www.trjfas.org
ISSN 1303-2712
Turkish Journal of Fisheries and Aquatic Sciences 18: 161-166 (2018) DOI: 10.4194/1303-2712-v18_1_18

RESEARCH PAPER

Compensatory Growth Response in *Oreochromis mossambicus* Submitted to Short-Term Cycles of Feed Deprivation and Refeeding

Ndakalimwe Naftal Gabriel[1,*], Edosa Omoregie[1], Tjipute Martin[1], Lesley Kukuri[2], Lahjia Shilombwelwa[2]

[1] Department of Fisheries and Aquatic Sciences, Sam Nujoma Campus, University of Namibia, Henties Bay, Namibia.
[2] Directorate of Aquaculture, Ministry of Fisheries and Marine Resources, Hardap, Namibia.

* Corresponding Author: Tel.: +26464 502651 ; Fax: +26464502608;
E-mail: ngabriel@unam.na

Received 20 September 2016
Accepted 29 May 2017

Abstract

This study was designed to determine compensatory growth response of short-term starvation and refeeding cycles on *Oreochromis mossambicus* juveniles. A total of 360 juveniles were randomly divided into 12 tanks in triplicate groups. The control group (C) was fed three times a day to satiation. The feeding regimes of the other groups were designed as follows: 2 days deprivation /2 days refeeding (2DD2DRF), 2 days deprivation /3 days refeeding (2DD3DRF), and 2 days deprivation /4 days refeeding (2DD4DRF). After 60 days, only fish in 2DD4DRF group presented partial compensatory growth; no significant difference (P>0.05) was observed in the final weight (FW), and specific growth weight (SGR) compared to the control. Hepatosomatic index (HSI), viscerosomatic index (VSI), and condition factor (CF) was not affected by these feeding regimes. Furthermore, improved feed conversion ratio (FCR), and feed efficiency ratio (FER) were observed in 2DD4DRF fish, among groups. Feed intake (FI) was significantly lower (P<0.05) in starved fish compared to C. Meanwhile, muscle crude protein and lipid content in 2DD2DRF, and 2DD3DRF groups was significantly lower (P<0.05) compared to C and 2DD4DRF group. Compensatory growth response in 2DD4DRF presents possibilities for economic optimization in *O. mossambicus* production.

Keywords: Aquaculture; compensatory growth; feed management; tilapia.

Introduction

The sustainability of aquaculture depends on cost effective practices during production period. Feeding practice is one of the practices that need to be optimized in aquaculture, because overfeeding could lead to higher production costs, and water pollution, whereas underfeeding could lead to poor growth performance, and poor economical gain (Eroldogan, Kumlu, & Akta, 2004). In tilapia farming, feed cost constitute about 60-70% of the total production cost (Borski *et al.,* 2011), and this has made it hard to convert the benefits of higher production associated with commercial feed into economic gains when fed fish are fed following traditional practices. In an effort to maximize aquaculture profits, fish farmers have developed various feeding management strategies, which reduce feed inputs (Cuvin-Aralar, Gibbs, Palma, Andayog, & Noblefranca, 2012), reduce water quality problems as well as labor cost (Blanquet and Oliva-Teles, 2010). Some of these strategies include mixed feeding such as alternative commercial pellets with farm-made feed (Akinwole & Faturoti, 2007), and restricted feeding such as feeding by body weight, or feed deprivation and refeeding cycles, with fish normally fed to satiation during refeeding period (Ali, Nicieza, & Wooton, 2003).

Feed restriction is the widely suggested feed management strategy in aquaculture (Yengkokpam *et al*., 2013; Jobling, Meløy, dos Santos, & Christiansen, 1994; Quinton & Blake, 1990; Oh *et al*., 2008). This strategy is believed to take advantage of a phenomena called compensatory growth, which is described as an accelerated growth rate resulting from an appropriate refeeding of the fish after a period of feed restriction or exposure to unfavorable conditions such as low temperature, low oxygen, and reproductive effort (Ali *et al*., 2003). Compensatory growth can be classified as over-compensation (Hayward, Noltie, & Wang, 1997), complete-compensatory (Jobling, Koskela, & Winberg, 1999) or partial compensation (Paul, Paul, & Smith, 1995), and it depends on the species, the duration, and severity of the process (Tian & Qin, 2004).

Despite extensive studies on compensatory growth in fish, equivocal results have been reported. For example, complete compensatory growth was reported in *Lates calcarifer* (Tian & Qin, 2004), over-

© Published by Central Fisheries Research Institute (CFRI) Trabzon, Turkey
in cooperation with Japan International Cooperation Agency (JICA), Japan

compensatory growth in hybrid sunfish (*Lepomis cyanellus* x *Lepomis macrochirus*) (Hayward *et al*., 1997), and no compensatory growth was reported in *Cyprinus carpio* (Schwarz, Plank, Kirchgessner, 1985). Similarly, inconsistent results were documented in tilapia species such as complete compensation in *Oreochromis niloticus* (Cuvin-Aralar *et al*., 2012; Passinato *et al*., 2015), a limited capacity in hybrid tilapia (*O. mossambicus* x *O. niloticus*) (Wang, Cui, Yang, & Cai, 2000; Gabriel, Omoregie, Tjipute, Kukuri, & Shilombwelwa, 2017), and a lack of compensatory growth in *Oreochromis niloticus* (Gao, Wang, Hur, & Lee, 2015). Adequate information is required to explain these inconsistent findings between and among fish species reared under different experimental systems and feeding protocols. Because, compensatory growth is of interest in aquaculture, and an understanding of its dynamics may allow the design of feeding regimes that improve production, save feed cost, labor cost, and reduce water quality problems (Xie, Cui, Yang, & Liu, 1997; Wang *et al*., 2000). Therefore, the aim of this study was to investigate short-term cycles feed deprivation and refeeding effect on growth performance, feed utilization, and muscle composition of *O. mossambicus*. To the best of our knowledge, this is one of the few studies on compensatory growth in *O. mossambicus* that had shorter feed restriction/refeeding cycles, which is demonstrated to be effective at inducing compensatory growth in fish (Tian & Qin, 2004).

Materials and Methods

Fish and Management

The experiment was conducted at Hardap Inland Aquaculture Center in a closed recirculating water system in Namibia, May 2016. The experimental fish *O. mossambicus* with an average body weight of 5.53 ± 0.38g were stocked in cylindrical white polyethylene tanks. They were supplied with 340 L of freshwater at 29.04 ± 0.45℃, pH 8.1 ± 0.47, dissolved oxygen (DO) 5.79 ± 0.37 mgL^{-1} (HACH- HQ40d multiple parameter meter, Inc. USA) with adequate aeration and under natural photoperiod on a commercial diet (38% crude protein, Aquanutro Pty, Ltd., Malmesburry, South Africa), which was administered three times a day (0900, 1300, and 1700), until apparent satiation. 2/3 of the water volume was exchanged bi-weekly to maintain water quality, during acclimatization period.

Experimental Design

Fish were randomly distributed into 12 tanks in 4 triplicates groups at a stocking density of 30 fish /tank, after acclimatization. Fish in group1 (control) were fed everyday, until satiation, and other groups were fed as follows: 2 days starvation /2 days refeeding (2DD2DRF) (15 cycles), 2 days starvation /3 days refeeding (2DD3DRF) (12 cycles), 2 days starvation/4 days refeeding (2DD4DRF) (10 cycles) for 60 days, three times a day (0900: 1300: 1700) until apparent satiation, respectively. This design is a modification of that used by (Urbinati, Sarmiento, & Takahashi, 2014). Furthermore, during the experiment continuous aeration, water recirculation, water temperature 28.8 ± 0.36, pH = 7.8 ± 0.36, DO 6.1 ± 0.31 mgL^{-1}, Ammonia-Nitrogen free and photoperiod 12h light /dark cycle were maintained. Moreover, 60% of the water in all tanks was exchanged bi-weekly with freshwater of similar temperature to maintain the water quality during the study.

Fish Growth, and Feed Utilization Performance

Fish growth was evaluated in terms of final weight (FW), weight gain (WG), specific growth rate (SGR), hepatosomatic index (HSI), viscerosomatic index (VSI), and condition factor (CF). Meanwhile, feed utilization parameters included feed intake, (FI), feed conversion ratio (FCR), feed efficiency ratio (FER), and protein efficiency ratio (PER). Survival was expressed as percentage. Accordingly, 24h after the last experimental feeding body weight and length of all the fish in each tank were measured. Furthermore, liver and gutted weights of three fish from each replicate were recorded, respectively. During the trial, the amount of feed consumed and mortality in each replicate was recorded. Calculations were carried out as previously demonstrated in (Gabriel *et al*., 2015).

Muscle Proximate Composition Analysis

Dorsal muscles (fillets) from three fish in each replicate were collected and stored at -20℃ for proximate composition analysis (moisture, crude protein, crude lipid, and ash). Moisture content was determined by oven drying at 105℃, until constant weight and expressed as percentage (% moisture = wet weight – dry weight /sample weight x 100). Crude protein (nitrogen x 6.25) was determined by the Kjeldahl method (Kjeltec™ 8200, Foss Analytic Co., Ltd., China) and was expressed as percentage. Crude lipid was determined by ether extraction system (Foss, Soxtec, 2043, Foss Scino, Co., Ltd) and was expressed as: % lipid = (weight of residue /weight of the sample taken x 100). Meanwhile, ash was determined by burning the dry samples at 560℃ for 5h and was as well expressed as percentage.

Statistical Analysis

Results for all parameters were expressed as mean ± standard error (M ± SE). Data were analysed using one-way analysis of variance (ANOVA) using statistical package for social sciences (SPSS Inc., USA). Tukey's test was used to determine differences between groups at 95% confidence level (*P* = 0.05).

Results

Growth Performance and Feed Utilization Parameters

Short-term cycles of feed deprivation and refeeding significantly influenced ($P<0.05$) growth performance and feed utilization parameters of hybrid tilapia (*O. mossambicus* x *O. niloticus*) (Table 1). FW, WG, and SGR was lower in feed deprived fish, with significant difference ($P<0.05$) observed in fish submitted to 2 days feed restriction /2 days refeeding cycle (2DD2DRF), and those subjected to a 2 days starvation /3 days refeeding cycle (2DD3DRF) compared to those fed daily, respectively. Meanwhile, no significant difference ($P>0.05$) was observed in FW and SGR of fish subjected to 2DD4DRF cycle when compared to the control. Feed deprivation and refeeding did not significantly affect ($P>0.05$) HSI, VSI, and CF, however somewhat higher values where reported in the control group. Furthermore, FI was significantly lower ($P<0.05$) in feed deprived fish when compared to the control, with 2DD2DRF and 2DD3DRF group presenting the lowest amount among groups. Improved FCR and FER ($P<0.05$) were recorded in 2DD4DRF group, among groups. Furthermore, no significant difference ($P>0.05$) was observed in 2DD4RF group compared to the control. Throughout the trial, no normality was recorded.

Muscle Proximate Composition Analysis

Consecutive feed deprivation and subsequent feeding also had significant effect ($P<0.05$) on some muscle composition parameters of *O. mossambicus* (Table 2). Lower muscle composition parameters were observed in feed deprived fish compared to the control group. Crude fat, and crude protein content was significantly lower ($P<0.05$) in 2DD2DRF and 2DD3DRF fish when compared to the control. No significant difference ($P>0.05$) was reported between 2DD4DRF and control group. Similarly, no significant difference ($P>0.05$) was observed in the moisture and ash content of feed deprived fish when compared to the daily fed ones.

Discussion

The results from the present study demonstrated compensatory growth in *O. mossambicus* during feed deprivation /refeeding cycles. Partial compensatory growth (when fish submitted to feed deprivation and refeeding regime and do not achieve the same body mass as those fed continuously) (Paul *et al*., 1995), was reported in fish that were subjected to 2 days deprivation / 4 days refeeding cycle. In accordance with our study, Christensen and McLean (1998) reported that compensatory growth was also demonstrated in the same fish (*O. mossambicus*). Furthermore, Abdel-Hakim, Abo State, Al-Azab, and El-Kholy (2009) reported a complete compensatory growth in hybrid tilapia (*O. niloticus* x *O. aureus*) starved once and twice a week, respectively. They further indicated that moderate feed deprivation regime (1, and 2 days per week) showed a significant reduction in feeding costs. Moreover, full compensatory growth was reported in Nile tilapia (Passinato *et al*., 2015; Cuvin-Aralar *et al*., 2012; Gao & Lee, 2012); Lates calcarifer (Tian & Qin, 2004) subjected to different feed restriction /refeeding regimes, respectively.

Several studies have shown that fish subjected to severe or longer feed deprivation cycles have shown poor compensatory growth. For instance, in the current study poor growth performance was observed in fish subjected to 2 days feed deprivation /2 days refeeding, and 2 days feed deprivation /3 days refeeding cycles when compared to those fed daily and the ones fed 4 days per week, respectively. Correspondingly, hybrid tilapia juveniles (*O. niloticus* x *O. aureus*) deprived of feed 3 days per week presented poor growth compared to those deprived for 1 and 2 days, respectively (Abdel-Hakim *et al*., 2009). Poor compensatory growth in fish exposed to longer deprivation periods were also reported in Nile tilapia (Gao & Lee, 2012; Passinato *et al*., 2015), *O. mossambicus* (Christensesn & Mclean, 1998), and in other species such as *Centropomus parallelus* (Ribeiro & Tsuzuki, 2010) and *Sparus aurata* (Peres, Santos, & Oliva-Teles, 2011).

Up to date, mechanisms for compensatory growth are poorly understood in fish, despite numerous studies. However, various studies suggested that compensatory growth in fish could be a result of low basal metabolism (Fu, Xie, & Cao, 2005), increased feed intake (hyperphagia) (Xie *et al*., 2001), or improved feed utilization indices such as FCR and FER (Foss *et al*., 2009; Adakli & Tasbozan, 2015) following period of starvation or intermitted feeding. Improved feed utilization parameters has been observed in many fish including hybrid tilapia (*O. niloticus* x *O. aureus*) (Abdel-Hakim *et al*., 2009), Nile tilapia (Passinato *et al*., 2015), and even in shellfish such as *Fenneropenaeus chinesis* (Zhang, Zhang, Li, & Gao, 2010) exposed to feed deprivation and refeeding regimes. Improvement in these parameters is attributed by an increase in digestive capacity of fish during refeeding period as reported by (Bolasina, Perez, and Yamashita, 2006). For instance, enhanced digestive activities were reported in *Labeo rohita* (Yengkokpam *et al*., 2013), and Atlantic salmon (Krogdahl & Bakke-Mckellep, 2005) subjected to feed deprivation and refeeding regimes. Meanwhile, Zhang *et al*. (2010) reported higher protease activities in *F. chinesis* juveniles during refeeding, and noticed improved FER and feed intake parameters and better growth performance compared

Table 1. Growth performance and feed utilization parameters of *Oreochromis mossambicus* subjected to different feeding regimens

	Feeding regimes			
Parameters	Control	2D2RF	2D3RF	2D4RF
FW	33.71 ± 2.79^{b}	19.73 ± 1.18^{a}	21.55 ± 1.28^{a}	27.29 ± 1.33^{b}
WG	28.09 ± 2.94^{c}	14.01 ± 0.94^{a}	16.00 ± 1.32^{a}	22.07 ± 1.23^{b}
SGR	2.71 ± 0.16^{b}	1.87 ± 0.04^{a}	2.04 ± 0.108^{a}	2.50 ± 0.06^{b}
HSI	2.41 ± 0.28^{a}	1.56 ± 0.99^{a}	2.19 ± 0.26^{a}	1.98 ± 0.31^{a}
VSI	2.90± 0.33^{a}	2.20 ± 0.81^{a}	2.98 ± 0.42^{a}	2.45 ± 0.38^{a}
CF	1.85 ± 0.14^{a}	1.76 ± 0.11^{a}	1.79 ± 0.12^{a}	1.83 ± 0.08^{a}
FI	54.67 ± 1.55^{c}	34.37 ± 1.69^{a}	39.97 ± 3.96^{ab}	45.89 ± 1.24^{b}
FCR	1.98 ± 0.19^{a}	2.21 ± 0.08^{ab}	2.00 ± 0.24^{ab}	1.57 ± 0.10^{c}
FER	0.51 ± 0.05^{ab}	0.42 ± 0.01^{a}	0.46 ± 0.03^{ab}	0.65 ± 0.03^{c}
PER	0.64 ± 0.08^{a}	0.41 ± 0.02^{b}	0.47 ± 0.03^{b}	0.59 ± 0.02^{a}
Survival (%)	100 ± 0.00^{a}	100 ± 0.00^{a}	100 ± 0.00^{a}	100 ± 0.00^{a}

[a]Data are expressed as mean ± standard error (M ± SE). Values with different superscript letters in the same row are significantly different (P <0.05) from the control. Where, FW = final weight, WG = weight gain, SGR = specific growth rate, HSI = hepatosomatic index, VSI = viscerosomatic index, CF = condition factor, FI = Feed intake, FCR = food conversion ratio, FER = Feed efficiency ratio, and PER = Protein efficiency ratio.

Table 2. Muscle composition of *Oreochromis mossambicus* reared at different feeding regimens

	Feeding regimes			
Parameters (%)	Control	2D2RF	2D3RF	2D4RF
Moisture	70.00 ± 0.66^{a}	72.75 ± 3.03^{a}	71.30 ± 0.24^{a}	71.72 ± 1.52^{a}
Crude fat	8.82 ± 0.46^{a}	6.09 ± 0.87^{b}	6.97 ± 0.01^{b}	7.82 ± 1.30^{a}
Crude protein	79.60 ± 1.03^{a}	77.25 ± 0.76^{b}	77.95 ± 1.30^{b}	78.63 ± 0.01^{a}
Ash	6.52 ± 0.08^{a}	5.51 ± 0.04^{a}	5.72 ± 0.06^{a}	6.31 ± 0.05^{a}

[a]Data are expressed as mean ± standard error (M ± SE). Values with different superscript letters in the same row are significantly different (P <0.05) from the control.

to the control group. Accordingly, the present study reported lower FCR and higher FER in fish submitted to a 2 days deprivation /4 days refeeding cycle compared to those fed daily. This could be a result of improved digestive enzymes activities during the refeeding period as demonstrated in earlier studies (Yengkokpam *et al*., 2013; Krogdahl & Bakke-Mckellep, 2005). This is also an indication that short-term feed deprivation /refeeding cycles could indeed be a useful tool in reducing feed amount without compromising fish farm production output.

Similar to growth performance and feed utilization parameters, mixed results were obtained for body composition in fish subjected to feed restriction /refeeding regimes. Studies on channel catfish (*Ictalurus punctatus*) (Gaylord & Garlin, 2000), gilbel carp (Xie *et al*., 2001), hybrid stripped bass, *Moronechrysops* x *Morone saxatilis* (Turano *et al*., 2007) failed to report significant effect of feeding management strategies on body composition. However, Adakli and Tasbozan (2015) reported a significant reduction in total fat *decentrarchus labrax* starved for 10 days and refed 40 days when compared to the control (fed daily). Comparably, lower body lipid content in fish subjected to starvation /refeeding regimes were reported in various studies (Tian & Qin, 2004; Oh, Noh, & Cho, 2007; Peres *et al*., 2011; Zhu *et al*., 2001). These findings in part concur with the present study, which presented significantly lower muscle lipid and protein in 2DD2DRF and 2DD3DRF fish compared to the control and those submitted to a 2DD4DRF treatment. These fish were unable to restore lipid and protein content utilized during starvation period to support basal metabolism and survival as explained by (Adakli & Tasbozan (2015). This is an indication that severe or long term feed deprivation /refeeding cycles can result in less fattening and higher energy consumption in fish.

In conclusion, short-term feed deprivation and refeeding cycles had influence on growth performance, feed utilization, muscle composition parameters of *O. mossambicus*, and 2 days deprivation /4 days refeeding cycle appears to be better among deprivation treatment groups. However, further studies on economical aspects, water quality parameters, and physiological responses of fish following feed deprivation and refeeding regimes are deemed necessary.

Acknowledgements

The authors are grateful for the financial assistance and facilities provided by the Ministry of Fisheries and Marine Resources (MFMR), directorate of aquaculture, Namibia. All authors give their sincere thanks to Mr Iyambo Andreas, and Ms. Elizabeth Ndivayele (Onavivi feed manufacturing station) for their technical assistance and provision of facilities for Muscle and feed proximate analysis.

References

Abdel-Hakim, N.F., Abo State, H.A., Al-Azab, A.A., & El-Kholy, F.K. (2009). Effect of feeding regimes on growth performance of juvenile hybrid tilapia (*Oreochromis niloticus* x *Oreochromis aureus*). World Journal of Agricultural Science, 5 (1), 49-54.

Adakli, A., & Tasbozan, O. (2015). The effects of different cycles of starvation and refeeding on growth and body composition on European seabass (*Dicentrarchus labrax*). Turkish Journal of Fisheries and Aquatic Science, 15, 419-427. doi: 10.4194/1303-2712-v15_2_28.

Akinwole, A.O., & Faturoti, E.O. (2007). Biological performance of African catfish (*Clarias gariepinus*) cultured in recirculating system in Ibadan. Aquacultural Engineering, 36, 18-23. http://dx.doi.org/10.1016/j.aquaeng.2006.05.001.

Ali, M, Nicieza, A., & Wooton, RJ. (2003). Compensatory growth in fishes: a response to growth depression. Fish Fisheries, 4(2), 147–190. doi: 10.1046/j.1467-2979.2003.00120.x.

Blanquet, I., & Oliva-Teles, A. (2010). Effect of feed restriction on the growth performance of turbot (*Scophthalmus maximus* L.) juveniles under commercial rearing conditions. Aquaculture Research, 41(8), 1255-1260. doi: 10.1111/j.1365-2109.2009.02416.x.

Bolasina, S., Perez, A., & Yamashita, Y. (2006). Digestive enzymes activity during ontogenetic development and effect of starvation in Japanese flounder, *Paralichthys olivaceus*. Aquaculture. 252(2-4), 503–515. http://dx.doi.org/10.1016/j.aquaculture.2005.07.015.

Borski, R.J., Bolivar, R.B., Jimenez, E.B.T., Sayco, R.M.V., Arueza, R.L.B., Stark, C.R., & Ferket P.R. (2011). Fishmeal-free diets improve the cost effectiveness of culturing Nile tilapia (*Oreochromis niloticus*, *L*.) in ponds under an alternate day feeding strategy. In*:* L. Liping, & K. Fitzsimmons (Eds.), *Proceedings of the Ninth International Symposium on Tilapia in Aquaculture* (pp. 95-101). Shanghai, China, CRSPs., 409 pp.

Christensesn, S.M., & Mclean, E. (1998). Compensatory growth in Mozambique tilapia (*Oreochromis mossambicus),* fed a suboptimal diet. Ribarstvo, 56 (1), 3-19.

Cuvin-Aralar, L.M., Gibbs, P., Palma, A., Andayog, A., & Noblefranca, L. (2012). Skip feeding as an alternative strategy in the production of Nile tilapia *Oreochromis niloticus* (Linn.) in cages in selected lakes in the Philippines. Philippine Agricultural Scientist, 95(4), 378-385.

Eroldogan, O.T., Kumlu, M., & Aktas, M. (2004). Optimum feeding rates for European sea bass *Dicentrarchus labrax* L. reared in seawater and freshwater. Aquaculture, 231(1-4), 501–515. http://dx.doi.org/10.1016/j.aquaculture.2003.10.020.

Foss, A., Imsland, K.A., Vikingstad, E., Stefansson, S.O., Norberg, B., Pedersen, S., … Roth, B. (2009). Compensatory growth in atlantic halibut: effect of starvation and subsequent feeding on growth, maturation, feed utilization and flesh quality. Aquaculture, 290(3-4), 304-310. http://dx.doi.org/10.1016/j.aquaculture.2009.02.021.

Fu, S.J., Xie, X.J., & Cao, Z.D. (2005). Effect of fasting on resting metabolic rate and postprandial metabolic response i *Silurus meridionalis*. Journal of Fish Biology, 67(1), 279–285. doi: 10.1111/j.0022-1112.2005.00723.x.

Gabriel, N.N., Omoregie, E., Tjipute, M., Kukuri, L., & Shilombwelwa, L. (2017). Short-term cycles of feed deprivation and refeeding on growth performance, feed utilization, and fillet composition of hybrid tilapia (*Oreochromis mossambicus* x *O. niloticus*). The Israeli Journal of Aquaculture-Bamidgeh, IJA_69.2017.1344.

Gabriel, N.N., Qiang, J., He, J., Ma, Y.X., Kpundeh, M.D., & Xu, P. (2015). Dietary *Aloe vera* supplementation on growth performance, some haemato-biochemical parameters and disease resistance against *Streptococcus iniae* in tilapia (GIFT). Fish Shellfish Immunology, 44 (2), 504-514. doi: 10.1016/j.fsi.2015.03.002.

Gao, Y., & Lee, J.Y. (2012). Compensatory responses of Nile tilapia *Oreochromis niloticus* under different feed-deprivation regimes. Fisheries and Aquatic Science, 15(4), 305-311. doi: 10.5657/fas.2012.0305.

Gao, Y., Wang, Z., Hur, J-W., & Lee, J.Y. (2015). Body composition and compensatory growth in Nile tilapia *Orechromis niloticus* under different feeding intervals. Chinese Journal of Oceanology and Limnlogy, 33 (4), 945-956. doi: 10.1007/s00343-015-4246-z.

Gaylord, T.G., & Gatlin III, D.M. (2000). Assessment of compensatory growth in Channel catfish, *Ictalurus punctatus*, R. and associated changes in body condition indices. Journal of the World Aquaculture Society, 31(3), 326-336. doi: 10.1111/j.1749-7345.2000.tb00884.x.

Hayward, R.S., Noltie, D.B., & Wang, N. (1997). Use of compensatory growth to double hybrid sunfish growth rates. Transaction of the American Fisheries Society, 126 (2), 316–322. doi: 10.1577/1548-8659(1997)126<0316:nuocgt>2.3.co;2.

Jobing, M., Koskela, J., & Winberg, S. (1999). Feeding and growth of whitefish fed restricted and abundant rations: influences on growth heterogeneity and brain serotonergitic activity. Journal of Fish Biology, 54(2), 437–449. doi: 10.1111/j.1095-8649.1999.tb00842.x.

Jobling, M., Meløy, O.H., dos Santos, J., & Christiansen, B. (1994). The compensatory growth response of the Atlantic cod: effects of nutritional history. Aquaculture International. 2 (2), 75–90. doi: 10.1007/bf00128802.

Krogdahl, A., & Bakke-Mckellep, A.M. (2005). Fasting and refeeding cause rapid changes in intestinal tissue mass and digestive enzyme capacities of Atlantic salmon (*Salmo salar* L.). Comparative Biochemistry Physiolpgy A, 141(4), 450–460. doi: 10.1016/j.cbpb.2005.06.002.

Oh, S.Y., Noh, C.H., & Cho, S.H. (2007). Effect of restricted feeding regimes on compensatory growth and body composition of Red sea bream, *Pagrus major*. Journal of the World Aquaculture Society, 38(3), 443-449. doi: 10.1111/j.1749-7345.2007.00116.x.

Oh, S.Y., Noh, C.H., Kang, R., Kim, C., Cho, S.H., and Jo, J. 2008. Compensatory growth and body composition of juvenile black rockfish *Sebastes schlegeli* following feed deprivation. Fisheries Science, 74(4), 846-852. doi: 10.1111/j.1444-2906.2008.01598.x.

Passinato, B.E., de Magalhaes Junior, F.O., Cipriano, S.F, de Souza, B.H.R, de Lima, S.K., Chiapetti, J., & Braga, T.G.L. (2015). Performance and economic analysis of the production of Nile tilapia submitted to different feeding regime. Supplemento, 36(6), 4481- 4492. doi: 10.5433/1679-0359.2015v36n6Supl2p4481.

Paul, A.J., Paul, J.M., & Smith, R.L. (1995). Compensatory growth in Alaska yellowfin sole, *Pleuronectes asper*, following food deprivation. Journal of Fish Biology, 46(3), 442–448. doi: 10.1111/j.1095-8649.1995.tb05984.x.

Peres, H., Santos, S., & Oliva-Teles, A. (2011). Lack of compensatory growth response in gilthead sea bream (*Sparus aurata*) juveniles following starvation and subsequent refeeding. Aquaculture, 318(3-4), 384-388. http://dx.doi.org/10.1016/j.aquaculture.2011.06.010.

Quinton, J.C.,& Blake, R.W. (1990). The effect of feed cycling and ration level on the compensatory growth-response in rainbow-trout, *Oncorhynchus mykiss*. Journal of Fish Biology, 37(1), 33–41. doi: 10.1111/j.1095-8649.1990.tb05924.x.

Ribeiro, F.F., & Tsuzuki, M.Y. (2010). Compensatory growth responses in juvenile fat snook, *Centropomus parallelus* Poey, following food deprivation. Aquaculture Research, 41(9), 226-233. doi: 10.1111/j.1365-2109.2010.02507.x.

Schwarz, F.J., Plank, J., & Kirchgessner, M. (1985). Effects of protein or energy restriction with subsequent reali-mentation on performance parameters of carp (*Cyprinus carpio* L.). Aquaculture, 48(1), 23–33.

Tian, X., & Qin, J.G. (2004). Effects of previous ration restriction on compensatory growth in barramundi *Lates calcarifer*. Aquaculture, 235(1-4), 273–283.doi: 10.1016/j.aquaculture.2003.09.055.

Turano, M.J., Borski, R.J., & Daniels, H.V. (2007). Compensatory growth of pond-reared hybrid striped bass, *Moronechrysops* x *Morone saxatilis*, fingerlings. Journal of The World Aquaculture Society, 38, 250-261.

Urbinati, C.E., Sarmiento, S.J., & Takahashi, S.L. (2014). Short-term cycles of feed deprivation and refeeding promote full compensatory growth in the Amazon fish matrinxa (*Brycon amazonicus*). Aquaculture, 433, 430-433.

Wang, Y., Cui, Y., Yang, Y., & Cai, F. (2000). Compensatory growth in hybrid tilapia, *Oreochromis mossambicus*×*O. niloticus*, reared in seawater. Aquaculture, 189(1-2), 101–108. doi: 10.1016/S0044-8486(00)00353-7.

Xie, S., Cui, Y., Yang, Y., & Liu, J. (1997). Energy budget of Nile tilapia (*Oreochromis niloticus*) in relation to ration size. Aquaculture, 154(1), 57–68. 10.1016/S0044-8486(97)00039-2.

Xie, S., Zhu, X., Cui, Y., Wooton, R. J., Lei, W., & Yang, Y. (2001). Compensatory growth in the gibel carp following feed deprivation: Temporal patterns in growth, nutrient deposition, feed intake and body Composition. Journal of Fish Biology, 58(4), 99-1009. doi: 10.1111/j.1095-8649.2001.tb00550.x.

Yengkokpam, S., Debnath, D., Pal, A.K., Sahu, N.P., Jain, K.K., Norouzitallab, P., & Baruah, K. (2013). Short-term periodic feed deprivation in *Labeo rohita* fingerlings: effect on the activities of digestive, metabolic and anti-oxidative enzymes. Aquaculture, 412-413, 186-192. doi: http://dx.doi.org/10.1016/j.aquaculture.2013.07.025.

Zhang, P., Zhang, X., Li, T., & Gao, T. (2010). Effects of refeeding on the growth, and digestive enzyme activities of *Fenneropeneaus chinesis* juveniles exposed to different periods of food deprivation. Aquaculture International, 18(6), 1191-1203. doi: 10.1007/s10499-010-9333-8.

Zhu, X., Cui, Y., Ali, M., & Wootton, R.J. (2001). Comparison of compensatory growth responses of juvenile three-spined stickleback and minnow following similar food deprivation protocols. Journal of Fish Biology, 58(4), 1149-1165. doi:10.1111/j.1095-8649.2001.tb00562.x.