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Original Article

Root crop-based dietary carbohydrate enhanced growth performance and feed efficiency on Nile tilapia (*Oreochromis Niloticus*) fry

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ABSTRACT

This study evaluated the use of dietary carbohydrates, namely, sweet potato starch, cassava starch, and corn starch, incorporated into the diet of Nile tilapia (*Oreochromis niloticus*) fry. A total of 360 tilapia fry (average body weight=0.10g) were randomly distributed into twelve 40L tanks and fed three experimental diets over eight weeks: a control diet (100% commercial feed), a sweet potato diet (15% SP), a cassava diet (15% Cas), and a corn starch diet (15% Cos). Tilapia fry fed the SP diet exhibited significantly the best growth performance and feed efficiency compared to the other groups. Weight gain, final average body weight, and specific growth rate were significantly higher in the SP diet group. Although the feed conversion ratio was lower in the SP group, the difference was not statistically significant compared to the control. Survival rates and attractability tests showed no significant differences among the groups. In conclusion, tilapia fry fed the SP diet demonstrated improved growth performance and feed efficiency, indicating effective utilization of feed containing sweet potato starch.

Keywords: growth performance; *Oreochromis niloticus*; Sweet potato starch

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INTRODUCTION

Aquaculture is responsible for producing half of global seafood consumption and is the fastest-growing industry due to rising demand for quality fish (FAO, 2022). However, with the increase in seafood demand, the price of feed increased simultaneously (Mahraomai et al., 2018). This increase in fish feed prices contributes significantly to overall production costs in aquaculture. Protein, especially from fish meal, is a critical and costly component of aquafeeds that is becoming scarcer due to heightened demand in the sector. On the other hand, carbohydrates yield almost the same energy as that of protein, routinely utilized for metabolism and energy requirements (Singh et al., 2006). Carbohydrate inclusion in diets can increase protein and lipid retention by preventing the catabolism of these expensive nutrients for energy needs (Kamalam et al., 2017). This has prompted the aquafeed sector to explore alternative plant-based ingredients with the aim to decrease the dependence on fish meal. The Nile tilapia (*Oreochromis niloticus*) is one of the most commonly cultured fish species worldwide. As omnivorous grazers, Nile tilapia efficiently utilize carbohydrates as a primary energy source (Kamalam et al., 2017), with carbohydrate content accounting for 15%–80% of their diet (Lauzon et al., 2019; FAO, 2018).

Kamalam and Panserat (2016) noted that including an optimal level of carbohydrates in feeds can act as a binder while significantly reducing feed costs. Starches and sugars are among the most cost-effective energy sources for fish diets (Fathima et al., 2022). Root crops, which are high in starch, are readily available, require less intensive management, and can be obtained cheaply in local markets. Although root crops are widely cultivated and primarily used for human consumption and animal feed, seasonal oversupply of crops such as sweet potato, cassava, taro, and yam often results in lower market prices, making root crops attractive and cost-effective ingredients for aquaculture feeds. Due to their high carbohydrate content, root crops signify a valuable and ideal energy source that could replace more expensive ingredients in aquaculture feeds. Carbohydrates are not only essential as a binding agent, but are also essential for energy metabolism, and can enhance growth performance and improve feed efficiency when formulated appropriately.

In the Philippines Region VIII, crops such as sweet potato, cassava, and corn are low-priced and produced year-round, providing a significant energy source for aquafeeds. However, despite their energy potential, the use of these crops as dietary carbohydrate for tilapia remains limited. This suggests a significant opportunity for improving feed sustainability and economic viability in aquaculture sector. Previous studies (Deng et al., 2021) support the idea that root crops, as alternative dietary carbohydrate sources, can be effectively used in the aquaculture diet. However, further research is needed to evaluate the performance in specific species and life stages. Therefore, this study aimed to evaluate the effects of root crop-based starches—specifically sweet potato, cassava, and corn starch—as dietary carbohydrate sources on the growth performance and feed efficiency of Nile tilapia fry.

MATERIALS AND METHODS

Location of the Study

The study was conducted at the freshwater hatchery of the Faculty of Fisheries and Aquatic Sciences, Visayas State University, Tolosa, Leyte, from April to May 2022.

Experimental Fish

Three hundred sixty (360) Nile tilapia fry average body weight (ABW) 0.10g were acquired from the Faculty of Fisheries and Aquatic Sciences Freshwater Hatchery. The fry were acclimatized in fiberglass tanks with aeration for one week and fed with a commercial diet prior to the feeding trial.

Diet Formulation and Preparation

The experimental diets' formulation and composition are shown in Table 1 (following the method of Lauzon et al., 2019). The experimental diets included sweet potato starch (SP), cassava starch (CaS), and corn starch (CoS) as dietary carbohydrate sources. The control group (T1) was commercial tilapia feed. Treatments T2, T3, and T4 were formulated with ingredients procured from the Southeast Asian Fisheries Development Center-Aquaculture Department (SEAFDEC-AQD), Tigbauan, Iloilo, Philippines and incorporated with 15% SP, 15% CaS, and 15% CoS, respectively. All dry ingredients were sieved and mixed well. Fish oil and soybean oil were added to the dry ingredients. Starch was cooked under medium heat at 90°C for 15mins and mixed last with the other ingredients. Diets were cooked in a mechanical oven at 80°C for 8h, cooled, and stored at 4°C until use. The final texture of the experimental diets was in powdered form, suitable for tilapia fry feeding.

Table 1. Composition of experimental diets fed to Nile tilapia fry

	Diets (% Composition)			
Feedstuff	$T_1^{(CONTROL)}$	$T_2^{(SP)}$	$T_3^{CaS)}$	T_4^{CoS}
Starch	Commercial feed	15	15	15
Peruvian fish		20.00	20.00	20.00
Soybean		27.00	27.00	27.00
Shrimp meal		18.00	18.00	18.00
Fish oil		2.00	2.00	2.00
Soybean oil		2.00	2.00	2.00
Vitamin mix		2.00	2.00	2.00
Mineral mix		2.00	2.00	2.00
CMC		12.00	12.00	12.00
Proximate Analysis				
Crude Protein	45.00	39.34	32.67	34.33
Crude Fiber	5.00	6.74	6.45	6.02
Crude Lipid	8.00	11.51	11.45	5.45
Ash	16.00	11.51	11.45	11.38
Moisture	12.00	9.69	9.19	9.91

Feeding Trials

A recirculating aquaculture system (RAS) was employed for the growth trials, maintaining the following water quality parameters: temperature at 28°C, pH at 7.0, dissolved oxygen (DO) levels of at least 5 mg L^{-1}, and total ammonia concentrations below 0.05mg L^{-1}. Forty fry (ABW=0.10g) were placed in each of twelve 40L culture tanks and fed three times daily (08:00am, 01:00pm, and 05:00pm) for two months at a feeding rate of 10% of the average body weight, which was adjusted weekly based on the following formula (BFAR, 2000):

Feed/day=ABW x FR x total no. of fry

The feeding rate was adjusted weekly according to fish ABW.

Response Parameters

Fish length (cm) and weight (g) were measured using a metric ruler and digital scale, respectively. For each tank, fish were bulk weighed weekly to obtain total weight. Average Body Weight (ABW), Weight Gain (WG), Specific Growth Rate (SGR), Feed Conversion Ratio (FCR), and Survival Rate (SR) were calculated using the following formulas:

A. ABW = total weight/n (number of samples)
B. Weight Gain (g)= Final ABW- Initial ABW
C. Specific Growth Rate = [Ln (Final ABW in g) – Ln(Initial ABW in g)]/(No. of days)*100
D. Feed Conversion ratio = (Total Feed Intake)/(Weight Gain)
E. Survival Rate (%) = (Total no. of live tilapia)/(Total no. of tilapia stocked) x 100

Assessment of Attractability

The attractability of the diets was tested in three rectangular glass tanks with multiple chambers. Each tank was divided into three principal chambers: an acclimitization chamber, a middle chamber, and a feeding chamber, with dimensions of 91cmx55cmx45cm. The acclimatization and intermediate chambers were separated by a retractable glass shutter. The feeding chamber was subdivided into three sub-chambers, each with an aperture to allow tilapia access to the experimental diets. Forty Nile tilapia fingerlings (ABW=5g) were obtain from the freshwater hatchery of the FFAS, VSU Tolosa, raised under standard hatchery conditions and fed a commercial booster feed prior to the experiment. Tilapia fingerlings were randomly stocked in the acclimatization chamber for one hour. Ten grams of each diet was placed in the respective feeding chambers. The shutter was removed three minutes after feed placement to allow access to the diets. The number of tilapia in the feeding chamber was counted at 1, 5, and 10mins post-release to evaluate feed preference. The percentage of tilapia in each feeding chamber was calculated at the various time intervals.

Statistical Analysis

The growth performance metrics and attractability tests were assessed for homogeneity of variances and normal distribution prior to conducting a One-way ANOVA. All statistical analyses were performed using SPSS version 16.0 at a 95% confidence level, with significance set at $p<0.05$. Tukey's test was employed to rank mean values where significant differences were found.

RESULTS

The growth performance, feed efficiency, and survival of *O. niloticus* fry fed with different diets for eight weeks are summarized in Table 2. The final average body weight (FABW), weight gain (WG), specific growth rate (SGR), and feed intake (FI) of fish fed with sweet potato starch (SP) were significantly higher than those in the control, corn, and cassava groups. Incorporating 15% sweet potato starch positively influenced the growth and efficiency of Nile tilapia fry. Additionally, while the feed conversion ratio (FCR) in the SP group was numerically lower that in the other treatment groups, no statistically significant differences in FCR were observed among the four diets. Similarly, there were no significant differences in survival rates across all treatment groups.

Table 2. Growth performance and feed efficiency of Nile tilapia fry fed experimental diets

Fish Diet	I_{ABW} (g)	F_{ABW} (g)	WG. (g)	SGR. (%)	FI. (g)	FCR	Survival
Control	0.10	2.66 ± 0.15^{b}	$2.56\pm0.20^{b,c}$	5.71 ± 0.10^{b}	4.78 ± 0.13^{b}	1.63 ± 0.04^{a}	98.33 ± 1.67^{a}
SP	0.10	3.64 ± 0.01^{a}	3.26 ± 0.12^{a}	6.18 ± 0.07^{a}	5.63 ± 0.16^{a}	1.52 ± 0.03^{a}	$97.50\pm1.^{a}$
CaS	0.10	2.40 ± 0.14^{c}	2.18 ± 0.13^{c}	5.38 ± 0.14^{c}	4.45 ± 0.17^{b}	1.83 ± 0.06^{a}	95.83 ± 0.83^{a}
Cos	0.10	2.83 ± 0.11^{b}	2.76 ± 0.02^{b}	5.49 ± 0.06^{c}	4.53 ± 0.13^{b}	1.95 ± 0.07^{a}	95.00 ± 1.44^{a}

The superscripts letter in the same column signifies significant differences between experimental diets ($p<0.05$). Values are mean ± SEM (I_{ABW}), Initial average body, weight final average body weight (F_{ABW}), weight gain (WG), feed intake (FI), specific growth rate (SGR), feed conversion ratio (FCR); Sweet potato (SP), Cassava (CaS), Corn (Cos).

The whole body composition of Nile tilapia fry fed the three experimental diets is presented in Table 3. Tilapia fed the sweet potato starch (SP) diet exhibited significantly higher protein content ($p<0.05$) compared to the cassava starch (CaS) and corn starch (CoS) groups. A similar observation was noted in the control group.

Table 3. Proximate composition of (% of dry weight) *O. niloticus* fed with different sources of carbohydrate

Diet	%Moisture	% Ash.	%Crude Lipid	%Crude Fiber	Crude Protein
Control	3.60 ± 0.04^{a}	14.12 ± 0.06^{a}	22.13 ± 0.10^{b}	3.32 ± 0.02^{b}	57.32 ± 0.12^{a}
SP	3.80 ± 0.10^{a}	13.24 ± 1.57^{a}	22.21 ± 0.43^{b}	5.08 ± 0.05^{a}	57.34 ± 0.12^{a}
CaS	3.60 ± 0.09^{a}	13.95 ± 0.02^{a}	26.11 ± 0.57^{a}	3.30 ± 0.51^{b}	55.29 ± 0.04^{b}
Cos	3.56 ± 0.06^{a}	13.17 ± 0.03^{a}	25.37 ± 0.20^{a}	3.25 ± 0.07^{b}	54.75±0.07c

Growth performance in terms of weight gain was positively correlated with the length and width of tilapia fry. The results presented in Table 4 indicate that each treatment significantly differed from the others.

Table 4. Length and width of *O. niloticus* fry fed with experimental diets

Treatments	IL(mm)	FL(mm)	IW(mm)	FW(mm)
Control	19.97±0.03[a]	59.87±0.52[b]	4.93±0.07[a]	17.33±0.18[b]
SP	19.93±0.07[a]	72±1.50[a]	4.97±0.03[a]	24.53±0.58[a]
CaS	20.0±0.06[a]	49.27±1.28[c]	4.90±0.06[a]	16.13±0.13[c]
Cos	19.93±0.33[a]	58.47±1.03[b]	4.97±0.33[a]	18.13±0.92[b]

Superscript letters in the same column indicate significant differences between experimental diets ($p<0.05$). Values are mean ± SEM (IL) initial length, (FL) final length, (IW) initial width, and (FW) final width.

The highest length (72mm±1.50[a]) and width (24.53mm±0.58[a]) were observed in *O. niloticus* fed the sweet potato (SP) diet, while the lowest length (49.27mm±1.28[c]) and width (16.13mm±0.13[c]) were noted in fish fed the corn starch (CS) diet. As the weight of fish fed the SP diet increased, both length and width also showed corresponding growth. As stated by Jobling (2002), fish growth is indicated by increases in both length and weight.

Attractability Test of the Experimental Diets

In this study, attractability did not contribute to the improved growth parameters. Table 5 presents the mean attractability data for Nile tilapia fry fed with different carbohydrate sources. The data indicated no significant differences among the four diets. The lowest mean value was observed in Treatment 3, which contained cassava starch at the 5mins interval, while the highest mean value of Nile tilapia fry entering the feeding chamber was recorded for the diet with sweet potato starch, showing a mean value of 3.67 at the same time interval.

Table 5. Attractability test of experimental diets for *O. niloticus*

Fish Diet	Number of Fish (%)		
	1 Minute	5 Minutes	10 Minutes
Control	1.83±0.31[a]	3.0±0.86[a]	3.33±0.49[a]
SP	2.00±0.37[a]	3.67±1.12[a]	2.33±0.42[a]
CaS	1.33±0.49[a]	2±0.68[a]	3.0±1.03[a]
Cos	1.67±0.33[a]	3.0±0.93[a]	2.5±0.89[a]

Superscript letters in the same column indicate no significant differences between experimental diets ($p<0.05$). Values are mean ± SEM.

DISCUSSION

Carbohydrates are considered a cost-effective source of energy and serve as an excellent dietary component of fish feed, promoting growth performance and providing metabolic intermediates for synthesizing various biological compounds. In this study, the survival rates of tilapia fry fed the sweet potato (SP), cassava starch (CaS), and corn starch (CoS) diets exceeded 90%, indicating that tilapia fry can efficiently utilize carbohydrates (Wilson, 1994). The inclusion of 15% starch in the diet significantly enhanced the growth performance and feed efficiency of Nile tilapia fry. Similar findings were reported by Lauzon et al., (2019) with corn starch. Specifically, the growth performance of tilapia fry fed with SP starch led to improvements in average body weight, feed intake, and feed conversion ratio (FCR).

The increase in weight gain and feed intake contributed to a lower feed conversion ratio (FCR) in tilapia fry fed the sweet potato (SP) diet, indicating efficient utilization of carbohydrates. Table 3 showed that the proximate analysis of tilapia fry fed the control and SP diets revealed no significant difference in protein content. The similar protein levels in the tilapia fed with the SP and control diets may be attributed to the starch content serving as an energy source for tilapia. Dietary starch can enhance growth and feed utilization in tilapia fry by providing sufficient energy compared to non-starch diets (Zhou et al., 2015). Insufficient starch levels in the diet can lead to poor nutritional status due to the inadequate energy supply.

According to Wilson (1994), the absence of dietary carbohydrates can lead to increased protein and lipid catabolism. While catabolism breaks down metabolites to produce active energy, a sufficient level of digestible carbohydrates allows for protein-sparing effects (Krogdahl et al., 2005). In this study, the 15% starch level and 39% protein content appear to strike an excellent balance to support the nutritional needs of tilapia and their specific physiological functions.

The growth performance observed in this study aligns with findings from Baleta et al. (2021), where tilapia fry fed a diet containing sweet potato shoots powder and extract demonstrated improved growth, as indicated by increased weight gain. Zhou et al. (2015) reported that a 20% level of dietary sweet potato starch is sufficient for normal growth, consistent with observations from Wang et al. (2017). Furthermore, Zainuddin et al. (2020) found that a combination of 50% sweet potato flour and 50% corn starch was the most effective treatment for improving feed conversion ratio (FCR), specific growth rate (SGR), and chemical body composition in juvenile white leg shrimp.

The utilization of carbohydrates varies among fish species, with the appropriate amounts improving growth performance and feed efficiency (Wang et al., 2005). As an omnivorous species, tilapia can tolerate higher dietary carbohydrate levels than carnivorous fish, exhibiting greater protein-sparing effects (Krogdahl et al., 2005). Additionally, tilapia possess a long digestive tract, enabling effective breakdown of polysaccharides. Maas (2020) noted that starch is highly digestible for tilapia, and gelatinized starch enhances digestibility, availability, and absorption (Kanmani et al., 2018). Starch gelatinization occurs when starch granules are heated with the presence of water, causing it to swell, rupture, and release their molecular structure, particularly the amylose and amylopectin.

In this study, a 15% inclusion of gelatinized starch proved effective, resulting in improved growth performance in tilapia fry. This is supported by Lauzon et al. (2019), who found that *O. niloticus* efficiently utilized 15% to 25% gelatinized corn starch in their diets. Similar results were reported by Maurice et al. (2018), where tilapia fed 16% gelatinized corn starch with 28% protein exhibited superior growth performance. Moreover, Wang et al. (2005) showed that a starch level of 22-46% resulted in a better protein efficiency ratio (PER) for *O. niloticus* compared to 6% or 14%. Wilson (1994) recommends a 40% dietary carbohydrate level for tilapia species, while suggesting below 20% for marine and carnivorous species such as salmon and trout. Additionally, Wilson (1994) highlighted those starches such as corn, wheat, cassava, and sweet potato can be included to reduce protein usage for energy. In addition to biological evaluations, such as growth performance and feed efficiency, physical assessments—including attractability tests—are essential for every fish diet. The nutrient and toxin content can significantly influence the palatability of food (Tantikitti, 2014). Fish utilize their senses of taste, smell, and sight to differentiate between foods that evoke pleasant or unpleasant sensations associated with eating.

In this present study, feed attractability did not contribute to the improved growth parameters, which contrasts with the findings of Lauzon et al. (2019) and Nudalo et al. (2020), who reported that the addition of benfotiamine enhanced feed attractability in fish. Although feeds formulated with starch as a carbohydrate source offer various nutritional benefits, the starches used in this study did not significantly affect the pigmentation or smell of the experimental diets. All the experimental diets exhibited a brown coloration, whereas the commercial feed had a more yellowish appearance.

Color, a potential factor in feed attractability, has shown mixed effects in previous studies. Arumugum (1997) found that hybrid tilapia fry exhibited no clear preference for feed color when offered green, orange, or yellow encapsulated diets. However, Jegede and Oluwatosin (2010) reported that *Tilapia zilli* demonstrated better growth and feeding efficiency when fed light-colored diets (yellow and light green) compared to dark-colored diets. In contrast, El-Sayed (2004) observed better feed efficiency and growth in juvenile tilapia when fed darker-colored diets.

The role of feed color and attractability in influencing growth performance remains limited and somewhat contradictory across studies, it is possible that additional nutrients in root crop-based feeds may contribute to improved feed efficiency and growth rates through mechanisms other than visual or olfactory cues. Further research is needed to know the effects of color, smell, and nutrient composition on feed preference and growth performance in tilapia and other aquaculture species.

CONCLUSION

In the present study, Nile tilapia fry fed a diet with 15% sweet potato exhibited the best growth performance and feed efficiency. This indicates that the SP diet promotes optimal growth performance in tilapia fry.

The implication of this study suggests that incorporating sweet potato starch into fish diets can enhance the growth performance of tilapia fry, potentially reducing reliance on more expensive protein sources while maintaining feed efficiency. This could lead to more sustainable aquaculture practices and improved economic viability for fish farmers.

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AUTHOR CONTRIBUTIONS

QDL is the study leader; designed the methodology, supervised the diet formulation, conducted growth trials, reviewed the data, wrote the review and edited the manuscript. MABM is responsible for the write-ups, feed formulation, growth trials, and analyses.

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AVAILABILITY OF DATA AND MATERIALS

Data will be made available upon request.

ETHICAL CONSIDERATIONS

In this study, tilapia (*Oreochromis niloticus*) were used solely for a controlled feeding trial to evaluate growth performance and feed efficiency. No invasive procedures were performed, and no animals were harmed during the conduct of the experiment. All husbandry practices followed the general principles of humane treatment and responsible care, in alignment with the Philippine Animal Welfare Act (RA 8485) and relevant ethical guidelines.

COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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