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Original Article

Feed-nutrients uptake rates of different weight groups of red tilapia (*Oreochromis* sp.) in a recirculating aquaculture system

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Abstract: The role of different weight groups of the red tilapia on nutrient uptake of the feed supply was investigated in a recirculating aquaculture system (RAS). Five weight groups of red Tilapia viz. 20 (20±0.0), 40 (39.7±0.44), 80 (80.38±0.41), 120 (113.62±1.92), and 180 (177.67±1.81) g in triplicate treatments were designed. The studied nutrients uptake rates by red tilapia were significantly different ($P<0.05$) between the treatments. It was found that the red tilapia could assimilate 11.46% Fe, 13.43% Zn, 6.81% Mn, 3.55% Cu, 26.81 Ca %, 20.29% Mg, 32.53% N, 7.16% K and 15.98% P content of the feed supply during three weeks culture period. The specific growth rate (SGR) and food conversion ratio (FCR) indices showed significant differences ($P<0.05$) between the treatments. The highest growth rate was recorded in 120 g treatment. It was concluded that nutrient requirements of the red tilapia are changed in different growth stages.

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Introduction

Fishes show different characteristics on nutrient uptake of the feed supply and metabolic excretions during their life cycle. The feeding habitat, stocking density, feed input rate and water quality effect the assimilation of nutrient by fish (Tacon, 1995; Rafiee et al., 2019). For desirable growth of fish, minerals in the feed supply must be nutritionally balanced, and elements and mineral concentrations in the water and fish body are major biological factor affecting dynamics of nutrient inputs in an aquaculture ecosystem e.g. recirculating aquaculture system (RAS) (Rafiee and Saad, 2005; Rafiee et al., 2019). A factorial deduction is known as the simplest method to determine nutrient requirements of fish; however, it does not comprise the changes in the absorption of the nutrient by fish during different life stages. Hence, the main objective of this study was to evaluate the role of different weight groups of the red tilapia (*Oreochromis* sp.) on nutrient uptake of the feed supply in a recirculating aquaculture system.

Materials and Methods

Five weight groups of red tilapia viz. 20±0.00 (20), 39.70±0.44 (40), 80.38±0.41 (80), 113.62±1.92 (120), and 177.67±1.81 (180) g in triplicate treatments were designed and fish randomly introduced into the experimental units. These weight classes were chosen based on our previous study using same culture system (Rafiee et al., 2002, 2019). It was estimated that the mean individual fish weight in each group would attain to next mean individual weight group after three weeks, for example 20 g fish would grow to 40 g in 3 weeks, thereby, duration of the study was 3 weeks. Each experimental system was a fiberglass tank (110x84x100 cm) equipped with three hydroponic troughs (110x30x5 cm), and a submersible pump (Model Aqua, 1500). A pump was used to circulate the water from the fish tank through the hydroponic troughs, then to fish tank again (Fig. 1). The hydroponic troughs were used to control the penetration of light to the fish tank and reduce algal growth and as a bed for water recycling (providing the

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Table 1. The (Mean±SD) percentage (%) of minerals* (Nutrients) content of the supplementary fish feed.

Growth indices	Concentrations of apple cider vinegar			
	Control	1%	2%	4%
BWI (%)	98.89 ±8.83	101.68±21.45	99.02±59.42	90.47±42.17
FCR	2.53±0.24	2.84±0.44	3.12±0.09	2.4±0.18
SGR (%)	1.64±0.81	1.75±0.35	1.65±0.99	1.50±0.70
CF (%)	1.24±0.38	1.23±0.08	1.30±0.09	1.23±0.95

*Fe (Ferrous), Mn (Manganese), Zn (Zinc), Cu (Cupper), Ca (Calcium), Mg (Magnesium), N (Nitrogen), P (Phosphorous) and K (Potassium).

similar condition to fish in an aquaponic system without plant). At the beginning, each rearing tank was stocked with 75 red tilapias.

Water supply: Each tank was filled with 640 L of water and aerated continuously with two circular air stones (3 L min^{-1}). The characteristics of water supply were followed: aged tap water: pH = 7.17, Ec = 0.16 mmhos, Ca = 5 mg L^{-1}, Mg = 2.5 mg L^{-1}, K = 0.00041 mg L^{-1}, P = 0.00031 mg L^{-1}, Fe = 0.578 mg L^{-1}, Mn = 0.033 mg L^{-1}, Zn = 0.00015 mg L^{-1} and Cu = 0.00013 mg L^{-1}.

Feed and feeding: The feed was a commercial diet floating pellet (Car-gill Company), with 24% protein, 6% fat, 6% fiber and 11% moisture. The fish were fed twice a day *ad libitum* at 09.00 and at 13.30 h. The minerals content of feed was measured before initiation of the study. The characteristics of feed are given in Table 1.

Sampling and water quality measurements: Dissolved oxygen (DO) and water temperature (T) in rearing tanks were measured twice a week (YSI Model 57). electro conductivity (EC) was determined twice a week using EC meter (HANA instrument conductivity meter HI 8033). Two 100 ml of water were sampled from each tank to determine pH using Orion model 410A pH meter. Total ammonia ($NH^{4+}+NH_3$) was measured (taking two samples of water from tanks with 10 times dilution using distilled water) weekly (Parsons, 1984). Nitrite (NO_2^+) was weekly measured (AHPH, 1980).

Fish weight measurement: The individual and biomass of fish were measured at the beginning and end of experiment using gravimetry and correction for water values. Daily growth rate (DGR) feed

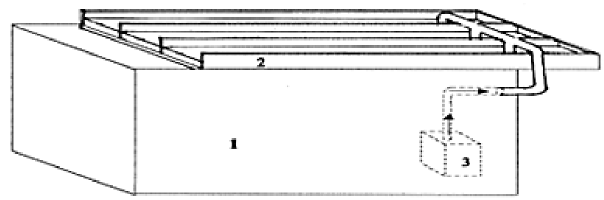

Figure 1. Schematic feature of the used recirculating aquaculture system: 1. the fish tank 2. The hydroponic troughs 3. The water pump (Rafiee and Saad, 2005).

consumption (FC), and feed conversion ratio (FCR) were calculated based on Sirimannaa and Dissanayaka (2019).

Sampling and dry fish weight measurements: Before the experiment, each fish group acclimated with experimental feed for 1 month, 5 fish were sampled and weighted, then cut into the small pieces and were put in a dry dish, then it was put inside an oven at 70°C and dry weight was recorded. The samples were reweighed until getting the fixed weight for each fish sample; this process was also done for fish sample at the end of the experiment (AHPH, 1980).

Nutrient (minerals) content of the dry fish and feed measurements: The dry fish and feed were pulverized and homogenized prior to mineral composition analysis process. A 0.25 g of dry feed and fish flesh (four replicates) were taken and digested by Kejeldahl method (HATCH Company, Cat. No.23130-18, instruction Manual). Then, the volume of digested samples was brought up to 100 ml using distilled water. The concentration of total nitrogen (modified Bertholet method) and phosphorous in each sample was measured using an auto analyzer (Chem lab - System 4). The percentage of elements in dry samples was measured using the following the equation of $A\% = n \times 0.04$; where A is percentage of element and

Table 2. The fish weight (Mean±SD) at the harvest time (FWT), feed conversion ratio (FCR), total feed consumption (TFC), daily growth rate (DGR) and feed consumption (g) per experimental unit per day (FCD).

Fish groups (g)	FWT (g)	FCR	TFC (g)	DGR (g)	FCD (g)
20	44.73±0.53	1.1±0.02^{a}	2025±000^{a}	1.18±0.03^{b}	96.4±0.00^{a}
40	63.02±0.00	1.18±0.05^{a}	2167±670^{a}	1.16±0.04^{b}	103.2±0.30^{a}
80	112.25±6.31	1.18±0.16^{a}	2702±197^{a}	1.52±0.29^{b}	128.63±9.37^{a}
120	172.76±1.11	0.9±0.01^{a}	3579±386^{c}	2.82±0.12^{c}	170.4±18.35^{c}
180	191.26±4.40	3.38±0.92^{b}	2868±282^{b}	0.65±0.18^{a}	136.6±13.40^{b}

Values with the same superscript letters in a column are not significantly different at the 0.05 level.

Table 3. Percentage of mineral (nutrients) composition (Mean±SD) of dry weight of red tilapia sampled at the beginning and end of the experimental period.

Fish groups (g)	Zn (%)	Fe (%)	Cu (%)	Mn (%)	Ca (%)	Mg (%)	N (%)	P (%)	K (%)
beginning									
20	0.0047± 0.00023^{d}	0.0052± 0.0.001^{a}	0.0004± 0.000018^{b}	0.00045± 0.00130^{b}	2.32± 0.24^{a}	0.100± 0.007^{bc}	5.60± 0.220^{a}	1.09± 0.625^{a}	0.19± 0.005^{a}
40	0.0031± 0.00023^{abc}	0.0300± 0.0084^{a}	0.0004± 0.000036^{abc}	0.00053± 0.00023^{a}	2.61± 0.41^{a}	0.102± 0.005^{c}	5.21± 0.222^{a}	1.09± 0.110^{a}	0.19± 0.027^{a}
80	0.0043± 0.00230^{bcd}	0.0320± 0.0055^{a}	0.00040± 0.000100^{c}	0.0004± 0.00020^{a}	2.81± 0.02^{a}	0.091± 0.002^{a}	5.21± 0.170^{a}	1.05± 0.611^{a}	0.18± 0.060^{a}
115	0.0029± 0.00220^{ab}	0.0320± 0.0010^{a}	0.00058± 0.000120^{ab}	0.00013± 0.00023^{a}	2.87± 0.09a^{b}	0.093± 0.004^{ab}	5.17± 1.110^{a}	1.12± 0.141^{a}	0.16± 0.009^{a}
177	0.0032± 0.0000^{abc}	0.0370± 0.0078^{a}	0.00055± 0.000230^{c}	0.0004± 0.00040^{a}	2.60± 0.11^{a}	0.092± 0.004^{ab}	5.21± 0.470^{a}	1.08± 0.130^{a}	0.16± 0.027^{a}
End									
44	0.0033± 0.00023^{abcd}	0.0320± 0.0150^{a}	0.00037± 0.000037^{abc}	0.00065± 0.00024^{a}	2.75± 0.53^{a}	0.980± 0.070^{c}	5.27± 0.860^{a}	1.09± 0.102^{a}	0.19± 0.034^{a}
63	0.0029± 0.00033^{ab}	0.0330± 0.0110^{a}	0.00040± 0.000062^{ab}	0.0007± 0.00023^{a}	2.83± 0.08^{a}	0.101± 0.005^{bc}	5.37± 0.025^{a}	1.26± 0.095^{a}	0.19± 0.036^{a}
112	0.0037± 0.00061^{abcd}	0.0310± 0.0031^{a}	0.00053± 0.000160^{ab}	0.0003± 0.00027^{a}	2.45± 0.27^{a}	0.093± 0.088^{ab}	5.23± 1.260^{a}	1.12± 0.150^{a}	0.18± 0.009^{a}
172	0.0044± 0.00040^{cd}	0.0360± 0.0084^{a}	0.00043± 0.000230^{c}	0.0004± 0.00040^{a}	2.61± 0.32^{a}	0.092± 0.004^{ab}	5.21± 0.470^{a}	1.08± 0.130^{a}	0.16± 0.027^{a}
191	0.0031± 0.00061^{abc}	0.0340± 0.0230^{a}	0.00053± 0.000260^{a}	0.0004± 0.00040^{a}	2.48± 0.31^{a}	0.093± 0.004^{ab}	5.10± 0.250^{a}	1.03± 0.140^{a}	0.16± 0.024^{a}

Values with the same superscript letters in a column are not significantly different at the 0.05 level.

n= auto analyzer reading. The mean feed nutrients accumulated in the body of the fish calculated using the fish growth rate (final mean fish weight - initiation mean fish weight) × A% and extended to the fish biomass considering density of 75 fish per unit of system.

Concentration of minerals in the water: The concentrations of dissolved nutrients in the fish tank was measured weekly by auto analyzers and atomic absorption devices. The unit of measurement was reported in mg L^{-1}.

Data analysis: Percent values were transferred to arc sin values. Data were subjected to One-way ANOVA, significant differences between the means were compared based on Duncan's new multiple range test, and statistical significance were tested at 0.05 level using SPSS (version 10.0).

Results

Fish growth: Growth parameters showed significant differences (P<0.05) between the treatments. The highest growth rate was recorded in 120 g treatment where the fish attained a mean individual weight of 172.8 g with the daily growth rate (DGR) of 2.82 g/day. The feed consumption (FC) in this treatment (3579 g) was higher with a mean feed conversion ratio (FCR) of 0.9, lower than others. The highest FCR and lowest growth rate were recorded in 180 g the treatment with average of 3.38 and 0.65 g/day, respectively (Table 2).

Nutrient content of feed uptaken by red tilapia: Table

Table 4. Average percentage of feed nutrients captured by different weight groups of red tilapia at the end of the experimental period.

Fish groups (g)	Zn (%)	Fe (%)	Cu (%)	Mn (%)	Ca (%)	Mg (%)	N (%)	P (%)	K (%)
20	0.75	10.01	27.21	5.34	34.66	80.85	27.87	14.08	6.85
40	8.33	6.30	30.41	6.04	33.65	4.23	31.22	19.14	7.00
80	9.83	6.18	8.10	0.57	22.10	5.37	36.56	20.36	8.00
120	38.38	11.55	1.37	5.79	33.77	5.98	34.48	19.16	8.59
180	0.015	0.019	0.065	0.02	9.85	5.03	32.53	7.18	5.38

Table 5. Changes in the concentration (Mean±SD) of total phosphorous (P) and magnesium (Mg) in the fish tanks during a 3 -week experimental period.

Treatments (g)		Phosphorus ($mg\ L^{-1}$)			Magnesium ($mg\ L^{-1}$)	
	Week 1	Week 2	Week 3	Week 1	Week 2	Week 3
20	10.55 ± 1.20^{abc}	11.37 ± 0.86^{a}	13.13 ± 1.80^{a}	1.20 ± 0.32^{bcd}	2.33 ± 0.79^{bc}	3.43 ± 1.81^{abc}
40	13.3 ± 3.00^{cd}	14.50 ± 0.70^{a}	16.60 ± 1.10^{a}	1.30 ± 0.40^{abc}	2.80 ± 0.20^{bc}	3.13 ± 1.89^{a}
80	9.71 ± 6.80^{abc}	11.29 ± 3.72^{a}	19.33 ± 4.8^{a}	1.47 ± 097^{ab}	2.67 ± 0.72^{ab}	3.83 ± 0.85^{c}
120	5.00 ± 6.25^{ab}	8.90 ± 1.46^{a}	15.63 ± 1.70^{a}	1.50 ± 0.51^{a}	2.87 ± 0.58^{abc}	3.98 ± 1.96^{bc}
180	2.59 ± 0.70^{a}	5.90 ± 1.00^{a}	18.49 ± 4.01^{a}	1.9 ± 0.98^{d}	12.57 ± 3.03^{c}	4.70 ± 0.17^{c}

Values with the same superscript letters in a column are not significantly different at the 0.05 level.

Table 6. Changes in the concentration (Mean SD) of total calcium (Ca) and potassium (K) in fish rearing tanks during the experiment.

Treatments (g)		Ca ($mg\ L^{-1}$)			K ($mg\ L^{-1}$)	
	Week 1	Week 2	Week 3	Week 1	Week 2	Week 3
20	13.00 ± 2.00^{a}	17.33 ± 1.53^{a}	24.67 ± 1.53^{a}	5.00 ± 1.70^{a}	6.00 ± 1.31	6.40 ± 1.30^{a}
40	14.33 ± 2.10^{a}	18.33 ± 0.58^{a}	27.00 ± 2.00^{a}	4.50 ± 1.00^{a}	6.70 ± 1.70^{a}	6.83 ± 1.80^{a}
80	12.7 ± 1.85^{a}	17.00 ± 2.19^{a}	22.00 ± 3.54^{a}	5.00 ± 1.13^{a}	6.70 ± 1.51^{a}	5.94 ± 1.60^{a}
120	12.67 ± 2.10^{a}	19.00 ± 3.00^{a}	27.00 ± 2.15^{a}	4.00 ± 0.58^{a}	5.20 ± 1.30^{a}	7.00 ± 2.00^{a}
180	15.00 ± 1.17^{a}	16.00 ± 3.93^{a}	24.67 ± 1.86^{a}	4.78 ± 0.21^{a}	6.70 ± 2.90^{a}	8.33 ± 1.20^{0a}

Values with the same superscript letters in a column are not significantly different at the 0.05 level.

3 shows the percentage of nutrient content of red tilapia in different weight groups. The mineral composition in different weight groups indicated that the body weight significantly ($P<0.05$) has affected the assimilation rate of Zn, Cu, Mn and Mg. Mean total feed nutrients uptaken by different weight classes reported in Table 4. The percentage of feed nutrients uptake by fish (20 to 191 g) varied in different treatments.

Water quality parameters: Total ammonia nitrogen ranged 0.73 to 9.66 mg L^{-1}, nitrate-N 0.03 to 9.77 mgL^{-1}**,** total inorganic nitrogen 6.50 to 19.34 mg L^{-1}**,** Ec 0.16 to 0.50 mmhos/cm and pH 7.26 to 5.89 (with a decrease in all treatments) during the experimental period.

Macro-elements concentration: The phosphorus (P) increased in all the treatments during the experiments. After one week, it showed significant differences ($P<0.05$) between treatments. The highest concentration was recorded in the treatment with 20 g fish i.e. P was lower in the treatments with higher weight and it reached to 19.33 mg L^{-1} in 80 g treatment after 2 weeks (Table 5). Mg showed significant differences ($P<0.05$) in all treatments during the experiment. The Mg increased in 80 and 120 g treatments with 10.83 and 11.9 mg L^{-1}, respectively (Table 5). Calcium was not different ($P>0.05$) between treatments and its lowest concentration was measured in 120 g group, and the highest values in 20 and 180 g groups, (24.67 mg L^{-1}). The concentration of K in 80, 120 and 180 g groups increased during the experiment and it was higher (39.33 mg L^{-1}) in 180 g treatment (Table 6).

Discussions

Based on the results, the nutrients uptake by fish per unit (kg) with the same biomass was different in different weight classes, showing that the nutrient requirements of red tilapia changed during its life cycle. It was estimated that the red tilapia on average can assimilate 11.46% Fe, 13.43% Zn, 6.81% Mn, 3.55% Cu, 26.81 Ca %, 20.29% Mg, 32.53% N, 7.16% K and 15.98% P of feed supply during rearing period. The assimilation rate of 32% (Quillere et al., 1993), and 40-43.2% (Siddiqui et al., 1988; El Sayed, 1990) for feed nitrogen reported for the fingerling and breed of tilapia in the conventional system while this was 20% for a male population in RAS without using plant (Suresh and Lin, 1992), 31% with a mixed population (Rakocy et al., 1993) and 37.4% for a male population (Zweig, 1986) and 29% by fish and shrimp (Avnimelech and Ritvo, 2002). It was calculated that averagely 88.54% Fe, 93.19% Mn, 86.57% Zn, 96.44% Cu, 73.19% Ca, 79.71% Mg, 67.47% N, 92.84 % K and 84.02% P of input feed were released to the culture system in the form of faecal material, urine and ammonia gas excretion forms. Other works have reported the rates of 20-40% of feed nitrogen as nitrogen excretion in the form of ammonia-N by fish. If 39.29% of feed nitrogen excreted in the form of ammonia by the red tilapia (Rafiee et al., 2019), a simple calculation shows that 25% of the feed nitrogen remained in the fecal materials as organic nitrogen. The composition i.e. the chemical form in which the minerals are present and the quantity of minerals in feed affect the feed availability to the fish. In this experiment, different weight groups of red tilapia were exposed to constant dietary nutrient input. The results showed that body size (biomass changes or density) affects the assimilation rates of some minerals supplied by the feed.

The levels of Mg in the feed supply have more effect on fish growth when combined with the adequate protein supply and its uptake reaches a higher level when it combined with a low protein supply (Dabrowska et al., 1991). The concentration of Mg in a whole body of carp fed with a diet with protein levels of between 24-34% ranged from 590 to 1000 mg kg^{-1}. An increase in the Mg concentration in the diet can causes more uptake of Mg (Dabrowska et al., 1991). The Mg concentration in the whole body of rainbow trout linearly increases with increasing the Mg content in fish diet and the optimum uptake between 299 to 385 mg kg^{-1} for wet weight of rainbow trout has been reported (Shearer, 1989). The mean concentration of Mg in the diet used in this experiment was 4.240 mg kg^{-1} and its uptake in the whole body as significantly different between treatments ranging 920 to 1010 mg kg^{-1} (dry weight), with the highest level in the 63 g group. Increasing Mg concentration in water led to a significant increase in Mg uptake by rainbow trout, and it depends on dietary Mg supply as well (Shearer and Asgard, 1992). In contrast, the lowest concentration of Mg recorded in the 40 g group (63 g at the harvest time). Based on these results, fish weight affects Mg retention in red tilapia and the Mg content of the diet was at the optimum level for red tilapia growth.

The requirement of fish for phosphorous depends on the fish species, feed composition and form of phosphorous supply. Phosphorous from vegetable feed components has an availability of 20-50% in carp and trout (NRC, 1983). The P concentration in the whole body of rainbow trout increase with an increase in dietary P content, and its concentration in a diet containing 3.4-8.6 g kg^{-1} (dry matter) causing P uptake between 3 to 4.3 g kg^{-1} of body weight (wet weight). The concentration of P in the present work was 11.8 g kg^{-1}, and uptake was measured 9.4 to 12.6 g kg^{-1} (dry weight). The highest concentration was recorded in the 63 g group. The concentration of P in water was significantly different between the treatments, but not significant in weight classes. Comparing these results to the previous work on rainbow trout (Nakamura, 1982), indicates that P requirement of red tilapia is greater. There is a negative linear correlation between calcium content of the diet and the amount of P absorbed by carp (Nakamura, 1982). This relationship in 63 g group can be related to the high concentration of Ca in the water compared to others.

Zn deficiency affects the fish growth rate (Hidalgo et al., 2002). A considerable excretion of Zn via the gills has been reported with faecal Zn excretion, which consists of both unabsorbed Zn and endogenous Zn. An amount of 5 to 20 mg kg^{-1} Zn in the diet is considered for trout and carp (Ogino and Yang, 1978) and that in our experiment was higher (56 mg kg^{-1}). The uptake of Zn in the body of different weight groups ranged 24 to 51 mg kg^{-1} showing significant differences between groups. The Zn in the whole body of rainbow trout has been reported 36 to 120 mg kg^{-1}, when the Zn in the diet and water supply were 1 to 590 mg kg^{-1} and 0.007 to 0.148 mg L^{-1}, respectively (Spry et al., 1988). Zn concentrations in the water linearly increase with an increase in the Zn content of diet and has a high turnover (Wekell et al., 1992). High concentration of Ca-phosphate is considered the reason for the low availability of Zn in diets containing higher fishmeal. The direct addition of different levels of Ca-phosphate resulted in a significant decrease in Zn concentration in the trout (Spry et al., 1988; Scarpa and Gatlin, 1992).

Severe dietary deficiency of the elements such as Cu, Mn, and Fe in the fish is generally resulted a decrease in the growth rates (Ogino and Yang, 1978). Experiments with semisynthetic ratios suggest a diet containing 12-20 mg Mn kg^{-1} to cover the requirements of carp and rainbow trout (Ogino and Yang, 1978). The concentration of Mn in the supplied feed of the current experiment was 30 mg kg^{-1}, higher than the levels suggested for carp and rainbow trout (Ogino and Yang, 1978). The Mn uptake in red tilapia ranged 3 to 7 mg kg^{-1}, higher in 63 g group. The availability of Mn in inorganic compounds differ according to the form of the bond within a compound (Satoh et al., 1987), with use of $MnSO_4$ and $MnCl_2$ showing higher availability than $MnCO_2$ or MnO_2.

The Fe storage in the liver is significantly reduced in the cases of Fe deficiency (Walker and Fromm, 1976). The Fe concentration in the diet was 1090 mg kg^{-1}. The recommended level of Fe in the diet of carp and rainbow trout varies 60 to 50 mg kg^{-1} (Cho and Cowey, 1991). Fe in different treatments was not significantly different, indicating that the high levels of Fe in the diet met the requirements of red tilapia and fish weight was not significantly affected by Fe retention. Reductions in the Fe, Mn, Cu, and Zn may be attributed to chemical interactions leading to precipitation or low concentration of these elements in the waterborne. The concentration of these elements in the different weight groups of red tilapia was higher compared to carp and rainbow trout, indicating higher requirements of red tilapia. As conclusion, it can be mentioned that red tilapia can assimilate 11.46% Fe, 13.43% Zn, 6.81% Mn, 3.55% Cu, 26.81 Ca %, 20.29% Mg, 32.53% N, 7.16% K and 15.98% P content of the feed supply. It was also demonstrated that the nutrient requirements of red tilapia are different during its life stage stages.

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