertec system M 1020 hot extractor (FossTecator, Höganäs, Sweden). Ash was analyzed through combustion in a muffle furnace at 540 °C for 12 hours. Moisture was measured using an oven (135 °C for 5 hours). The gross energy of each diet was determined using a bomb calorimeter (IKA calorimeter system, C2000 basic, Germany).

*2.3.3. Digestibility analysis*

For the digestibility analysis, diets were prepared and supplemented using chromic oxide ($Cr_2O_3$) as an inert marker. The feces within the fiberglass tanks were removed from the water by using filtration (Whatman No. 2), freeze-dried, placed in a plastic bag, and stored in a freezer at −40 °C before analysis. After a mixture of nitric acid (65% $HNO_3$, Fulka) with 3 mL hydrogen peroxide (30% $H_2O_2$, Merck) was digested using a microwave (Multiwave, Anton paar), the total chromic oxide concentrations of the samples were determined using inductively coupled plasma optical emission spectroscopy. Percentages for the apparent digestibility of the dry matter (ADd) were calculated as $100 - (Cd \times NXf) \times (Cf \times NXd)^{-1} \times 100$. Percentages for the apparent digestibility of nutrients or energy (ADe) were calculated as $(1 - (Cd/Cf) \times (NXf$ or $NXfe/NXd$ or $NXfe)) \times 100$, where $d$ is diet, $f$ is feces, $e$ is energy, $C$ is chromic oxide concentration, and $NX$ is nutrient concentration.

*2.4. Statistical analysis*

All experimental data were subjected to a one-way analysis of variance by using SAS-PC. When a significant difference ($p < 0.05$) was observed, Tukey's range test was conducted to identify any significant differences between treatments [57].

## 3. Results

The rates of dissolution (in %) in water after 8 hours of the experimental diets containing various carbohydrate sources are shown in Fig. 1. A higher dissolution rate in water (77%) was observed in the Sta diet compared with the other diets. The Dex diet was relatively stable in water.

The growth parameters of dog conch fed the experimental diets for 120 days are shown in Table 2. At the end of the feeding trial, the overall survival rate of the dog conch was >83%, whereas the survival of the CMC diet group was significantly lower ($p < 0.05$) than that of the Sta diet group. Dog conch fed the Sta diet demonstrated a significantly higher weight gain percentage and FCR than those fed the

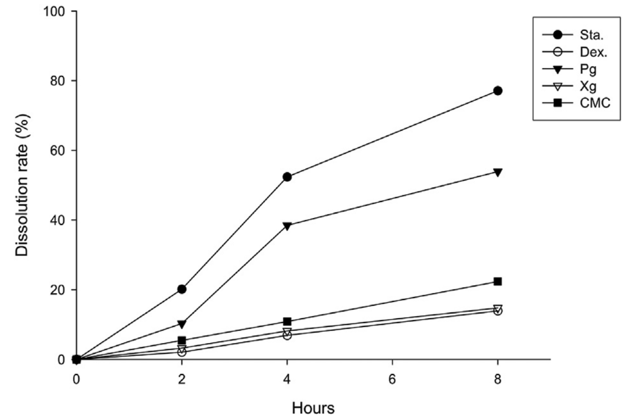


*Fig. 1. Dissolution rates in water of the various experimental diets (in %).*

Pg, Xg, and CMC diets. However, the weight gain percentage, FCR, and PER of dog conch fed the Dex diet did not significantly differ from those fed the Sta diet. Dog conch fed the Sta diet had a lower FCR than those fed the Pg, Xg, and CMC diets.

The analytical results of the dog conch muscle samples are presented in Table 3. Dog conch muscle protein and lipid content ranged from 48.11% to 54.99% and from 5.27% to 8.67%, respectively. Ash content was between 1.02% and 1.05%. Moreover, different moisture levels were observed, which varied with the complexity of the carbohydrate sources. A significantly higher hepatic glycogen content was observed in dog conch fed the Sta diet compared with those fed the Pg, Xg, and CMC diets.

Increases in shell length, soft body muscle, and mean protein of the dog conch are listed in Table 4. The increase in shell length of dog conch fed the Sta diet was the highest among all the experimental diets, whereas the increase in shell length of the dog conch fed the CMC diet was the lowest. The soft body muscle rate and mean protein gain of dog conch fed the Sta diet were significantly higher than those of the dog conch fed the Xg and CMC diets. An increase in shell length was positively correlated with an increase in body weight. The shell length increased as dietary Sta supplementation increased, which indicated that when dietary carbohydrate sources were available, a proportion of these carbohydrates contributed to growth.

The apparent digestibility coefficients of dietary protein (ADp), ADd, and ADe of the dog conch fed different experimental diets are shown in Table 5. The ADd of dog conch fed the Sta diet (64.33%) was significantly higher than that of dog conch fed the Pg (60.07%), Xg (60.30%), and CMC diets (50.47%). The ADp was significantly lower when the dog conch was fed the CMC diet (87.10%) compared

*Table 2. Initial weight, final weight, weight gain, protein efficiency ratio (PER), feed conversion ratio (FCR), and survival of dog conch, Laevistrombus canarium, fed diets containing various carbohydrate sources for 120 days.*

| Treatments | Initial weight (g) | Final weight (g) | Weight gain (%) | FCR | PER | Feed intake (g/dog conch/day) | Survival (%) |
|---|---|---|---|---|---|---|---|
| Sta | 0.72 ± 0.01 | 3.90 ± 0.17$^{a}$ | 442.23 ± 25.59$^{a}$ | 2.04 ± 0.04$^{c}$ | 1.07 ± 0.02$^{a}$ | 0.05 ± 0.00$^{e}$ | 100 |
| Dex | 0.72 ± 0.02 | 3.79 ± 0.19$^{a}$ | 426.23 ± 15.63$^{a}$ | 2.30 ± 0.15$^{c}$ | 0.95 ± 0.06$^{a}$ | 0.06 ± 0.00$^{d}$ | 96 |
| Pg | 0.72 ± 0.01 | 2.85 ± 0.60$^{b}$ | 296.11 ± 88.90$^{b}$ | 3.92 ± 0.95$^{b}$ | 0.58 ± 0.16$^{b}$ | 0.07 ± 0.00$^{c}$ | 93 |
| Xg | 0.72 ± 0.02 | 2.86 ± 0.12$^{b}$ | 295.82 ± 12.02$^{b}$ | 3.95 ± 0.23$^{b}$ | 0.55 ± 0.03$^{bc}$ | 0.07 ± 0.00$^{b}$ | 90 |
| CMC | 0.72 ± 0.02 | 2.44 ± 0.34$^{b}$ | 236.45 ± 41.40$^{b}$ | 5.46 ± 0.87$^{a}$ | 0.40 ± 0.06$^{c}$ | 0.08 ± 0.00$^{a}$ | 83 |

Mean values and standard error (mean ± S.E.) are presented for each parameter.
$^{a,b,c}$ Means in the same row with different letters are significantly different ($p < 0.05$).

*Table 3. Muscle composition (in %) and hepatic glycogen content (in mg/g) of Laevistrombus canarium fed diets containing various carbohydrate sources for 120 days.*

| Treatments | Composition | | | | |
|---|---|---|---|---|---|
| | Moisture | Ash | Crude protein | Crude lipids | Hepatic glycogen content |
| Sta | 69.30 ± 1.13$^{c}$ | 1.04 ± 0.04 | 54.99 ± 0.11$^{a}$ | 8.67 ± 0.14$^{a}$ | 33.61 ± 0.89$^{a}$ |
| Dex | 78.67 ± 0.57$^{a}$ | 1.02 ± 0.08 | 54.11 ± 0.57$^{a}$ | 7.58 ± 0.11$^{b}$ | 31.28 ± 0.87$^{a}$ |
| Pg | 73.71 ± 1.32$^{b}$ | 1.03 ± 0.05 | 51.27 ± 1.28$^{b}$ | 7.26 ± 0.16$^{b}$ | 22.17 ± 1.94$^{b}$ |
| Xg | 68.15 ± 0.37$^{c}$ | 1.05 ± 0.01 | 51.56 ± 0.53$^{b}$ | 5.31 ± 0.29$^{c}$ | 23.61 ± 2.02$^{b}$ |
| CMC | 69.02 ± 0.74$^{c}$ | 1.02 ± 0.05 | 48.11 ± 0.54$^{c}$ | 5.27 ± 0.35$^{c}$ | 19.57 ± 0.57$^{c}$ |

Mean values and standard error (mean ± S.E.) are presented for each parameter.
$^{a,b,c}$ Means in the same row with different letters are significantly different ($p < 0.05$).

*Table 4. Shell length increase, shell width increase, shell height increase, soft body muscle rate (SB), and mean protein gain (MPG) of Laevistrombus canarium fed diets containing various levels of carbohydrate sources for 120 days.*

| Carbohydrate sources | Shell length increase (%) | Shell width increase (%) | Shell height increase (%) | SB (%) | MPG (mg/shell) |
|---|---|---|---|---|---|
| Sta | 38.19 ± 0.81$^{a}$ | 35.36 ± 0.70$^{a}$ | 37.06 ± 0.56$^{a}$ | 1.60 ± 0.43$^{a}$ | 1.60 ± 0.43$^{a}$ |
| Dex | 32.06 ± 1.92$^{b}$ | 29.65 ± 1.89$^{b}$ | 31.06 ± 2.00$^{b}$ | 1.55 ± 0.13$^{a}$ | 1.55 ± 0.13$^{a}$ |
| Pg | 29.38 ± 1.20$^{c}$ | 26.84 ± 1.14$^{bc}$ | 28.47 ± 1.38$^{c}$ | 1.44 ± 0.05$^{a}$ | 1.44 ± 0.05$^{a}$ |
| Xg | 27.83 ± 1.20$^{c}$ | 25.31 ± 0.84$^{c}$ | 27.08 ± 0.95$^{c}$ | 0.75 ± 0.10$^{b}$ | 0.75 ± 0.10$^{b}$ |
| CMC | 25.02 ± 0.80$^{d}$ | 24.45 ± 3.89$^{c}$ | 24.26 ± 1.68$^{d}$ | 0.58 ± 0.04$^{b}$ | 0.58 ± 0.04$^{b}$ |

Mean values and standard error (mean ± S.E.) are presented for each parameter.
$^{a,b,c,d}$ Means in the same row with different letters are significantly different ($p < 0.05$).

*Table 5. Effect of dietary carbohydrate sources on the apparent digestibility (AD) values of dog conch, Laevistrombus canarium, fed experimental diets.*

| Carbohydrate sources | ADd (%) | ADp (%) | ADe (%) |
|---|---|---|---|
| Sta | 64.33 ± 1.25$^{a}$ | 88.53 ± 0.60$^{a}$ | 76.53 ± 0.60$^{a}$ |
| Dex | 63.17 ± 0.58$^{a}$ | 88.57 ± 0.59$^{a}$ | 74.67 ± 0.71$^{b}$ |
| Pg | 60.07 ± 0.45$^{b}$ | 87.93 ± 0.06$^{ab}$ | 69.97 ± 0.21$^{c}$ |
| Xg | 60.30 ± 0.44$^{b}$ | 87.97 ± 0.97$^{ab}$ | 70.13 ± 0.85$^{c}$ |
| CMC | 50.47 ± 0.91$^{c}$ | 87.10 ± 0.20$^{b}$ | 56.17 ± 0.93$^{d}$ |

Mean values and standard error (mean ± S.E.) are presented for each parameter.
$^{a,b,c}$ Means in the same row with different letters are significantly different ($p < 0.05$).

with the Sta (88.53%) and Dex diets (88.57%). The highest ADe was observed in dog conch fed the Sta diet (76.53%) followed by the Dex diet (74.67%), whereas the ADe was lowest for dog conch fed the CMC (56.17%) diet.

## 4. Discussion

The growth parameters identified during this study suggest that Sta is a better carbohydrate source for dog conch than Pg, Xg, and CMC. In blacklip abalone (*Haliotis rubra*), wheat flour and semolina-based diets yielded slightly better growth rates relative to maize starch-based diets [18]. Furthermore, Dex was more effective for growth in flounder, *Paralichthys olivaceus*, than other saccharides, such as glucose and cellulose [37]. In the present study, the growth parameters were only affected by dietary carbohydrate sources containing Sta and Dex. Uki et al. [62] and Cruz-Suárez et al. [16] indicated that complex polysaccharides can affect the growth rate of a variety of animals. However, in the present study, the weight gain and PER of dog conch fed the CMC diet were significantly lower than those of the dog conch fed the Sta and Dex diets, which supports the hypothesis that dog conch larvae utilize digestible starch polysaccharides more effectively than nonstarch polysaccharides. This finding is consistent with the findings for many fish species, such as African catfish, *Clarias gariepinus* [38,39]; Nile tilapia, *O. niloticus* L. [7]; and common carp, *Cyprinus carpio* L. [34]. By contrast, nonstarch carbohydrate-based substrates can be nutrient sources for crustacean species, such as giant Malaysian prawn, *Macrobrachium rosenbergii* [17,27,44]; snow crab, *Chionoecetes opilio* [9]; and redclaw crayfish, *Cherax quadricarinatus*. [21,64].

Fleming et al. [20] indicated that commercial artificial diets for abalone primarily provide energy in the form of carbohydrates, such as wheat flour, maize flour, sodium alginate, Dex, starch, and bran. Such carbohydrates often make up between 30% and 60% of the diet. For slow aquatic feeders such as abalone and dog conch, artificial diet particles must remain bound together, and the loss of water-soluble nutrients in water must be minimized. The Sta diet had a higher dissolution rate in water (77%) after 8 hours than the other diets yet resulted in a higher growth rate. These findings may be attributed to specific feeding habits of the dog conch. In this study, dog conch used their proboscis to gnaw and swallow food. Therefore, although Xg and CMC have greater stability in water, this enhanced stability did not promote feeding efficiency. Similar results were found when a diet containing 10%–30% fiber resulted in diminished growth [30,35,41]. Our results suggest that Sta is the most suitable single carbohydrate source for artificial dog conch feed.

In this study, significantly lower ADd, ADp, and ADe values were observed from dog conch fed the CMC diet than dog conch fed the other treatment diets. Moreover, poor digestive gland enzyme activity levels were observed in the dog conch fed the CMC diet. Thus, CMC does not contribute to the energy of dog conch. Catacutan [12] found that when the diet of *P. monodon* was supplemented with more than 7% dietary fiber, the ADd value was 82.7%, which was significantly lower than other treatments. When Sudaryono et al. [60] administered a diet supplemented with 7.84% dietary fiber to *P. monodon*, the ADd and ADp levels were significantly lower than those of other treatments. Hansen et al. [30] observed a decrease in ADp levels in response to increases in dietary cellulose levels.

The digestible energy from cellulose in aquafeed is limited, although some fish can digest cellulose by harboring beneficial microorganisms in their intestines [46]. Cellulose reduces the absorption of some nutrients in animals, including minerals [48,51], cholesterol [26], and fat [5,59].

The dog conch fed the CMC diet exhibited the worst growth performance in the present study. Poor growth performance has been associated with CMC dietary supplementation in tilapia, *O. niloticus* × *O. aureus* [56]; Japanese flounder, *P. olivaceus* [66]; channel catfish, *Ictalurus punctatus* [36]; rainbow trout, *Salmo gairdneri* [33]; and red seabream, *Pagrus major* [23]. Poor growth performance may be caused by a delay in the passage of food through the stomach due to the food's relatively high viscosity. Slow passage through the gut may result in an imbalance in the absorption of nutrients, leading to a decline in the PER [52]. Antonio et al. [3] found that the gastropod, *Cipangopaludina japonica*, can digest proteins and starch well but not cellulose. Thus, water-soluble dietary fibers such as guar gum, CMC, and pectin can increase the feed's viscosity and delay physiological digestion. Consequently, the time required to metabolize the nutrients that provide energy and protein can be extended [23]. Yamamoto and Akiyama [66] found that CMC is unsuitable as a binder for Japanese flounder diets because it inhibited proteolytic enzyme activity, which led to poor growth and feed performance. Therefore, the reduced growth response of dog conch to dietary carbohydrate from CMC may be due to inefficient nutrient utilization, particularly the digestion and absorption of proteins.

In the present study, the glycogen content in the hepatopancreas was significantly higher when the dietary carbohydrate source was Sta. However, the glycogen in hepatopancreas tissues was significantly lower when CMC was the dietary carbohydrate source. Nevertheless, key glucose enzyme activity levels were upregulated in the dog conch fed a Sta diet. Similar results have been observed in blunt snout bream, *Megalobrama amblycephala* [52], and spotted babylon, *B. areolata* [67]. Our findings indicated a positive correlation between soft body lipid content and the dietary starch source. Therefore, when carbohydrate is supplied and digested by dog conch, lipids are deposited in the soft body through lipogenesis. Crude protein content in muscles was significantly higher in dog conch fed the Sta diet, suggesting that the utilization of Sta may improve protein utilization. Similar results have been observed in donkey's ear abalone, *Haliotis asinina* L. [61]; gilthead sea bream, *Sparus aurata* [19]; and spotted babylon, *B. areolata* Link 1807 [67].

This study provides valuable information on the nutritional values of various dietary carbohydrate sources for larval dog conch. Overall, our findings indicate that Sta is the optimal carbohydrate source for larvae dog conch to obtain maximum weight gain.

## Acknowledgements

This work was partially supported by grants from 110 to 2313-B-415-011- from the Ministry of Science and Technology, Executive Yuan, Taiwan, R.O.C.

## Conflict of interest

The author declares that there are no conflicts of interests.

## References

[1] Abbott RT. The genus strombus in the Indo-Pacific. Indo-Pac Mollusca 1960;1:33−146.
[2] Alava VR, Pascual FP. Carbohydrate requirements of *Penaeus monodon* (Fabricius) juveniles. Aquaculture 1987;61:211−7.
[3] Antonio ES, Kasai A, Ueno M, Kurikawa Y, Tsuchiya K, Toyohara H, Ishihi Y, Yokoyama H, Yamashita Y. Consumption of terrestrial organic matter by estuarine molluscs determined by analysis of their stable isotopes and cellulase activity. Estuar Coast Shelf Sci 2010;86:401−7.
[4] AOAC (Association of Analytical Chemists). Official methods of analysis of the association of official analytical chemists. fourteenth ed. Arlington, VA, USA.: AOAC. Inc.; 1984. p. 1141.
[5] Aslaksen MA, Kraugerud OF, Penn M, Svihus B, Denstadli V, Jørgensen HY, Hillestad M, Krogdahl A, Storebakken T. Screening of nutrient digestibilities and intestinal pathologies in Atlantic salmon fed diets with legumes, oilseeds, or cereals. Aquaculture 2007;272: 541−55.
[6] Anderson J, Jackson AJ, Matty AJ, Capper BS. Effects of dietary carbohydrate and fibre on the tilapia *Oreochromis niloticus* (Linn.). Aquaculture 1984;37:303−14.
[7] Amirkolaie AK, Leenhouwers JI, Verreth JAJ, Schrama JW. Type of dietary fibre (soluble versus insoluble) influences digestion, faeces characteristics and faecal waste production in Nile tilapia (*Oreochromis niloticus* L.). Aquacult Res 2005;36: 1157−66.
[8] Bernhart FW, Tomarelli RM. A salt mixture supplying the national research council estimates of mineral requirements of the rat. J Nutr 1966;89:495−500.
[9] Brethes JC, Parent B, Pellerin J. Enzymatic activity as an index of trophic resource utilisation by the snow crab *Chionoecetes opilio* (O. Fabricius). J Crustac Biol 1994;14:220−5.
[12] Catacutan MR. Apparent digestibility of diets with various carbohydrate levels and the growth response of Penaeus monodon. Aquaculture 1991;95:89−96.
[13] Chu JH, Lan YW, Sheen SS. The protein requirement for the juvenile dog conch, *Laevistrombus canarium*, in a recirculating aquaculture system. J Fish Soc Taiwan 2018;45:261−9.
[14] Chu JH, Lan YW, Sheen SS, Chien A. Effects of different dietary lipid levels on the growth performance, body composition and digestive enzymes of the dog conch, *Laevistrombus canarium*. Pakistan J Zool 2021;53:1649−57.
[15] Cob ZC, Arshad A, Sidik JB, Amin SMN, Ghaffar MA. Growth, mortality, recruitment and yield-per-recruit of *Strombus canarium* Linnaeus, 1758 (Mesogastropoda: Strombidae) from the West Johor Straits, Malaysia. Res J Fish Hydrobiol 2008;3:71−7.
[16] Cruz-Suárez LE, Ricque-Marie D, Pinal-Mansilla JD, Wesche-Ebelling P. Effect of different carbohydrate sources on the growth of *Penaeus vannamei*: economical impact. Aquaculture 1994;123:349−60.
[17] D'Abramo LR, Sheen SS. Nutritional requirements, feed formulation and feeding practises for intensive culture of the freshwater prawn *Macrobrachium rosenbergii*. Rev Fish Sci 1994;2:1−21.
[18] Dunstan GA, Brown MR, Volkman JK, Maguire GB. Formulated feeds for newly settled juvenile abalone based on natural feeds : diatoms and crustose coralline algae. Bibliography 2002:39−47.
[19] Enes P, Panserat S, Kaushik S, Oliva-Teles A. Growth performance and metabolic utilization of diets with native and waxy maize starch by gilthead sea bream (*Sparus aurata*) juveniles. Aquaculture 2008;274:101−8.
[20] Fleming AE, Van Barneveld RJ, Hone PW. The development of artificial diets for abalone: A review and future directions. Aquaculture 1996;140:5−53.
[21] Figueiredo MSRB, Kricker JA, Anderson AJ. Digestive enzyme activities in the alimentary tract of redclaw crayfish, *Cherax quadricarinatus* (Decapoda; Parastacidae). J Crustac Biol 2001;21:334−44.
[22] Folch J, Lees M, Sloane-Stanley CH. A simple method for the isolation and purification of total lipids from animal tissue. J Biol Chem 1957;226:497−509.
[23] Furuichi M, Morita K, Yone Y. Effect of carboxymethylcellulose supplement on the absorption of dietary nutrients and on the levels of blood sugar and plasma amino nitrogen. Bull Jpn Soc Sci 1983;49:1367−70.
[24] Furuichi M, Yone Y. Changes in activities of hepatic enzymes related to carbohydrate metabolism of fishes in glucose and insulin-glucose tolerance tests *Chrysophrys major, Cyprinus carpio, Seriola quinqueradiata*. Bull Jpn Soc Sci Fish 1982;48:463−6.
[25] Gatlin III DM, Barrows FT, Brown P, Dabrowski K, Gaylord TG, Hardy RW, Herman E, Hu G, Krogdahl Å, Nelson R, Overturf K, Rust M, Sealey W, Skonberg D, Souza EJ, Stone D, Wilson R, Wurtele E. Expanding the utilization of sustainable plant products in aquafeeds: a review. Aquacult Res 2007;38:551−79.
[26] Gee JM, Blackburn NA, Johnson IT. The influence of guar gum on intestinal cholesterol transport in the rat. Br J Nutr 1983;50:215−24.
[27] Gonzalez-Pena M, Anderson AJ, Smith DM, Moreira GS. Effect of dietary cellulose on digestion in the prawn *Macrobrachium rosenbergii*. Aquaculture 2002;211:291−303.
[28] Guo R, Liu YJ, Huang JW. Effect of dietary cornstarch levels on growth performance, digestibility and microscopic structure in the white shrimp, *Litopenaeus vannamei* reared in brackish water. Aquacult Nutr 2006;12:83−8.
[29] Guzmán JM, Viana MT. Growth of abalone Haliotis fulgens fed diets with and without fish meal, compared to a commercial diet. Aquaculture 1998;165:321−31.
[30] Hansen JØ, Storebakken T. Effects of dietary cellulose level on pellet quality and nutrient digestibilities in rainbow trout (*Oncorhynchus mykiss*). Aquaculture 2007;272:458−65.
[31] Heinen JM. Evaluation of some binding agents for crustacean diets. Prog Fish-Cult 1981;43:142−5.
[32] Hemre GI, Sandnes K, Lie Ø, Torrissen O, Waagbø R. Carbohydrate nutrition in Atlantic salmon, *Salmo salar* L.: growth and feed utilization. Aquacult Res 1995;26:149−54.
[33] Hilton JW, Atkinson JL, Slinger SJ. Effect of increased dietary fiber on the growth of rainbow trout (*Salmo gairdneri*). Can J Fish Aquat Sci 1983;40:81−5.
[34] Hossain MA, Focken U, Becker K. Galactomannan-rich endosperm of Sesbania (*Sesbania aculeate*) seeds responsible for retardation of growth and feed utilisation in common carp, *Cyprinus carpio* L. Aquaculture 2001;203:121−32.
[35] Hsieh F, Mulvaney SJ, Huff HE, Lue S, Brent Jr J. Effect of dietary fiber and screw speed on some extrusion processing and product variables. Lebensm Wiss Technol 1989;22:204−7.
[36] Leary DF, Lovell RT. Value of fibre in production-type diets for channel catfish. Trans Am Fish Soc 1975;104:328−32.
[37] Lee SM, Kim KD, Lall SP. Utilization of glucose, maltose, dextrin and cellulose by juvenile flounder (*Paralichthys olivaceus*). Aquaculture 2003;221:427−38.
[38] Leenhouwers JI, Ter VM, Verreth JAJ, Schrama JW. Digesta characteristiscs and performance of African catfish (*Clarias gariepinus*) fed cereal grains that differ in viscosity. Aquaculture 2007a;264:330−41.

[39] Leenhouwers JI, Ortega RC, Verreth JAJ, Schrama JW. Digesta characteristics in relation to nutrient digestibility and mineral absorption in Nile tilapia (*Oreochromis niloticus* L.) fed cereal grains of increasing viscosity. Aquaculture 2007b; 273:556−65.
[40] Liu LH, Chen LQ, Dong AH, Zheng SX, Liu ZG. Effects of different dietary protein levels on the growth performances and body composition of *Babylonia formosae*. Fish Sci 2006;25:601−7.
[41] Lue S, Hsieh F, Peng IC, Huff HE. Expansion of corn extrudates containing dietary fiber: A microstructure study. Lebensm Wiss Technol 1990;23:165−73.
[42] Mai K, Mercer JP, Donlon J. Comparative studies on the nutrition of two species of abalone, *Haliotis tuberculata* L. and *Haliotis discus* hannai Ino. III. Response of abalone to various levels of dietary lipid. Aquaculture 1995;134:65−80.
[44] Noborikawa DK. The determination of cellulose in the giant Malaysian prawn, *Macrobrachium rosenbergii*. Proc Natl Shellfish Assoc 1978;69:205.
[45] NRC (National Research Council). Nutrient requirement of warmwater fishes and shellfishes. Washington D. C: National Academies Press; 1983. 94pp.
[46] NRC (National Research Council). Nutrient requirements of fish and shrimp. Washington D.C: National Academy Press; 2011. p. 135−62.
[47] Palmer TN, Ryman BE. Studies on oral glucose intolerance in fish. J Fish Biol 1972;4:311−9.
[48] Partridge IG. Studies on digestion and absorption in intestines of growing pigs. 4. Effects of dietary cellulose and sodium levels on mineral absorption. Br J Nutr 1978;39:539−45.
[49] Peragón J, Barroso JB, Garcia Salguero L, de la Higuera M, Lupiáñez JA. Carbohydrates affect protein-turnover rates, growth, and nucleic acid content in the white muscle of rainbow trout (*Oncorhynchus mykiss*). Aquaculture 1999;179:425−37.
[50] Purchon RD, Purchon DEA. The marine shelled Mollusca of West Malaysia and Singapore. Part I. General introduction and account of the collecting stations (abstract). J Molluscan Stud 1981;47:290−312.
[51] Reinhold JG, Ismailbeigi F, Faradji B. Fiber vs phytate as determinant of availability of calcium, zinc and iron of breadstuffs. Nutr Rep Int 1975;12:75−85.
[52] Ren M, Habte-Tsion HM, Xie J, Liu B, Zhoua Q, Ge X, Pan L, Chen R. Effects of dietary carbohydrate source on growth performance, diet digestibility and liver glucose enzyme activity in blunt snout bream, *Megalobrama amblycephala*. Aquaculture 2015;438:75−81.
[53] Sales J, Janssens GPJ. Use of feed ingredients in artificial diets for abalone: a brief update. Nutr Abs Rev Ser B 2004;74: 13−21.
[54] Shiau SY. Utilization of carbohydrates in warmwater fish—with particular reference to tilapia, *Oreochromis niloticus* × *O. aureus*. Aquaculture 1997;151:79−96.
[55] Shiau SY, Huang SL. Optimum dietary protein level for hybrid tilapia (*Oreochromis niloticus* × *O. aureus*) reared in seawater. Aquaculture 1989;81:119−27.
[56] Shiau SY, Yu HL, Hwa S, Chen SY, Hsu SI. The influence of carboxymethylcellulose on growth, digestion, gastric emptying time and body composition of tilapia. Aquaculture 1988;70:345−54.
[57] Steel RGD, Torrie JH. Principles and procedures of statistics. second ed. New York: McGraw-Hill; 1980.
[58] Stone DAJ, Allan GL, Anderson AJ. Carbohydrate utilization by juvenile silver perch, *Bidyanus bidyanus* (Mitchell). III. The protein-sparing effect of wheat starch-based carbohydrates. Aquacult Res 2003;34:123−34.
[59] Storebakken T. Binders in fish feeds.1. Effect of alginate and guar gum on growth, digestibility, feed intake and passage through the gastrointestinal tract of rainbow trout. Aquaculture 1985;47:11−26.
[60] Sudaryono A, Tsvetnenko E, Evans LH. Digestibility studies on fisheries by-product based diets for Penaeus monodon. Aquaculture 1996;143:331−40.
[61] Thongrod S, Tamtin M, Chairat C, Boonyaratpalin M. Lipid to carbohydrate ratio in donkey's ear abalone (*Haliotis asinina*, Linne) diets. Aquaculture 2003;225:165−74.
[62] Uki N, Kemuyama A, Watanabe T. Development of semipurified test diets for abalone. Bull Jpn Soc Sci Fish 1985;51: 1825−33.
[63] Wilson P, Shan W, Mootoo DR. A novel strategy for the preparation of substituted tetrahydrofurans based on neighboring group participation by the ring oxygen of monosaccharides. J Carbohydr Chem 1994;13:133−40.
[64] Xue XM, Anderson AJ, Richardson NA, Anderson AJ, Xue GP, Mather PB. Characterisation of cellulase activity in the digestive system of the redclaw crayfish (*Cherax quadricarinatus*). Aquaculture 1999;180:373−86.
[65] Xu YB, Ke CH, Wang DX, Wei YJ, Lv JQ. Studies on protein in requirement of *Babylonia areolate* Link. Chiang Mai Univ J Nat Sci 2006;45:216−20.
[66] Yamamoto T, Akiyama T. Effect of carboxymethylcellulose, alpha-starch, and wheat gluten incorporated in diets as binders on growth, feed efficiency, and digestive enzyme activity of Japanese flounder. Fish Sci 1995;61:309−13.
[67] Zhang LL, Zhou QC, Cheng YQ. Effect of dietary carbohydrate level on growth performance of juvenile spotted Babylon (*Babylonia areolata* Link 1807). Aquaculture 2009;295: 238−42.