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Utilization of several different carbohydrate sources by juvenile yellowfin seabream (*Sparus latus*)

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Abstract: Six isonitrogenous (crude protein: 45% of dry matter), isolipidic (crude lipid: 9% of dry matter) semi-purified diets including a cellulose control diet and five 25% glucose, maltose, dextrin, corn starch and pre-gelatinized corn starch diets were prepared. Each was fed to triplicate groups of juvenile yellowfin seabream *Sparus latus* [initial body weight: (3.57 ± 0.13) g means ± SD] reared in 18 fiberglass tanks connected as a closed recirculating system at (27 ± 1) °C for 8 weeks. The growth indices, feed efficiency (FE), protein efficiency rate (PER) and hepatic glucose-6-phosphate dehydrogenase (G6PDH, EC 1.1.1.49), 6-phosphogluconate dehydrogenase (6PGDH, EC 1.1.1.44), malic enzyme (ME, EC 1.1.1.40) and isocitrate dehydrogenase (ICDH, EC 1.1.1.42) activities were measured to evaluate the ability of yellowfin seabream to utilize different carbohydrate sources in diets. Results showed that weight gain (WG), specific growth rate (SGR), hepatosomatic index (HSI), intraperitoneal fat (IPF) ratio, FE, PER, hepatic lipogenic enzymes activities and the compositions of whole body, muscle and liver of juvenile yellowfin seabream were significantly affected by different dietary carbohydrate sources. The pre-gelatinized corn starch and maltose groups, displayed significantly better WG and SGR than other carbohydrate sources groups ($P < 0.05$), but had no significant difference with the control group ($P > 0.05$). Growth and WG were not dependent on the complexity of dietary carbohydrate source. Fish fed with the pre-gelatinized corn starch and control diets had significantly higher FE and PER than those fed with glucose, maltose, dextrin and corn starch diets ($P < 0.05$). HSI was improved by the digestible carbohydrate inclusion. The IPF ratio in the pre-gelatinized corn starch group was higher than all other diet groups. In conclusion, pre-gelatinization of corn starch and maltose at a 25% inclusion level fed to fish significantly improved the growth of juvenile yellowfin seabream. In addition, pre-gelatinization of corn starch significantly improved corn starch utilization in yellowfin seabream.

Key words: *Sparus latus*; juvenile; carbohydrates; utilization; growth

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1 Introduction

One problem in the development of diets for

aquaculture is the high protein requirement of many species of fish, especially since protein accounts for a high proportion of feed costs^[1]. Therefore increased

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retention of dietary protein for growth is the aim of finfish nutritionists in the development of cost-efficient, environmentally friendly and sustainable diets. Maximizing the utilization of dietary protein for growth is related to both inclusion level of protein and availability of non-protein energy sources, namely lipid and carbohydrate, and hence carbohydrate as one of the cheapest non-protein energy sources in diet has been paid much attention to.

The ability of fish to utilize different types and levels of carbohydrate sources differs among species^[2]. Sturgeon fed either the maltose or glucose showed better growth than those fed dextrin, raw corn starch, sucrose, lactose or fructose at a 27.2% inclusion level^[3]. Rainbow trout fed glucose or maltose showed higher SGR, feed efficiency than those fed dextrin or starch at a 32% inclusion level^[4]. Similar results were also reported in sunshine bass^[5] and tilapia^[6]. In general, the nutritional value of carbohydrates varies among fishes: freshwater and warmwater fish are able to utilize dietary carbohydrate more effectively than coldwater and marine fish^[7].

Utilization of starch is related to the physical state of the starch (i. e. crude or gelatinized)^[8]. It has been shown that there is potential for improvement of starch digestibility through technological treatments like gelatinization and extrusion^[9]. The improvement in complex carbohydrate digestibility by gelatinization or extrusion has been established in freshwater^[10,11], marine species^[12,13] and euryhaline species^[14,15].

Yellow fin seabream (*Sparus latus*), a euryhaline, omnivorous, benthal-inhibited and warmwater species of fish^[16], have been cultured artificially in China for about a decade due to its high value and export demand but the knowledge about its nutrition is still limited^[17]. The first objective of this study was to evaluate the carbohydrate utilization in yellowfin seabream fed a carbohydrate-free control diet and 25% glucose, maltose, dextrin, corn starch and pre-gelatinized corn starch diets in terms of growth indices, body, liver and muscle composition and hepatic lipogenic enzymes activities. The second was to determine the effects of carbohydrate

complexity and pre-gelatinization of corn starch on yellowfin seabream growth, body, liver and muscle composition.

2 Materials and methods

2.1 Pre-gelatinization of corn starch

Corn starch was mixed with solvent (70% ethanol; 30% water) at a ratio of 1:5 and the pH was adjusted to 8.0, then gelatinized at 85–92 °C for 1 h. The gelatinized mixture was filtrated through a cloth-filler and oven-dried at 60 °C to a constant weight, and then finely ground, stored at –20 °C until use. The α -value of pre-gelatinized corn starch in this experiment was measured to be 39% by a traditional enzyme-hydrolyzation method^[18] using amyloglucosidase (Sigma, No. A-7255, 12 100 IU·g⁻¹).

2.2 Experimental diets and diet preparation

Six isonitrogenous (crude protein: 45% of dry matter) semi-purified diets including a control diet and five experimental diets containing 25% glucose, maltose, dextrin, corn starch or pre-gelatinized corn starch, were prepared prior to the experiment. The 45% crude protein of dry matter in diets in this study was similar to that in gilthead sea bream (*Sparus auratus*) diets^[19]. The composition and formulation of the diets are presented in Tab. 1. All weighed dry ingredients were mixed in a Hobart mixer (A-200T Mixer Bench Model unit, Resell Food Equipment Ltd., Ottawa, Canada) for 30 min; whereafter oil was gradually added, while mixing constantly. 10–50 mL of water was slowly blended into the mixture for each 100 g of dry matter, resulting in suitably textured dough. The diets were produced in a noodle-like shape of 1.2 mm in diameter using a twin-screw extruder (Institute of Chemical Engineering, South China University of Technology, Guangzhou, PR China). Then the diets were pelletized, air-dried, sieved and stored at –20 °C until fed. The gross energy values used for calculation were as follows: 16.7 kJ·g⁻¹ protein or carbohydrate and 37.7 kJ·g⁻¹ lipid as used in Garling and Wilson^[22].

Tab.1 The composition (as fed) of the experimental diets

ingredient	test diet nos. (g·100g ⁻¹)						ingredient	test diet nos. (g·100g ⁻¹)					
	1	2	3	4	5	6		1	2	3	4	5	6
white fish meal	29.6	29.6	29.6	29.6	29.6	29.6	casein	26.9	26.9	26.9	26.9	26.9	26.9
glucose	0	25	0	0	0	0	maltose	0	0	25	0	0	0
dextrin	0	0	0	25	0	0	corn starch	0	0	0	0	25	0
pre-gelatinized corn starch	0	0	0	0	0	25	cellulose	25.5	0.5	0.5	0.5	0.5	0.5
fish oil	3.5	3.5	3.5	3.5	3.5	3.5	corn oil	3.5	3.5	3.5	3.5	3.5	3.5
vitamin premix ^a	2	2	2	2	2	2	mineral premix ^b	5	5	5	5	5	5
choline chloride	0.5	0.5	0.5	0.5	0.5	0.5	ascorbic phosphate ester	0.5	0.5	0.5	0.5	0.5	0.5
calcium phosphate, dibasic	1	1	1	1	1	1	caroxymethyl cellulose	2	2	2	2	2	2
analyzed composition ^c							crude protein (%) ^d	44.9	47.3	45.5	45.5	45.8	45.1
dry matter (%)	93.3	90.3	92.4	92.8	92.6	89.8	gross energy (kJ·g ⁻¹) ^d	10.8	15.9	15.6	15.2	15.3	15.5
crude lipid (%) ^d	8.7	10.3	10.2	9.2	9.2	10.1							

Notes: (a). Contained (as mg·kg⁻¹ of dry diet): retinol (IU) 50000; cholecalciferol (IU) 2000; α -tocopherol (IU) 300; thiamin 37; riboflavin 48; pyridoxine 20; cyanocobalamin 0.1; folic acid 10; calcium pantothenate 74; menadione 11; ascorbic acid 240; myo-inositol 337; biotin 0.5; nicotinic acid 300. (From Reference[20]). (b). contained (as g·kg⁻¹ of dry diet): Ca(H₂PO₄)₂·H₂O, 6.80; Ca(C₆H₁₀O₆)₂·3H₂O, 17.42767; FeSO₄·7H₂O, 0.25; MgSO₄·7H₂O, 6.60; K₂HPO₄, 12.00; NaH₂PO₄·H₂O, 4.40; NaCl, 2.25; AlCl₃, 0.0042; KI, 0.0075; CuSO₄·5H₂O, 0.025; MnSO₄·H₂O, 0.035; CoCl₂·H₂O, 0.05; ZnSO₄·7H₂O, 0.15; NaSeO₃·1.5H₂O, 0.000635. (From Reference [21]). (c). Values are means of 2–3 samples. (d). Dry-matter basis.

2.3 Fish and feeding trial

Yellowfin seabream *Sparus latus* larvae obtained from a commercial producer (Doumen Fish Farm, Doumen, Zhuhai, China) were reared to juveniles by feeding a commercial diet in an earthen pond and then transferred to indoor culture systems where they were acclimated to experimental conditions. The feeding trial was conducted in 250 L fiberglass tanks (1 m × 0.5 m × 0.5 m) connected as a closed recirculating system with artificial sponge (3 cm thickness), coral-sand (25 cm thickness) and active-carbon filter (25 cm thickness). Low pressure electrical blowers provided aeration via air stones and oxygen (DO) levels were maintained at or near to saturation. Filtered water was supplied at a flow rate of 4.5 L·min⁻¹ to each rearing tank, and water temperature was measured daily and was maintained at (27 ± 1) °C. Dissolved oxygen (> 6.94 mg·L⁻¹), pH (8.02 – 8.33), salinity (6.42 – 10.03 g·L⁻¹), and total ammonia (< 0.1 mg N·L⁻¹) were measured weekly using methods described in the work of Allen *et al.*^[23]. Fish were subjected to a 12 L:12 D photoperiod using fluorescent lighting during the experimental period. Before the start of the experiment, fish were acclimated to the experiment conditions at a density of 45 fish per tank for 2 weeks

during which they were fed the control diet. After acclimation, fish [initial body weigh: (3.57 ± 0.13) g means ± SD] were pooled and randomly distributed into 18 fiberglass tanks to form groups of 30 fish. The six diets were randomly assigned within the 18-tank system with each dietary treatment being given to three tanks. Fish were fed in slight excess of their prescribed diets by hand twice daily at 08:00 and 18:00 for about 25 minutes during which time the fish were satiated (observed in the acclimation period). The feces in each tank were removed prior to feeding and the uneaten diets were collected after feeding by siphoning out as used in a previous work^[24] into a plastic sieve. The collected diets were oven-dried at 105 °C for 24 h and stored at – 20 °C for the calculation of feed intake. Tanks were thoroughly cleaned once every 2 weeks when the fish were removed for weighing. The experiment continued for 8 weeks.

2.4 Sampling

At the beginning of the growth study, 24 fish from an initial fish pool were sampled and stored at – 20 °C for analysis of whole body composition. 18 fish from the same initial pool were also withdrawn to dissect the liver and white muscle for analysis of liver and white muscle composition.

At the end of the trial, fish were deprived of food for 24 h prior to sampling and then the same protocol of slaughter was followed for each tank. 21 fish from each tank were randomly collected for proximate analysis, 5 for analysis of whole body composition, 16 were killed by puncturing the head with a needle and dissected to separate and weigh the viscera, liver and mesenteric fat in 8 fish before weighing the individual whole body and the livers in other 8 fish were taken for measuring the hepatic enzymes activities. White muscles were also dissected from both sides of the fillets without skin. Samples of liver for enzyme assay were frozen immediately in liquid nitrogen and stored at $-70\text{ }^{\circ}\text{C}$ until use.

2.5 Analytic methods

Proximate composition analysis of diets and chemical composition of whole body, liver and muscle was conducted following the standard methods^[25]. Crude protein ($\text{N} \times 6.25$) was determined by the Kjeldahl method after an acid digestion using an auto Kjeldahl System (1030-Auto-analyzer, Tecator, Sweden). Crude lipid was determined by the ether-extraction method using Soxtec System HT (Soxtec System HT6, Tecator, Sweden). Dry matter was analyzed by oven-drying at $105\text{ }^{\circ}\text{C}$ for 24 h. Crude ash was incinerated at $550\text{ }^{\circ}\text{C}$ in a muffle furnace for 24 h. Glycogen in liver was determined by the method of Murat and Serfaty^[26]. The concentration of glucose from glycogen after being hydrolyzed by amyloglucosidase (Sigma, No. A1602) was determined by using an automatic blood analyzer (Hitachi 7170A, Japan) from a clinical laboratory.

For assays of hepatic enzymes activities, the preparation of the liver sample was the same as described in Hung *et al.*^[3]. Protein and enzyme activities were measured in the resulting clear supernatant fractions. Glucose-6-phosphate dehydrogenase (G6PDH, EC 1.1.1.49) and 6-phosphogluconate dehydrogenase (6PGDH, EC 1.1.1.44) activities were measured according to Glock and McLean^[27] as modified by Kawaga *et al.*^[28], malic enzyme (ME, EC 1.1.1.40) according to

Wise and Ball (1964)^[29], and NADP-dependent isocitrate dehydrogenase (ICDH, EC 1.1.1.42) according to Bernt and Bergmeyer^[30]. Soluble protein content of liver homogenates was determined by the Lowry method using a Sigma kit (kit no. P5656). Enzyme activity units (IU) defined as μmol substrate converted to product per min measured by reading the change in absorbance at 340 nm at assay temperature ($24\text{ }^{\circ}\text{C}$), were expressed per mg hepatic soluble protein.

2.6 Statistic analysis

All data are presented as means \pm S D and subjected to one-way analysis of variance (ANOVA) to test the effects of experimental diets using the software of the SPSS (version 11.0) for windows. Duncan's new multiple range test was used to resolve the differences among treatment means^[31]. Differences among means were considered significant at $P < 0.05$.

3 Results

Initial whole body, muscle, liver compositions and growth, feed utilization and survival of all diet groups are given in Tab.2 and Tab.3, respectively.

Tab.2 The initial whole body, muscle and liver composition of juvenile yellowfin seabream

	dry matter (%) ^b	protein (%) ^b	lipid (%) ^b	ash (%) ^b
whole body ^a	24.78	15.56	3.52	4.76
muscle ^a	20.78	17.64	0.84	1.55
liver	31.03	13.61	8.98	-

Notes: (a). Values are means of 2 - 3 samples. (b). Fresh - weight basis. (-) No enough sample for analysis.

Fish fed the maltose or pre-gelatinized corn starch exhibited significantly higher WG and SGR than those fed either glucose, dextrin or corn starch ($P < 0.05$), but no significant difference with fish fed the control diet. Feed intake in maltose and dextrin groups was relatively higher compared to that in other groups. The pre-gelatinized corn starch and control groups had significantly higher FE, PER than other groups ($P < 0.05$). NR in pre-gelatinized corn starch group was significantly higher than that in other groups ($P < 0.05$). HSI was increased by inclusion

of glucose, maltose, dextrin, corn starch and pre-gelatinized corn starch. A significantly higher ($P < 0.05$) IPF ratio existed in fish fed the pre-gelatinized corn starch than in fish fed any of the other experimental diets. Survival of fish was equal in all groups.

Whole body, muscle and liver compositions were significantly affected by dietary carbohydrate sources (Tab. 4), with significantly higher whole body protein concentration observed in the maltose group compared to the other groups ($P < 0.05$).

Tab.3 The performance and body condition indices of juvenile yellowfin seabream fed the experimental diets for 8 weeks

	diet nos.					
	1	2	3	4	5	6
IBW	3.61 ± 0.12	3.55 ± 0.06	3.56 ± 0.10	3.60 ± 0.08	3.60 ± 0.05	3.59 ± 0.07
FBW	13.24 ± 0.39 ^{bc}	11.12 ± 0.51 ^a	13.61 ± 0.32 ^c	12.61 ± 0.56 ^b	12.22 ± 0.58 ^a	13.88 ± 0.42 ^c
WG	267.2 ± 22.7 ^{bc}	213.6 ± 9.2 ^a	282.8 ± 19.6 ^c	250.0 ± 16.6 ^b	211.2 ± 12.5 ^a	284.3 ± 13.2 ^c
SGR	2.32 ± 0.11 ^{bc}	2.04 ± 0.05 ^a	2.40 ± 0.09 ^c	2.23 ± 0.09 ^b	2.03 ± 0.07 ^a	2.40 ± 0.06 ^c
FI	17.25 ± 1.05 ^a	17.24 ± 1.05 ^a	21.56 ± 0.76 ^c	19.87 ± 0.87 ^{bc}	18.54 ± 2.12 ^{ab}	17.54 ± 1.29 ^{ab}
FE	55.87 ± 0.72 ^c	44.01 ± 2.79 ^{ab}	46.60 ± 0.35 ^b	45.31 ± 0.81 ^b	41.23 ± 2.77 ^a	58.64 ± 2.11 ^c
PER	1.24 ± 0.02 ^c	0.93 ± 0.06 ^{ab}	1.02 ± 0.01 ^b	1.00 ± 0.02 ^b	0.90 ± 0.06 ^a	1.30 ± 0.05 ^c
NE	21.45 ± 0.10 ^c	16.01 ± 1.22 ^a	19.04 ± 0.49 ^b	16.44 ± 0.69 ^a	15.60 ± 1.33 ^a	23.02 ± 0.27 ^d
HSI	1.18 ± 0.12 ^a	1.49 ± 0.17 ^{bc}	1.56 ± 0.12 ^c	1.33 ± 0.05 ^{abc}	1.27 ± 0.15 ^{ab}	1.57 ± 0.19 ^c
IPF ration	2.67 ± 0.17 ^a	2.45 ± 0.28 ^a	2.65 ± 0.13 ^a	2.81 ± 0.09 ^a	2.60 ± 0.22 ^a	3.24 ± 0.25 ^b
survival	100.0	95.6 ± 1.9	98.9 ± 1.9	97.8 ± 1.9	94.4 ± 6.9	100.0

Notes: Values are means ± S.D. of three replicates and values within the same row with different letters are significantly different ($P < 0.05$); IBW ($\text{g} \cdot \text{fish}^{-1}$): initial mean body weight; FBW ($\text{g} \cdot \text{fish}^{-1}$): final mean body weight; WG (%) = $100 \times (\text{final mean weight} - \text{initial mean weight}) / \text{initial mean weight}$; SGR (% day⁻¹) = $100 \times (\ln(\text{final mean weight}) - \ln(\text{initial mean weight})) / \text{days}$; FI ($\text{g} \cdot \text{fish}^{-1}$): Feed intake (as dry matter basis); FE = (FBW - IBW) / Feed intake; PER = g gain / g protein fed; NR = $100 \times \text{retained nitrogen (g)} / \text{nitrogen fed (g)}$; hepatosomatic index (HSI) = liver weight × 100 / body weight; intraperitoneal fat (IPF) ratio = IPF weight × 100 / body weight; survival (%) = $100 \times (\text{final fish number}) / (\text{initial fish number})$.

Tab.4 The whole body, muscle and liver composition of juvenile yellowfin seabream fed the experimental diets for 8 weeks

	diet nos.					
	1	2	3	4	5	6
whole body composition*						
dry matter (%)	31.5 ± 0.9 ^{bc}	29.9 ± 0.3 ^a	31.8 ± 0.5 ^{bc}	30.6 ± 1.2 ^{ab}	30.0 ± 1.0 ^a	32.2 ± 0.1 ^c
protein (%)**	16.8 ± 0.1 ^{ab}	16.7 ± 0.3 ^{ab}	17.8 ± 0.3 ^c	16.2 ± 0.3 ^a	16.8 ± 0.3 ^{ab}	17.2 ± 0.4 ^b
lipid (%)**	9.16 ± 0.62 ^{bc}	7.36 ± 0.09 ^a	8.98 ± 0.59 ^{bc}	8.74 ± 0.73 ^b	8.20 ± 0.76 ^{ab}	9.83 ± 0.22 ^c
ash (%)**	5.01 ± 0.08	5.23 ± 0.08	5.24 ± 0.06	5.09 ± 0.16	5.08 ± 0.10	5.23 ± 0.21
muscle composition*						
dry matter (%)	25.4 ± 0.3	24.7 ± 0.4	25.0 ± 1.4	24.8 ± 0.3	26.5 ± 2.5	24.9 ± 0.5
protein (%)**	19.3 ± 0.3 ^a	19.5 ± 0.1 ^a	19.8 ± 0.8 ^{ab}	19.3 ± 0.1 ^a	21.4 ± 2.2 ^b	19.6 ± 0.3 ^a
lipid (%)**	4.12 ± 0.50 ^b	3.48 ± 0.56 ^{ab}	3.40 ± 0.43 ^{ab}	3.56 ± 0.29 ^{ab}	3.08 ± 0.39 ^a	3.57 ± 0.31 ^{ab}
ash (%)**	1.50 ± 0.07	1.47 ± 0.08	1.47 ± 0.05	1.50 ± 0.01	1.62 ± 0.16	1.46 ± 0.05
liver composition						
dry matter (%)	36.8 ± 1.2 ^{bc}	35.8 ± 1.3 ^{ab}	35.2 ± 0.9 ^{ab}	34.7 ± 0.4 ^a	38.5 ± 0.5 ^c	36.8 ± 1.4 ^{bc}
Protein (%)**	13.3 ± 0.3 ^b	11.6 ± 0.0 ^a	11.4 ± 0.5 ^a	11.6 ± 0.5 ^a	12.7 ± 0.1 ^b	12.5 ± 0.8 ^b
lipid (%)**	18.0 ± 2.2 ^b	13.7 ± 1.4 ^a	12.3 ± 1.5 ^a	12.2 ± 0.3 ^a	17.2 ± 1.5 ^b	14.2 ± 1.3 ^a
glycogen (%)**	4.82 ± 0.50 ^a	11.43 ± 0.54 ^c	11.71 ± 0.47 ^c	9.61 ± 0.43 ^d	6.85 ± 0.26 ^b	8.32 ± 0.50 ^c

Notes: Values are means ± S.D. of three replicates and values within the same row with different letters are significantly different ($P < 0.05$); *: Values are means of 2-3 samples; **: Fresh-weight basis.

Fish fed the pre-gelatinized corn starch and control diets had higher whole body and muscle lipid

concentration compared to those fed the other diets. Pre-gelatinization of corn starch resulted in significantly increased body lipid and dry matter levels ($P < 0.05$). The pre-gelatinized corn starch group also had higher whole body protein and muscle lipid compared to fish fed the corn starch. Whole body ash level showed no significant difference among these

groups ($P > 0.05$). The cellulose control group had greater liver protein and lipid concentrations, and lower liver glycogen values compared to the other groups. Fish had significantly higher liver glycogen when fed glucose or maltose than those fed dextrin, corn starch or pre-gelatinized corn starch ($P < 0.05$).

Tab.5 The activities of hepatic glucose-6-phosphate dehydrogenase (G6PDH), 6-phosphogluconate dehydrogenase (6PGDH), malic enzyme (ME) and isocitrate dehydrogenase (ICDH) of juvenile yellowfin seabream fed the experimental diets for 8 weeks

	diet nos.					
	1	2	3	4	5	6
G6PDH*	0.24 ± 0.21 ^a	1.20 ± 0.55 ^{ab}	2.22 ± 0.34 ^b	1.50 ± 0.58 ^b	1.80 ± 1.05 ^b	1.24 ± 0.24 ^{ab}
6PGDH*	0.18 ± 0.03 ^a	0.30 ± 0.11 ^a	0.78 ± 0.27 ^b	0.76 ± 0.20 ^b	0.22 ± 0.05 ^a	0.28 ± 0.15 ^a
ME*	0.09 ± 0.02 ^a	0.17 ± 0.08 ^a	0.47 ± 0.16 ^b	0.25 ± 0.15 ^a	0.19 ± 0.10 ^a	0.24 ± 0.08 ^a
ICDH*	0.60 ± 0.51 ^a	1.63 ± 0.28 ^{ab}	4.05 ± 0.84 ^c	2.38 ± 0.73 ^b	2.58 ± 0.97 ^b	2.74 ± 0.52 ^b

Notes: Values are means ± S.D. of three replicates and values within the same row with different letters are significantly different ($P < 0.05$);

* : expressed as μ mol NADPH / (min × mg protein)

Liver G6PDH, 6PGDH, malic enzyme and ICDH activities of yellowfin seabream were significantly affected by dietary carbohydrate sources (Tab.5). Fish fed the control diet had lower liver G6PDH, 6PGDH, ME and ICDH activities compared to those fed other diets. The ME and ICDH activities of yellowfin seabream fed either the glucose, dextrin, corn starch or pre-gelatinized corn starch were not significantly different ($P > 0.05$), but significantly lower ($P < 0.05$) than those fed the maltose. The G6PDH activity of the different dietary carbohydrate sources groups was not significantly different. The 6PGDH activity of the maltose or dextrin group was significantly higher than that of any other carbohydrate source group ($P < 0.05$).

4 Discussion

Our study demonstrated that inclusion of pre-gelatinized corn starch or maltose in the diet at a 25% level increased the growth of yellowfin seabream in light of better WG and SGR obtained compared to fish fed a cellulose diet. This may partially be due to a protein-sparing effect of maltose and pre-gelatinized corn starch, which had been reported in previous study^[1]. The improvement of fish growth obtained in pre-gelatinized corn starch group may be ascribed to

more rapid absorption and higher digestibility of starch compared to the raw corn starch group^[32], reminding by the improvement of body lipid deposition in the pre-gelatinized corn starch group compared to the value obtained in the corn starch group. Cooking or gelatinization or pre-gelatinization of starch has been demonstrated to improve carbohydrate utilization for fish in previous studies^[10-15]. No effect on growth related to the complexity of the carbohydrate source in the diet, interpreted due to lack of difference in SGR between fish fed maltose and pre-gelatinized corn starch, differs from the studies in some other fish^[7] but agrees with the study in striped bass^[5]. The low utilization of corn starch by yellowfin seabream might be attributed to a low intestinal amylase activity, which had been reported in trout^[33]. Further studies should be done in yellowfin seabream in future to evaluate the intestinal carbohydrase activities given different carbohydrate sources. The poor growth performance in the glucose-fed yellowfin seabream agreed with results in other fish^[7], and it can be explained by the failure to utilize absorbed glucose^[6]. This has been confirmed in other studies^[34-35].

The significantly higher PER in pre-gelatinized corn starch and control groups than the other groups may be due to higher FE obtained in fish fed the pre-

gelatinized corn starch and control diets, agreeing with results observed in juvenile sunshine bass^[36] and juvenile flounder^[37]. HSI of yellowfin seabream was increased by the inclusion of digestible carbohydrate compared to that of fish fed the control diet, in agreement with other studies^[5,36-37]. In this study, the relatively higher liver lipid but lower liver glycogen concentrations in the low-HSI control group indicated that liver glycogen was more responsible for the liver enlargement than lipid. The same result was reported by Lee *et al*^[37]. Protein and dry matter content in muscle were less affected by the varied treatments. The higher whole body lipid content of the control group than that of the group sampled prior to the feeding trial indicated that the accumulation of lipid was largely attributed to the inclusion of lipid in the diet. Increased storage of body fat as found in the pre-gelatinized corn starch group is an indication of carbohydrate being a precursor of de novo lipid synthesis. The significantly higher liver glycogen content in the glucose or maltose group compared to the dextrin, corn starch or pre-gelatinized corn starch group may indicate that liver glycogen was more responsive to the inclusion of glucose and maltose than to the inclusion of dextrin, corn starch or pre-gelatinized corn starch. In rainbow trout^[4] and flounder^[37], it was also reported that fish fed glucose or maltose had higher liver glycogen content than those fed dextrin or corn starch. The activities of hepatic G6PDH, 6PGDH, ME and ICDH in yellowfin seabream were improved by the dietary digestible carbohydrate inclusion, which was in accord with other studies^[38-39]. In this experiment, the maltose group had relatively higher hepatic G6PDH, 6PGDH, ME and ICDH activities compared to other groups. In juvenile white sturgeon, the glucose and maltose groups had significantly higher liver G6PDH, ME and ICDH activities^[3] and these enzymes activities were significantly higher in tilapia fed the dextrin diet^[6]. The observed differences in these studies might be due to varied experimental fish species or different experimental designs or conditions.

In conclusion, data from the present study

indicate yellowfin seabream is able to utilize pre-gelatinized corn starch and maltose as non-protein energy sources in light of the better growth performance compared to the cellulose group and the other carbohydrate sources groups in this experiment at a 25% inclusion level.

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黄鳍鲷幼鱼对几种不同糖源的利用

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摘要:本研究用来评价黄鳍鲷幼鱼对饲料中葡萄糖、麦芽糖、糊精、玉米淀粉和预糊化玉米淀粉的利用。本试验饲料为6种等氮(粗蛋白:45%,干重)等脂(粗脂肪:9%,干重)的半纯化饲料,其中对照组糖源为纤维素。每种饲料设3个平行。试验鱼初始体重为(3.57±0.13)g(平均值±均差)。试验鱼饲养在含18个水族箱的循环系统中。水温保持在(27±1)℃。试验周期为8周。本试验用来评价黄鳍鲷幼鱼对饲料中不同糖源利用的指标为生长指标、饲料效率、蛋白质效率和肝脏的6-磷酸葡萄糖脱氢酶、苹果酸脱氢酶、异柠檬酸脱氢酶和葡萄糖-6-磷酸脱氢酶。试验结果表明,黄鳍鲷幼鱼体增重、特定生长率、肝体比、肠系膜脂肪体比、饲料效率、蛋白质效率、肝脂肪合成有关酶活性和全鱼、肌肉、肝脏组成均受到饲料中不同糖源的显著影响。预糊化玉米淀粉和麦芽糖组比其它糖源组显著具有更好的体增重和特定生长率,但与对照组没有显著性差异。黄鳍鲷幼鱼生长和体增重与饲料中糖源的复杂性没有相关性。饲喂预糊化淀粉和对照饲料鱼的饲料效率和蛋白质效率显著比其它组高。饲料中糖的添加增加了黄鳍鲷幼鱼的肝体比,但对照组肝体比与糊精组,玉米淀粉组没有显著性差异。预糊化玉米淀粉组肠系膜脂肪体比比其它饲料组要高。结论:基于体增重和特定生长率为指标,饲料中添加25%预糊化玉米淀粉和麦芽糖可以提高黄鳍鲷幼鱼的生长。另外,玉米淀粉预糊化显著提高了黄鳍鲷对玉米淀粉的利用。

关键词:黄鳍鲷;幼鱼;糖;利用;生长

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