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Temperature and feeding on the modulation of ammonia excretion rate of piaussu *Leporinus macrocephalus*

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ABSTRACT. The aim of this study was to evaluate the combined effect of temperature and feeding on ammonia excretion rate in piaussu. Fish (10.3 ± 1.7 g) were acclimated in a RAS and subjected to five different temperatures (15, 19, 23, 27 and 31°C), feeding (twice a day until satiation) and fasting regimens. Nine fish per treatment were individually distributed in tanks and ammonia excretion rate was estimated for up to 24h, at every four hours, for the feeding and fasting treatments. During this period the food consumption was estimated. As expected, the excretion rate of fed animals was generally higher compared to non-fed fish, except for fish maintained at 15°C. Higher temperatures increased excretion from 27°C and forward in fasting treatments. Temperature was directly related to higher food consumption, which in turn was the main responsible for the variability of excretion rate. Postprandial excretion peaks occurred since the first 4 up to 12 h after feeding and were followed by a return to baseline levels after 16 h. Ammonia excretion rate in piaussu is influenced by both temperature and feed, being strongly influenced by the latter. Based on the findings of the present study, the temperature for the rearing of this species should be around 27°C.

Keywords: freshwater fish; metabolism; nitrogen; recirculation system; teleosts.

Temperatura e alimentação na modulação da taxa de excreção de amônia do piaussu *Leporinus macrocephalus*

RESUMO. O objetivo desse trabalho foi avaliar o efeito combinado da temperatura e alimentação sobre a taxa de excreção de amônia do piaussu. Os peixes (10,3 ± 1,7 g) foram aclimatados em um sistema de recirculação de água e submetidos a cinco temperaturas (15, 19, 23, 27 and 31°C), alimentação (duas vezes ao dia até saciedade) e regimes de jejum diferentes. Nove peixes por tratamento foram distribuídos individualmente em tanques e a taxa de excreção de amônia foi estimada até 24 h, a cada quatro horas, para os tratamentos de animais alimentados e em jejum. Durante esse período o consumo de ração foi estimado. Como esperado, a taxa de excreção dos animais alimentados, em termos gerais, foi maior comparada aos peixes não alimentados, exceto pelos peixes mantidos a 15°C. Temperaturas mais altas aumentaram a excreção a partir de 27°C nos tratamentos em jejum. O aumento da temperatura foi diretamente proporcional a um maior consumo de ração, o qual foi o principal responsável pela variabilidade na taxa de excreção. Picos de excreção pós-prandial ocorreram desde as primeiras quatro horas até 12 h após a alimentação e foram seguidos por um retorno aos níveis basais após 16 h. A taxa de excreção de amônia do piaussu é influenciada conjuntamente pela temperatura e alimentação, sendo fortemente influenciada pela última. Baseando-se nos dados do presente estudo, a temperatura de criação para essa espécie deverá ser mantida em torno de 27°C.

Palavras-chave: peixes de água doce, metabolismo, nitrogênio, sistema de recirculação, teleósteos.

1. Introduction

Nitrogen compounds in intensive aquaculture systems are limiting factors in terms of water quality, mainly in the case of ammonia build-up, due to its high toxicity for fish (RANDALL; TSUI, 2002). Ammonia exposure determines several sublethal impacts (BENLI et al., 2008; CHING et al., 2009; DINESH et al., 2013), which may affect growth (SCHRAM et al., 2010; PAUST et al., 2011) and cause death (DONG et al., 2013; KÜÇÜK, 2014).

Ammonia build-up in aquaculture systems is a consequence of gill excretion, which is favoured by a blood-to-water gradient for NH_3 diffusion in fresh water (WILKIE, 2002). Ammonia excretion is an energetically less demanding process compared to the elimination of ammonia in the form of urea (MOMMSEN; WALSH, 1991) and is the main product of protein catabolism for most teleost fish (DABROWSKI, 1986; CHEW et al., 2006).

Ammonia excretion rate is species-specific and is affected by temperature and feeding (JOBLING, 1981; LIED; BRAATEN, 1984; RAMNARINE et al., 1987; HANDY; POXTON, 1993; YAGER; SUMMERFELT; 1993; FRISK et al., 2013). Fish are ectothermic animals, therefore, their metabolic and ammonia excretion rates are directly affected by increases in temperature (FORSBERG; SUMMERFELT, 1992; KIKUCHI et al., 1995; LEUNG et al., 1999). Fish also show an increase in metabolism after feeding (SEGINER, 2008), resulting in increased ammonia excretion rates (ALTINOK; GRIZZLE, 2004).

Quantifying ammonia excretion by fish is important for the design of appropriate systems and the use of adequate maximum densities in rearing and transportation, so that deleterious concentration of ammonia are prevented (ALTINOK; GRIZZLE, 2004). In addition, ammonia excretion data can be used for the assessment of the environmental impact of fish farming activity (WU, 1995; DOSDAT et al., 1996), evaluation of the environmental and nutritional factors on protein turnover (YIGIT et al., 2003; PERSON-LE RUYET et al., 2004) and as an indirect stress marker (KAYALI et al., 2011).

Piaussu *Leporinus macrocephalus* is a native species to Paraguay river basin, and plays an important economic role in sport fishing (RODRIGUES et al., 2006). It is an omnivorous species, presents good growth rate, rusticity and has great potential for fish farming (GARAVELLO; BRITSKI, 1988; SOARES et al., 2000), however, information in literature on the appropriate rearing conditions for piaussu is scarce. The objective of this study was to evaluate the combined effect of temperature and feeding on ammonia excretion rate in piaussu juveniles.

2. Material and Methods

Experimental animals

Juvenile piaussu (10.3 ± 1.7 g) were acquired from a commercial fish farm and maintained for 30 days in a recirculation aquaculture system (RAS) with constant aeration (dissolved oxygen > 7 mg L^{-1}) temperature of 27°C, and fed twice a day until satiation with commercial feed (38% crude protein, 7.5% ether extract). The experiments were approved by the Ethical and Animal Welfare Committee of the Federal University of Rio Grande – FURG (# 23116000632/2015-66).

Experimental design

Ninety fish were individually distributed in tanks (6 L useful volume), with constant aeration, in a static system. Five temperatures (15, 19, 23, 27 and 31°C), feeding and fasting regimens were tested, in a total of 10 treatments (nine fish/treatment). Temperatures were gradually reduced or increased at a rate of 2°C day^{-1} with the aid of an air conditioner and/or heater with thermostat devices. After temperatures were stabilised, fishes were acclimated for seven days to the experimental conditions. Feeding was stopped 24 h prior to the beginning of the experiment. The ammonia excretion rate (TANex) in fasting treatments was estimated only after 24 h of permanence in the tanks. Excretion rate in feeding treatments was estimated every four hours up to 24 h. Animals were fed twice a day (at 9:00 a.m and 5:00 p.m) until satiation with the same feed used during acclimation and the amount of feed consumed (g) was registered. A tank without fish was used as control and maintained under the same conditions for each treatment with a known initial concentration of ammonia after the addition of ammonium chloride (NH_4Cl). The ammonia concentration was measured at the beginning and at the end of the experimental period (24 h) to check consumption/production of ammonia caused by other factors (NERICI et al., 2012).

Water quality analyses

Parameters of water quality (mean ± SEM) were maintained as follows: dissolved oxygen: 8.13 ± 0.18 mg L^{-1} (oximeter, Yellow Springs Instruments YSI DO200A), pH: 7.8 ± 0.018 (pH meter, Hanna Instruments HI 8424), total ammonia: 0.78 ± 0.08 mg L^{-1} (UNESCO, 1983), nitrite: 0.0 ± 0.0 mg L^{-1} (BENDSCHNEIDER; ROBINSON, 1952) and total alkalinity: 70.0 ± 0.82 mg $CaCO_3$ L^{-1} (EATON et al., 1995) were controlled and monitored daily.

Ammonia excretion rate determination

The determination of ammonia to estimate the excretion rate was performed in triplicate. The TANex (TAN mg kg^{-1} h^{-1}) was calculated according to the following formula: TANex = (TAN_F - TAN_0) x V / W x h), where: TAN_F = final concentration of TAN (mg L^{-1}); TAN_0 = initial concentration of TAN (mg L^{-1}); V = volume of water in the tank (L); W = fish weight (kg) and h = hours. The excreted ammonia as a function of the ingested feed (TAN/feed; g TAN kg^{-1}) was calculated as: (TAN_F - TAN_0) x V / FI), where: TAN_F = final concentration after 24 h = TAN (mg L^{-1}); TAN_0 = initial concentration of TAN (mg L^{-1}); V = volume of water in the tank (L); FI = feed intake (kg). The thermal coefficient (Q_{10}) to TANex was calculated for temperature ranges only in fasting treatments, using the formula: $Q_{10} = (TANex_2 - TANex_1)^{10/(T2-T1)}$, where: $TANex_2$ and $TANex_1$ are excretion rates at temperatures T1 and T2, respectively.

Statistical analyses

All data are expressed as mean ± SEM. Data were tested for normality (Shapiro-Wilk test) and homogeneity of variances (Levene's test). When necessary data were transformed (square root or log) accordingly. To evaluate the effect of temperature and feeding on the average daily excretion rate of ammonia, a two-way ANOVA was applied. Postprandial excretion rates within each temperature were submitted to one-way ANOVA. Tukey test was used to check differences among treatments in both cases (SOKAL; ROHLF, 1995). A simple linear regression was performed to investigate the relationship between food consumption and temperature, and a polynomial regression of second order was used to check the relationship between fish excretion rate in fasting treatments with temperature. A multiple stepwise regression analysis was performed to generate a model to explain the excretion rate as a function of temperature and feed consumption, and to verify the relevance of each of the variables in the model. A Student's t test was performed to verify differences between the concentrations of ammonia in control tank. All tests were performed with a minimum significance level of 5% ($p<0.05$).

3. Results

No mortalities were observed throughout the experimental period. Initial and final concentrations of ammonia in control tank were not significantly different.

Fish submitted to fasting treatment of 27°C had significantly lower ($p<0.05$) TANex compared to fish from 31°C treatment and both were significantly higher ($p<0.05$) compared to all other treatments. Fishes at the temperature of 15°C had the lowest ($p<0.05$) TANex among fed treatments. Rise in temperature to 19°C and then to 27°C increased TANex, nevertheless, no differences ($p>0.05$) were observed between 19 and 23°C and 27 and 31°C. Except for the 15°C treatment, TANex was higher ($p < 0.05$) in fed compared to non-fed fish (Figure 1). The calculated Q_{10} values were 7.46 for the range between 23 and 27ºC and 3.25 for the range between 27 and 31ºC.

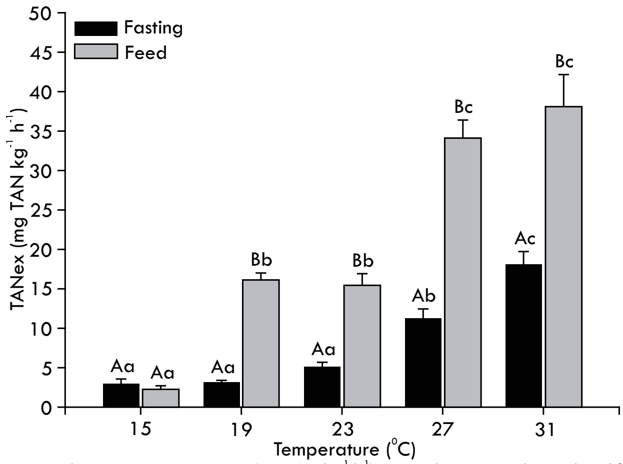

Figure 1. Total ammonia excretion rate (mg TAN kg^{-1} h^{-1}) in juvenile piaussu submitted to different temperatures, fasting regimens (black bars) and fed twice a day (grey bars). Uppercase letters indicate significant differences ($p<0.05$) between fasting and fed fish within the same temperature. Lowercase letters indicate significant differences among different temperatures within the same treatment (fasting or fed fish). / **Figura 1.** Taxa de excreção de amônia (mg TAN kg^{-1} h^{-1}) de juvenis de piaussu submetidos a diferentes temperaturas para os peixes em jejum (barras pretas) e alimentados duas vezes ao dia (barras cinzas). Letras maiúsculas diferentes indicam diferença estatística significativa ($p<0,05$) entre peixes em jejum e alimentados na mesma temperatura. Letras minúsculas diferentes indicam diferença estatística significativa ($p<0,05$) entre as diferentes temperaturas dentro do mesmo tratamento (peixes em jejum ou alimentados).

The polynomial regression model showed a positive relationship between excretion rate and temperature (Figure 2-A), which can be described by the following equation: $y = 0.078x^2 - 2.6326x + 24.813$ ($r^2 = 0.99$). Food consumption showed a positive linear relationship with temperature, described by the equation: $y = 0.02x - 0.28$ ($r^2 = 0.9496$) (Figure 2-B).

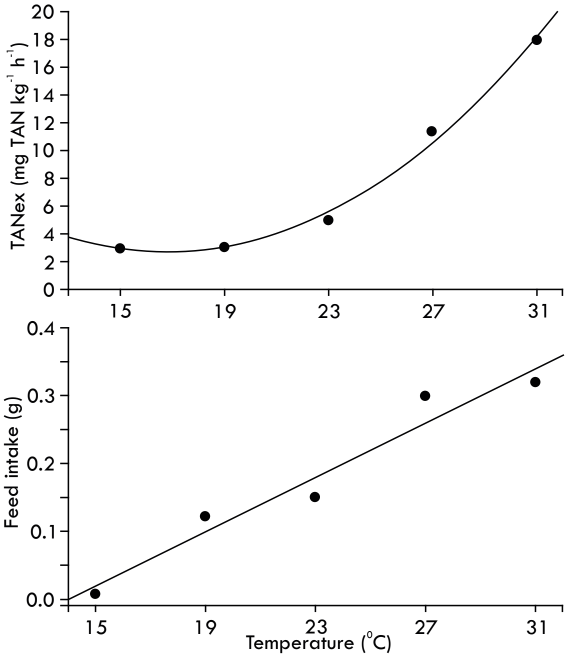

Figure 2. (A) - Ammonia excretion in juvenile piaussu over increasing temperatures. Relation is described by the equation: $y = 0.078.x^2 - 2.6326x + 24.813$ ($r^2 = 0.99$), where y = ammonia excretion (mg TAN kg^{-1} h^{-1}) and x = temperature (°C); (B) - Feed intake of juvenile piaussu over temperature. Data were fitted to the following linear equation: $y = 0.02x - 0.28$ ($r^2 = 0.94$), where y = feed intake (g) and x = temperature (°C). / **Figura 2.** (A) - Excreção de amônia em juvenis de piaussu em função de crescentes temperaturas. Esta relação é descrita pela equação: $y = 0{,}078x^2 - 2{,}6326x + 24{,}813$ ($r^2 = 0{,}99$), em que y = excreção de amônia (mg TAN kg^{-1} h^{-1}) e x = temperatura (°C). (B) - Consumo de ração em de juvenis de piaussu em função da temperatura. Os dados foram ajustados à seguinte equação linear: $y = 0{,}02x - 0{,}28$ ($r^2 = 0{,}94$), em que y = consumo de ração (g) e x = temperatura (°C).

According to the stepwise multiple linear regression model, food intake was the main variable ($r^2 = 0.84$) influencing the excretion rate. The temperature was also included in the analysis, generating a model in which the excretion rate varies in relation to temperature and feed intake according to the equation: $y = -12.03 + (0.8757x) + (72.1881z)$ ($r^2 = 0.9697$) (Figure 3).

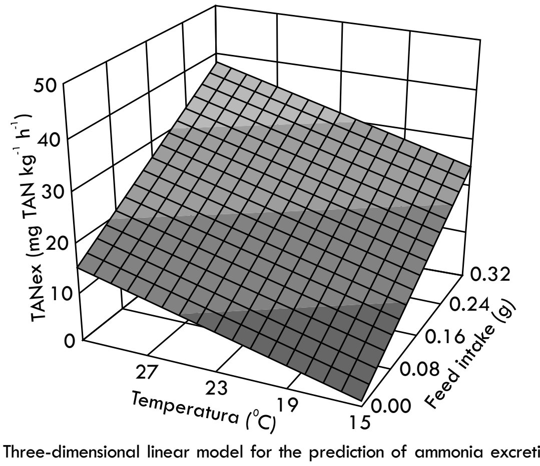

Figure 3. Three-dimensional linear model for the prediction of ammonia excretion rate of juvenile piaussu as a function of temperature and feed intake. Data were fitted to the following equation: $y = -12.03 + 0.8757x + 72.1881z$ ($r^2 = 0.96$), where y = excretion rate (mg TAN kg^{-1} h^{-1}), x = temperature (°C) and z = feed intake (g). / **Figura 3.** Modelo linear tridimensional para predição da excreção de amônia em função da temperatura e ingestão de alimento. Os dados foram ajustados à seguinte equação: $y = -12{,}03 + 0{,}8757x + 72{,}1881z$ ($r^2 = 0{,}96$), onde y = taxa de excreção (mg TAN kg^{-1} h^{-1}), x = temperatura (°C) e z = ingestão de alimento (g).

The TAN/FEED were 30.27 ± 2.35; 22.96 ± 3.01; 24.83 ± 1.15 and 27.1 ± 1.77 g TAN kg^{-1} of feed intake to 19, 23, 27 and 31°C, respectively. There were no significant differences ($p>0.05$) among treatments and since food intake was extremely low, this relation was not calculated for 15°C treatment. In addition, TANex between fed fish and fasting treatments at 15°C was undistinguishable ($p>0.05$).

No differences ($p>0.05$) were observed in excretion rate between sampling times at 15°C. Excretion rate increased ($p < 0.05$) at 19°C from 8-16 h after the first feeding, and a reduction was observed between 16-20 h, returning to baseline levels between 20-24 h. TANex increased ($p<0.05$) from 0 up to 16 h in 23°C compared to fasting levels, being higher between 8-12 h than in the interval of 12-16 h. Fish increased ($p<0.05$) TANex in treatment 27°C between 4-8, 12-16 and 16-20 h compared to baseline profile. At the temperature of 31°C, TANex increased from 0-4 up to 12-16 h compared to baseline levels (Figure 4).

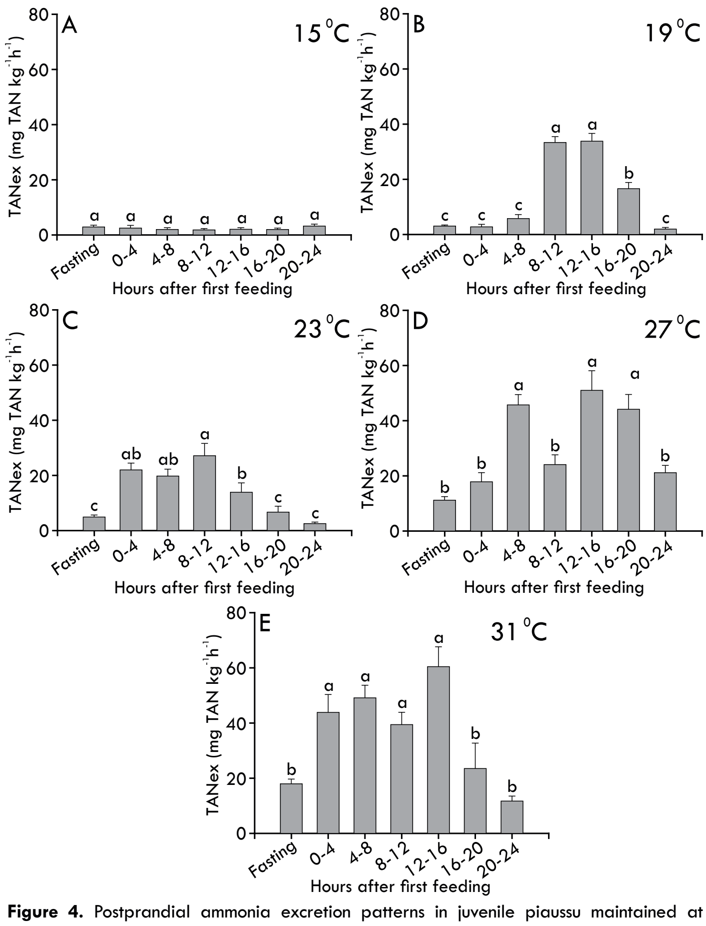

Figure 4. Postprandial ammonia excretion patterns in juvenile piaussu maintained at different temperatures for 24 h. Different letters indicate significant differences ($p<0.05$), n = 9. / **Figura 4.** Excreção pós-prandial de amônia em juvenis de piaussu mantidos em diferentes temperaturas por 24 h. Letras distintas indicam diferenças significativas ($p<0{,}05$), n = 9.

4. Discussion

Excretion rate of ammonia in piaussu varied from 2.92 to 17.98 and from 2.24 to 38.02 mg TAN kg^{-1} h^{-1}. Values found for piaussu ressemble those reported in literature. Zakes et al. (2005) and Nowosad et al. (2013) found values between 1.27 and 21.82 mg TAN kg^{-1} h^{-1} for *Tinca tinca* (L.) in fasting condition. Values ranging from 2.7 to 4.2 TAN kg^{-1} h^{-1} for fasted fish, and from 10.70 to 16.40 TAN kg^{-1} h^{-1} for feeding fish were reported for palm fish *Seriolella violacea* (NERICI et al., 2012). Similarly to our findings, some results have been reported for other fed fish species such as *Tinca tinca* (34.54 mg TAN kg^{-1} h^{-1}) (NOWOSAD et al., 2013), *Epinephelus areolatus* (15.6 mg TAN kg^{-1} h^{-1}) and *Lutjanus argentimaculatus* (23.3 mg TAN kg^{-1} h^{-1}) (LEUNG et al., 1999), and gilthead seabream, *Sparus aurata* (33.3 mg TAN kg^{-1} h^{-1}) (ECHEVARRIA et al., 1993).

The excretion rate of either fed or fasted piaussu was positively correlated to the temperature. The same pattern was observed in other species (LEUNG et al., 1999; ZAKES et al., 2003; PERSON-LE RUYET et al., 2004; NERICI et al., 2012; ENGIN et al., 2013). This increase in ammonia excretion rate may be related to higher metabolic rates at higher temperatures (HANDY; POXTON, 1993), which is partially caused by deamination of ingested amino acids, and also released from muscle proteolysis when fish are starved (FORSBERG; SUMMERFELT, 1992; WOOD, 1993). Protein intake is the most important factor affecting ammonia excretion rate (WOOD, 1993), therefore, fasting is essential for optimal evaluation of the effects of other variables, such as temperature, as shown in the present study. The period of 24 h of fasting used herein is an appropriate time frame to investigate ammonia excretion rate and estimate baseline levels as a result of protein endogenous metabolism (BRETT; ZALA, 1975).

The thermodynamic expression (Q_{10}) calculates the response of biological processes to a change of 10°C in temperature. This standardization allows comparisons among different studies (GILLOOLY et al., 2001) and also investigations on the influence of different temperature ranges on a given variable. The higher the value of Q_{10}, the greater the sensitivity of the biological process in relation to temperature changes (LE et al., 2011). Piaussu was more sensitive to changes in temperature between 23 and 27°C (Q_{10}=7.46) compared to 27 and 31°C (Q_{10}=3.25) interval, indicating a higher homeostasis capacity within the higher range (DIVYA; RANJEET, 2014). In general, the excretion rate of piaussu was strongly influenced by temperature, since Q_{10} values calculated for ammonia excretion of fish are generally lower than 3 (Kieffer and TUFTS, 1996; KIEFFER et al., 1998; ALSOP et al., 1999; GOMES et al., 1999). However, Maetz (1972) reported a Q_{10} = 4 for goldfish (*Carassius auratus*) when abruptly transferred from 16 to 6°C.

Feed intake increased excretion rate (2.1 to 5.3 times at 31°C and 19°C, respectively) in all temperatures compared to excretion rate of fasting fish, except for fish exposed to 15°C, in which feed intake was minimal and only basal metabolism was present. The species *Tinca tinca* (L) had a 1.6-fold increase in excretion rate at 27°C (NOWOSAD et al., 2013) which was similar to that found in fish at 31°C in our study. Similarly, Nerici et al. (2012) observed a 4-fold increase in the excretion rate of palm fish (*Seriolella violacea*) maintained at 19°C compared to non-fed fish held at 14 and 18°C. Previous studies have shown that fish fed to satiation may present excretion rate 10-fold higher than fasted fish (WOOD, 1993; ZAKES et al., 2005).

Piaussu feed consumption was directly influenced by temperature. This enhanced feeding behaviour has been observed in Atlantic halibut *Hippoglossus hippoglossus* (LOHNE et al., 2012), Patagonian blennie *Eleginops maclovinus* (VANELLA et al., 2012), pikeperch *Sander lucioperca* (WANG et al., 2009); Nile tilapia *Oreochromis niloticus* (MOURA et al., 2007) and Atlantic salmon parr *Salmo salar L* (BENDIKSEN et al., 2002) and may be related to the elevation of metabolic rates at higher temperatures (HANDY; POXTON, 1993), as a means to cope with a higher energy demand. Moreover, piaussu is a tropical species, which indicates a presumable preference for higher temperatures between 25 and 28°C. Fish reduce or even cease food intake when water temperature is beyond optimal ranges (SCHIMITTOU, 1993). Temperatures between 26 and 30°C enhanced performance and food intake of piapara *Leporinus elongatus*, whereas feed intake decreased at 14°C (PIANA et al., 2003), which was similar to that behaviour observed for piaussu when submitted to 15°C.

The multiple stepwise regression shows a positive correlation between excretion rate over temperature and food intake, being those factors alone responsible for about 97% of ammonia excretion variability of piaussu. The increased excretion rate in fed fish is likely a result of the direct effect of temperature, which increased metabolic rates and was followed by a higher feed consumption which in turn played a major role in the variability observed (83.8%). These results were rather expected, and as aforementioned, intake of diet protein is the main factor influencing ammonia excretion rate (WOOD, 1993). Nitrogen intake in brook trout *Salvelinus fontinalis* and rainbow trout *Oncorhynchus mykiss* was the main factor influencing ammonia excretion, whereas temperature was less important (PAULSON, 1980).

The estimated ammonia excretion rate in relation to the amount of food intake is also an important tool for the proposal of suitable management practices and appropriate design of production systems (NERICI et al., 2012). Values found for ammonia excretion in this study varied between 22.96 and 30.27 g TAN kg^{-1} of feed, resembling those reported for Atlantic salmon (*Salmo salar L.*) and Arctic charr (*Salvelinus alpinus L.*) (FIVELSTAD et al., 1990), and hybrid tilapia (BRUNTY et al., 1997). However, values between 5 and 12.4, and 2.9 and 4.5 g TAN kg^{-1} of feed were found for *Perca fluviatilis* (ZAKES; DEMSKA-ZAKES, 2002) and palm fish *Seriolella violácea* (NERICI et al., 2012). Therefore, values observed in the present study are rather elevated, indicating that piaussu has a poor utilisation of protein and a high discharge of nitrogen is expected to flow into the production system.

The ammonia excretion rate in relation to the amount of feed intake (TAN/feed) was not affected by temperature changes, which is in accordance with previous reports (MEDALE et al., 1991; ZAKES; KARPINSKI, 1999; FRISK et al., 2013). Although an increased excretion rate over rising temperatures was observed, a considerable increase in feed intake occurred because fish were fed until satiation. However, a study with palm fish fed 1% of biomass at two temperatures (14 and 18°C) demonstrated that this relation might be influenced by temperature (NERICI et al., 2012).

Excretion did not increase only at 15°C, presumably because no feed consumption occurred at this temperature. Increases in excretion rates of fishes maintained at 19°C took longer (8-12 h) to be observed, and were marked by a sharp peak (8-16 h) compared to fasting animals. Engin et al. (2013) and Frisk et al. (2013) reported a similar pattern for *Sander lucioperca* and *Dicentrarchus labrax*, respectively, in which the time required for the occurrence and the intensification of postprandial peaks of excretion was longer in lower temperatures. Temperatures of 23, 27 and 31°C increased excretion rates between 0-4 and 4-8 h after each feeding and no marked peaks were observed.

After the excretion peaks, piaussu excretion returned to baseline levels, which occurred between 8 and 16 h after feeding, with time varying either according to the temperature or the feeding time (first or second), as demonstrated at 27°C. Return to baseline levels was observed 10 hours post feeding for sea bass (*Lates calcarifer*) (ALMENDRAS, 1994). Liu et al. (2009) and Lied and Braaten (1984) found similar values for palmetto bass (*Morone saxatilis* X *M. chrysops*) and Atlantic cod (*Gadus morhua*), in 24 and 25 h, respectively. On the other hand, ammonia excretion in southern catfish (*Silurus meridionalis*) only returned to baseline levels between 53-74 h post feeding (LUO; XIE, 2009). Even long-term ammonia excretion of up to a week long has been observed, as in the case of common carp and rainbow trout (KAUSHIK, 1980).

Therefore, it is recommended a period of at least 16 h of fasting before transportation of piaussu, so that the risk of high ammonia build-up during the procedure is minimized. After this period the excretion rates will have returned to baseline levels. This information may be also useful in open production systems, in which water change could be adjusted to overlap the excretion peaks, therefore minimizing ammonia accumulation in the system. The time gap between piaussu feeding must be from 8 to 12 h, so that the total excretion of the first feeding takes place before the second feeding is offered. Once the overlapping of excretion peaks is avoided, the occurrence of high concentrations of ammonia and mortalities can be prevented (NERICI et al., 2012). According to Wang et al. (2009), short-term postprandial excretion peaks are desirable in aquaculture as they allow for a greater feeding frequency and a faster growth. In this way 27°C is the most suitable temperature for the rearing of piaussu, with faster excretion peaks and resumption of baseline levels occurring both at this temperature. Moreover, at 27°C fish sustain a lower metabolic rate compared to fish exposed to water at 31°C, thus sparing energy and making it available for growth (FRISK et al., 2013).

No information exists in literature as to the ideal temperature for the production of piaussu in aquaculture systems. Results obtained in this study should be used as preliminary data. Since no mortality was observed throughout the experiment, short-term exposure to temperatures between 15 and 31°C is not lethal for this species. However, at 15°C food consumption was affected, indicating a situation of thermal stress. Therefore, temperatures below 19°C should be avoided.

The equation generated from the multiple regression estimates the ammonia excretion rate of piaussu as a function of temperature and feed intake. However, ammonia excretion may be affected by other factors other than temperature and feeding, such as the size of the fish (LEUNG et al., 1999), life stage (GARCIA et al., 2012), stocking density (LIU et al., 2009), pH (SCOTT et al., 2005) and environmental ammonia concentration (ZIMMER et al., 2010). Future studies should be conducted taking into consideration the influence of other variables over the excretion rates of piaussu, to further improve the rearing of this species.

In conclusion, ammonia excretion rate of piaussu is positively influenced by temperature and mostly by feed intake, which in turn is boosted by higher temperatures. Peaks of postprandial excretion occur from 4 up to 12 h after feeding, returning to basal levels in 16 h. The suitable temperature for the rearing of this species should be around 27°C.

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