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Processing traits of European catfish (Silurus glanis Linnaeus, 1758) from outdoor flow-through and indoor recycling aquaculture units

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Abstract :

The quality of fish cultured using recycling units may differ from that of fish from outdoor farming units due to a range of deviating environmental determinants. This applies not only to flesh quality but also to morphological (processing) traits. This study evaluates processing yields of sibling fish cultured in two different farming units: (i) an outdoor pond aquaculture system with a flow-through regime (24.6 ± 0.2°C), and (ii) indoor tanks using a recirculation aquaculture system (RAS; 26.0 ± 1.0°C). Clear differences were observed in the most important processing traits, i.e. skinned trunk and fillet yields, which were both significantly higher ($P < 0.01$) in RAS fish due to significantly smaller ($P < 0.05$) head weight in fish of the flow-through system. Skin represented a significantly higher ($P < 0.01$) proportion of total weight in both RAS males and females. The most obvious difference was in the deposited fat weight, which was significantly higher ($P < 0.01$) in RAS fish. Visceral fat deposits were significantly higher ($P < 0.01$) in females and ventral and dorsal fat deposits higher ($P > 0.05$) in males.

Introduction

The European catfish (hereafter catfish), *Silurus glanis* Linnaeus 1758, is a highly valued fish in Europe and has a very long tradition in European pond aquaculture, having been cultured extensively in temperate region ponds for several centuries. In addition to its high quality flesh, catfish were valued (and in extensive pond aquaculture still are) as a 'police' fish, as they are able to utilise low-value non-commercial fish (especially small cyprinids) and thereby control their overpopulation (Proteau et al. 1996). In open public waters, catfish are considered both as important predators as regards biomanipulation and as a highly-valued sport and trophy fish in recreational fisheries (Randák et al. 2013).

The flesh of catfish is white, boneless and highly palatable, with high processing yield, good flavour and texture and a low amount of fat (Proteau et al. 1996). When compared with the two other aquaculturely important silurids (i.e. channel catfish, *Ictalurus punctatus*, and African catfish, *Clarias gariepinus*), some consumers indicate a clear preference for European catfish based on sensory evaluation alone (Manthey et al. 1988). In the market, catfish are sold whole or whole and eviscerated, cut into skinned steaks or as fillets (skin on or off). Processing may also include smoking (Martin et al. 1995; Fauconneau, Laroche 1996).

The high quality of catfish flesh, its excellent growth performance under high stocking densities, and its ability to ingest pelleted diets has led to its wide utilisation in intensive warm-water farming units, with a consequent increase in its production. Theoretically, the use of recirculating systems for catfish culture should result in higher growth rates as it eliminates the slow rates of growth observed at ambient water temperatures below 10 °C (David 2006). Recent production levels for catfish in France (produced by small-scale enterprises) are presently around 200-300 tonnes (Linhart et al. 2002), which is unlikely to fullfil future market demand. Despite this, catfish have the potential to cater for the increasing demand for fish (and especially fish fillets) caused by the widening gap produced by dwindling wild fish stocks (Tournay 2003).

The quality of catfish raised under different aquaculture production systems has been evaluated in a number of recent studies. Linhart et al. (2002), for example, have published a synthesis of basic culture principles in the Czech Republic and France, while Martin et al. (1995) have summarised data on catfish processing yields, chemical composition and sensory quality. Processing yields and traits have also been reported in contributions by Manthey et al. (1988), Haffray et al. (1998) and Jankowska et al. (2007). These authors accentuate both the quality of catfish flesh, reflected in the consumer's appreciation of the fish as a delicacy, and the catfish's high carcass yield. This study focuses on a comparison of processing yield in market-sized catfish originating from two different small-scale production units (outdoor flow-through and indoor recycling) in the Montpellier region of France.

Material and Methods

Evaluation of processing yields was performed on marketable catfish at age 18 months originating from two different farming units: (1) an outdoor open-pond aquaculture system with a flow-through regime, and (2) an indoor tank aquaculture system utilising a recirculation regime (RAS). The experimental fish in both systems were all siblings originating from a single induced stripping of one female and one male, stocked into both units at an average weight of 28 g. During culture, both flow-through and RAS fish were supplied with a pelleted feed mixture (Ecolife 15No8 Biomar) comprising 45 % protein and 16 % fat.

In the flow-through system (Viviers de la Castillonne, Montagnac, France), 500 fish were cultured in a 50 m^3 (10 x 5 x 1 m) earth pond which resulted in a density of 10 fish per m^3 and a biomass of around 22.3 kg per m^3 over the sampling period. The outflow area of the pond was partly covered with metal roof plates of 2 x 5m, thereby providing shelter for the fish. Water was supplied from a geothermal source (approx. depth 1,500 m, constant temperature 26.4 °C; Ribes and Ribes 1994), the inflow being adjusted to 15 m^3 per hour in order to exchange the entire pond volume once per 3 h 20 min. Water temperature and oxygen concentration were relatively stable throughout the sampling period, amounting to 24.6 ± 0.2 °C and 6.84 ± 0.44 $mg.l^{-1}$, respectively. Fish were fed manually with pelleted feed corresponding to 0.3% of their total biomass per day. In addition, approx. 5,000 ornamental live bearer fish (*Xiphophorus helleri* and *X. variatus*; mean total length (TL) 37 ± 4.6 and 24 ± 9.5 mm, respectively) were also present in the pond at an approximate ratio of 1:6.

The RAS system (IFREMER Experimental Aquaculture Station, Palavas les flots, France) consisted of two 10 m^3 self-cleaning tanks connected by a recirculating water system. Temperature and photoperiod were maintained at a constant 26 ± 1 °C and 4 h of light per day, respectively; pH was maintained at around 7.1 by continuous injection of a sodium hydroxide solution; and pure oxygen was supplied to ensure a minimum concentration of 6.5 $mg.l^{-1}$. Replacement water was added at a controlled flow rate corresponding to 0.75 m^3 per kg of feed supplied. During the experiment, fish biomass varied around 150 $kg.m^{-3}$. Fish were fed 1.2 % of their total biomass per day using disc feeders.

At slaughter, the following variables were measured:

- total length (mm), standard length (SL, mm)
- total weight (Wt, g), eviscerated weight (Wev, g), skinned trunk weight (Wst, g), head weight (Wh, g), fillet weight (two manually prepared fillets with skin, ribs and pelvic basipterygia removed; Wfil, g)
- liver weight (Wl, g), fin weight (Wfin, g), skin weight (Ws, g), gonad weight (Wg, g).

Special attention was given to weight of fat deposits at different locations:

- fat ligaments in the body cavity (mesenteric adipose tissue) – visceral fat weight (Wvif, g)
- adipose tissue on top of the caudal peduncle (intermediate tissue between lateral muscles (*musculus lateralis major*)) – dorsal fat weight (Wdf, g)
- adipose tissue surrounding the anal fin pterygiophores in the caudal peduncle – ventral fat weight (Wvef, g).

The following indices were calculated from the data of fish evaluation:

- viscerosomatic index (VSI) as a percentage of Wev to Wt
- hepatosomatic index (HSI) as a percentage of Wl to Wt
- gonadosomatic index (GSI) as a percentage of Wg to Wt
- condition coefficients (Ct and Cev) as

$Ct = 10^5 * (Wt/SL^3)$ and $Cev = 10^5 * (Wev/SL^3)$, respectively.

In total, 25 fish were evaluated from the flow-through system and 28 from the RAS. The mean initial Wt of females and males was 2117 ± 376 and 2373 ± 535 g in the flow-through system, respectively; and 2460 ± 512 and 2451 ± 589 g in the RAS, respectively (Table 1). Differences in length and weight between males and females in the two systems, and of individual sexes within each system, were not significant ($p > 0.05$). Final processing trait data were calculated as parameters related to Wt. In all cases, one-way ANOVA was applied for statistical analysis, except for the comparison between processing yield of left- and right-hand fillets, for which the paired Student t-test was used.

In addition to processing yield, the stomach contents of all slaughtered fish were evaluated to check for occurrence of natural food items in the diet. Results were evaluated with respect to experimental conditions (intensive culture) as frequency of occurrence $FO = 100 * (n_i/n)$; where n_i is the number of fish with food item i in thei digestive tracts and n is the total number of fish examined.

Results

Processing yield

The viscerosomatic index (VSI) was higher in fish from the RAS compared to fish from the flow-through system, and in males compared to females, though the differences were not significant ($p > 0.05$; Fig. 1). The proportion of skinned trunk to total fish weight ranged between 55 and 60%, being significantly higher ($p < 0.05$) in RAS females compared to females from the flow-through system (59.5 ± 1.7 vs. 57.0 ± 2.1, respectively; Fig. 1). Fillet yields (%) were slightly higher in RAS than in fish from the flow-through trial (45.4 ± 1.9 vs. 41.9 ± 2.3, $p < 0.01$ [females] and 44.8 ± 4.2 vs. 42.2 ± 2.7, $p > 0.05$ [males], respectively; Fig. 1). No significant differences were observed between left- and right-hand fillet (21.9 ± 1.5 and 21.7 ± 1.7, respectively; $p = 0.11$; Fig. 2).

Processing off-products

Catfish heads represented 20.7 to 21.2% of total fish length, and no significant differences ($p > 0.05$) were observed between flow-through system and RAS fish or between males and females. Mean relative head weight (%) fluctuated between 22.3 ± 1.3 and 25.3 ± 1.5 in RAS females and males from the flow-through system, respectively (Fig. 3), resulting in significantly higher ($p < 0.05$) head/body length and weight ratios in fish in the flow-through system.

Relative skin weight in slaughtered fish, representing around 5% of total weight, was significantly higher ($p < 0.01$) in RAS fish (Fig. 3). The relative weight of fins was also higher, though the difference was not significant ($p > 0.05$). Fins were missing or damaged to various extents in 69% of fish from the RAS and only 16% of fish in the flow-through trials. Ventral fins were the most affected (48 and 16% of fish from RAS and flow-through units, respectively), followed by the pectoral (28%), anal (10%), caudal (7%) and dorsal (7%) fins in RAS fish (none of the latter fins were found damaged or missing in fish from the flow-through system).

The proportion of visceral, ventral and dorsal fat deposits as a percentage of total fish weight was significantly higher ($p < 0.05$) in RAS fish compared to fish from the flow-through system trials (Fig. 4), differences being highest in the proportion of ventral fat ligaments, which was 4.0 and 1.8 times higher in RAS females and males, respectively. On average, total fat deposits represented 4.6% in RAS females and 4.7% in RAS males, and 2.5% in females and 2.9% males in flow-through tanks.

Condition coefficients

Average condition coefficients related to total body biomass fluctuated within a very narrow range in all examined fish, with lowest values in males from the flow-through tests (1.05 ± 0.28). Both Ct and Cev coefficients were higher in RAS fish, with no obvious differences between females and males (Table 2).

Gonad development
Female percentage ripeness was considerably higher in the flow-through trials (71%) compared to RAS females (22%). Similarly, mean GSI was higher in flow-through females compared to RAS females (3.86 ± 2.01 vs. 1.55 ± 1.47, $p < 0.01$) and in males of the flow-through tanks compared to RAS males (0.70 ± 0.10 vs. 0.53 ± 0.31, $p > 0.05$). Both absolute and relative fecundity of ripe females, however, were higher in RAS fish (NS, Table 3).

Stomach content
Stomach inspection confirmed that all fish from RAS and from the flow-through system ingested feed pellets. In addition, fish from the flow-through system also ingested detritus (64% FO) and organic debris (36% FO), including plant fragments and filamentous algae (*Vaucheria*, *Spirogyra*, *Chara* and Rhodophyceae). Periphytic diatoms were also observed in the stomach contents of five fish (20% FO). Items of zero nutritional value included small stones (up to 11 mm diameter) and woody debris, which were registered in 36 and 16% of fish, respectively. Additionally, snails (e.g. *Physa* sp.(32%)) and chironomid larvae (4%) were also consumed. Snail numbers ranged from 1 to 78 individuals, all of which appeared to be of relatively uniform size (7.80 ± 0.76 mm, n = 10), though many were present as broken shells only. No fish remains were recorded in the stomach contents of catfish held in the flow-through system.
Pellets, at various stages of digestion, were the only food type recorded in RAS fish stomachs.

Discussion
The adaptability of the catfish enables farming this fish in various types of systems (e.g. as a predator in polyculture, in open warm-water systems (e.g. power plant effluents) and in recirculating systems (Proteau et al. 1996).
As shown by stomach analysis, all fish ingested pelleted food. Catfish of the flow-through system also ingested a proportion of natural food items. Despite the known predatory behaviour of this size of catfish, no fish was observed in the diet, despite being present in high numbers in the pond (~ 100 individuals per m^2).
All the experimental fish, being siblings from the stripping of a single female and male, showed the same growth rate in both culture systems. Catfish in the flow-through units were fed manually, which enabled the person responsible to regulate feeding (intentionally or subconsciously) based on perceived level of satiation (i.e. feeding would stop, or subsequent feeds be reduced, when fish showed no further interest in feeding); RAS catfish, on the other hand, were fed using automated disc feeders. As a result, RAS fish were supplied with a daily feed ration of about four-times greater than that of fish in the flow-through units (1.2 and 0.3% of stock biomass, respectively), indicating a better feed conversion rate under pond conditions.

The better feed conversion rates were also associated with lowered fat deposits in fish from the flow through system (Fig. 4). Note, however, that food conversion rates were not within the original scope of this experiment and, therefore, the causes are speculative as also the feeding level differed between the two systems. For example, factors such as higher stress (under the RAS system?) and/or improved fish welfare (under the flow-through system?) may also account for better food utilisation. Further studies are required to prove this speculative assumption.

According to Fauconneau and Laroche (1996), catfish processing potential is high in terms of mechanisation but rather low in terms of processing yield. Filleting, however, gives added value to the fish and facilitates marketing (Proteau et al. 1996). Our results show that more than half of the fresh fish weight is composed of off-products. The proportion of skinned trunk as a product of catfish processing corresponds to around 60% (58.2-60.0%), thus subsequent losses (fat, bones and associated flesh) due to filleting correspond to about 14.1-18.0%.

For the majority of comparisons, fish from the RAS and flow-through units showed significant differences between the total proportions of final products ($p < 0.05$). Only VSI (eviscerated fish) was similar in both females and males of both systems (Fig. 1). While processing yields (eviscerated fish, skinned trunk, fillet) were significantly higher ($p < 0.05$) for RAS females, differences between males of the flow-through trials and RAS for all final products were insignificant ($p > 0.05$), despite the proportion of final product yield to total weight being higher in RAS fish (Fig. 4). Data from the yield of off-products (Fig. 3), suggests that the main reason for this difference was the significantly larger head of fish in the flow-through system, which was 1.9 % and 2.8% bigger in females and males (both $p < 0.05$). The average total proportion of processing off-products (viscera, head, skin, fins, fat deposits) amounted to 39.0% in PAS females and 37.5% in males of the flow-through system, but only 36.6% (females) and 37.1% (males) in the RAS (differences insignificant [$p > 0.05$] due to high variability in the proportions of individual items). Comparisons of individual off-products between fish from RAS and the flow-through system, however, were mostly significant, with head proportion significantly higher ($p < 0.05$) in the flow-through system fish and proportion of skin and fins significantly higher ($p < 0.01$) in RAS fish. The minimal differences in skinned trunk weight between RAS and PAS fish, therefore, resulted from a higher relative head weight of fish in the flow-through system, which was compensated for by higher relative weight of skin, fins and fat deposits in RAS fish.

Stejskal et al. (2008) undertook a similar study to ours on Eurasian perch (*Perca fluviatilis*). In accordance with our results, the authors found no significant difference between weight of eviscerated perch from the RAS and flow-through system. The relative weight of skinned perch fillets was 0.7% higher in RAS perch ($p > 0.05$) but 3.2% higher ($p < 0.05$) in the RAS catfish in our study. While RAS cultured perch showed a significant increase ($p < 0.05$) in HSI, however, our study showed no significant differences ($p > 0.05$) between the flow-through system and RAS cultured catfish. RAS culture resulted in a significant increase in the proportion of visceral fat and a reduced GSI in both perch (Stejskal et al. 2008) and catfish (our study). These differences were particularly obvious as regards visceral fat, with respective RAS and flow-through values of 2.9 vs. 1.0 in perch and 0.98 vs. 0.29 in catfish (without taking gender into consideration).

Damaged fin condition is a regular phenomenon associated with intensive fish farming (Latremouille 2006). It has been recorded, for example, in rainbow trout (*Oncorhynchus mykiss*; St-Hilaire et al. 2006, Ellis et al. 2009), salmon (*Salmo salar*; Jones et al. 2011), perch (Stejskal et al. 2011), sea bass (*Dicentrarchus labrax*; Person-Le Ruyet, Le Bayon 2009), cod (*Gadus morhua*; Hatlen et al. 2006), and many others, and is usually a result of bacterial infection and/or aggressive behaviour of fish cultured at high densities (e.g. Jobling et al. 1998).

No significant differences ($p > 0.05$) were observed between left- and right-hand fillet weights (Fig. 2), indicating that the skill of the person undertaking the filleting does not affect filleting yield.

Our results support the view that RAS culture methods represent a good means of fish aquaculture that minimises the potentially adverse ecological impacts of intensive aquaculture on the surrounding environment. In addition, it provides opportunities for reducing water usage and improving water management and nutrient recycling (Martins et al. 2010). Operationally, the warm-water RAS system used in this study proved highly suitable for the culture of European catfish, resulting in good processing traits.

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Fig. 1. Processing yields (% fish total weight) in 18-month-old catfish, *Silurus glanis,* from pond (flow-through system; black columns; n♀ = 14, n♂ = 11) and recycling aquaculture systems (RAS; white columns; n♀ = 18, n♂ = 9). VSI = viscerosomatic index, Wst = skinned trunk weight, Wfil = fillet weight. Different small letters and capitals indicate the significance at p<0.05 and p<0.01, respectively.

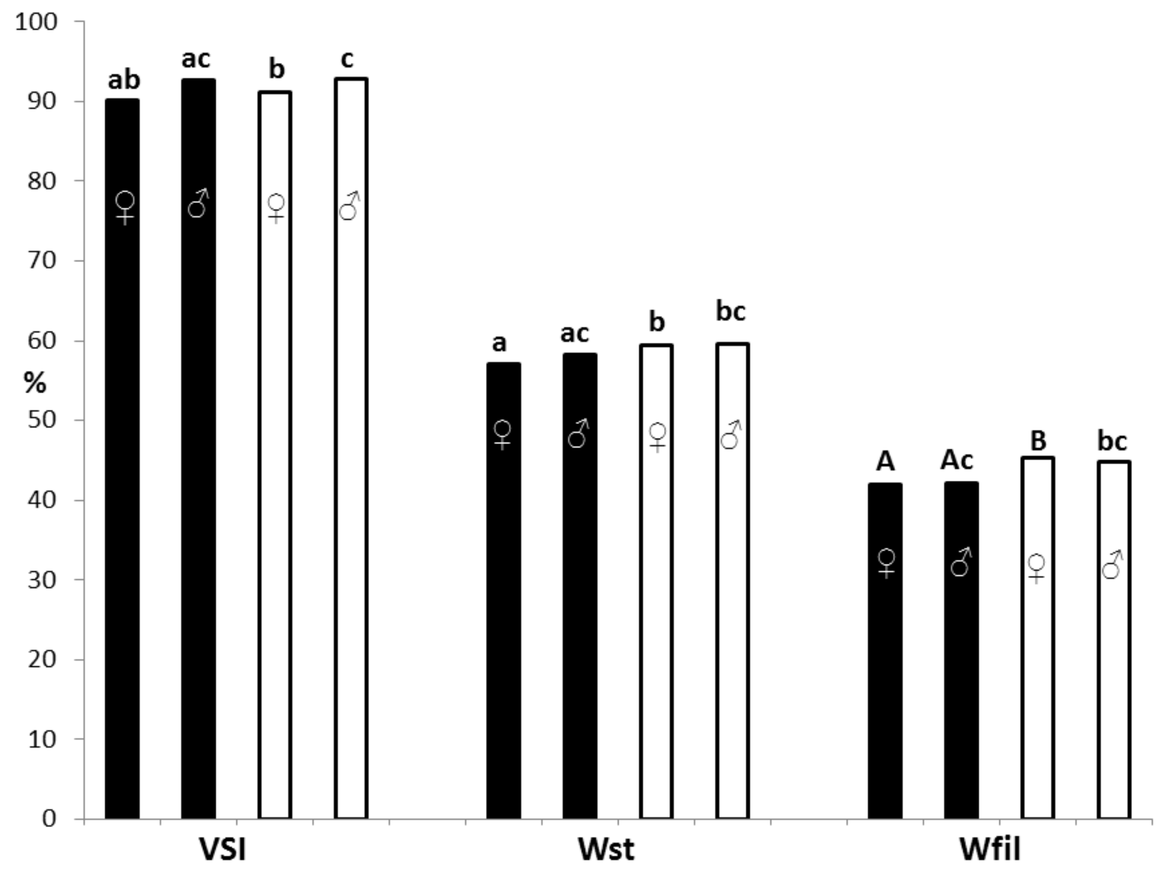

Fig. 2. The relationship between left (LF; dashed line) and right (RF; solid line) fillet weight (Wfil) and total weight (Wt) in 18-month-old catfish, *Silurus glanis*, (n = 52 each) from pond and recycling aquaculture systems.

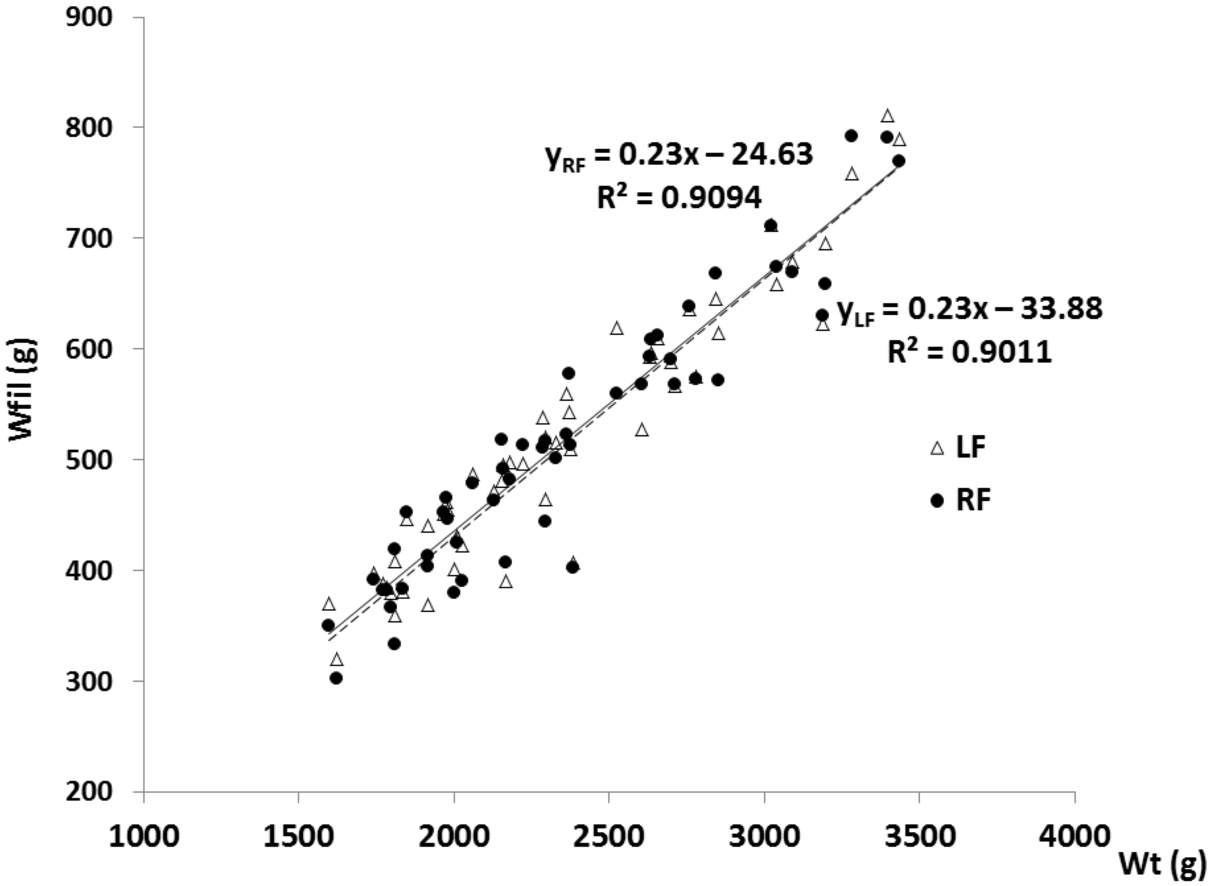

Fig. 3. Mean proportion (%) of processing off-products (weight of head - Wh, weight of skin – Ws, and weight of fins - Wfin) against fish total weight in 18-month-old catfish, *Silurus glanis*, from pond (flow-through system; black columns; n♀ = 14, n♂ = 11) and recycling (RAS; white columns; n♀ = 18, n♂ = 9) aquaculture systems. Note: different small and capital letters indicate significance at $p < 0.05$ and $p < 0.01$, respectively.

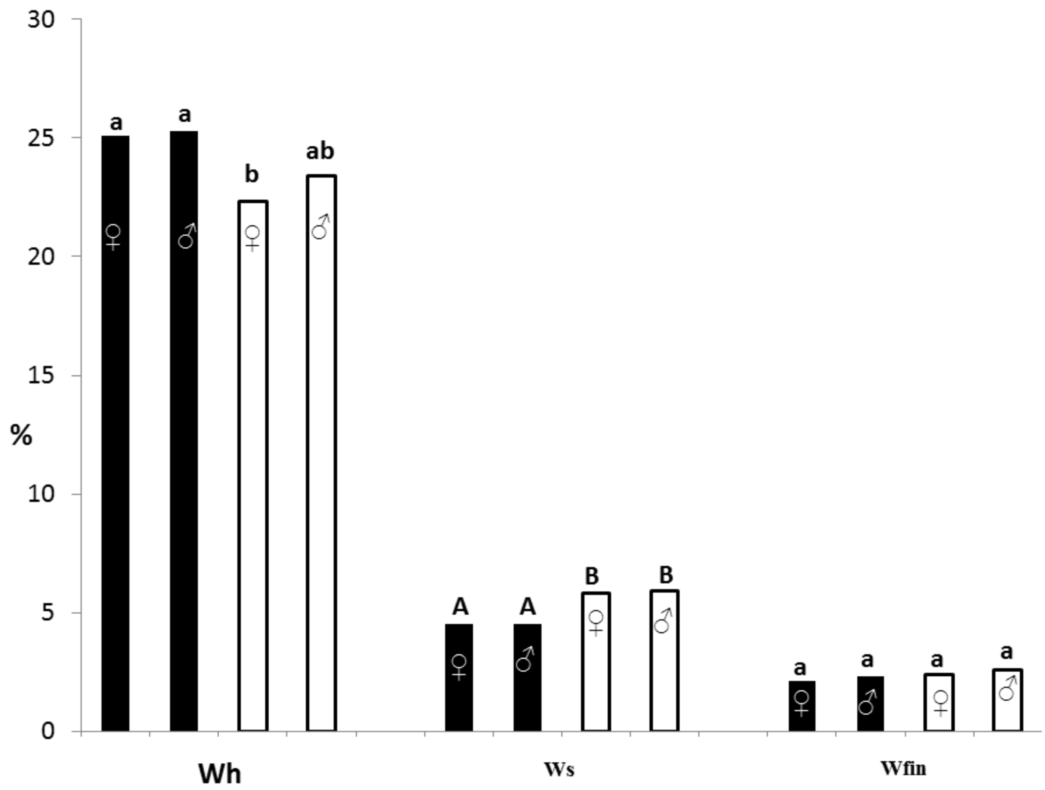

Fig. 4. Mean proportion (%) of fat deposits against fish total weight in 18-month-old catfish, *Silurus glanis*, from pond (flow-through system; dark bars; n♀ = 14, n♂ = 11) and recycling (RAS; white bars; n♀ = 18, n♂ = 9) aquaculture systems. Note: Wvif - visceral fat weight, Wvef – ventral fat weight, Wdf – dorsal fat weight. Different capital letters indicates significance at $p < 0.01$.

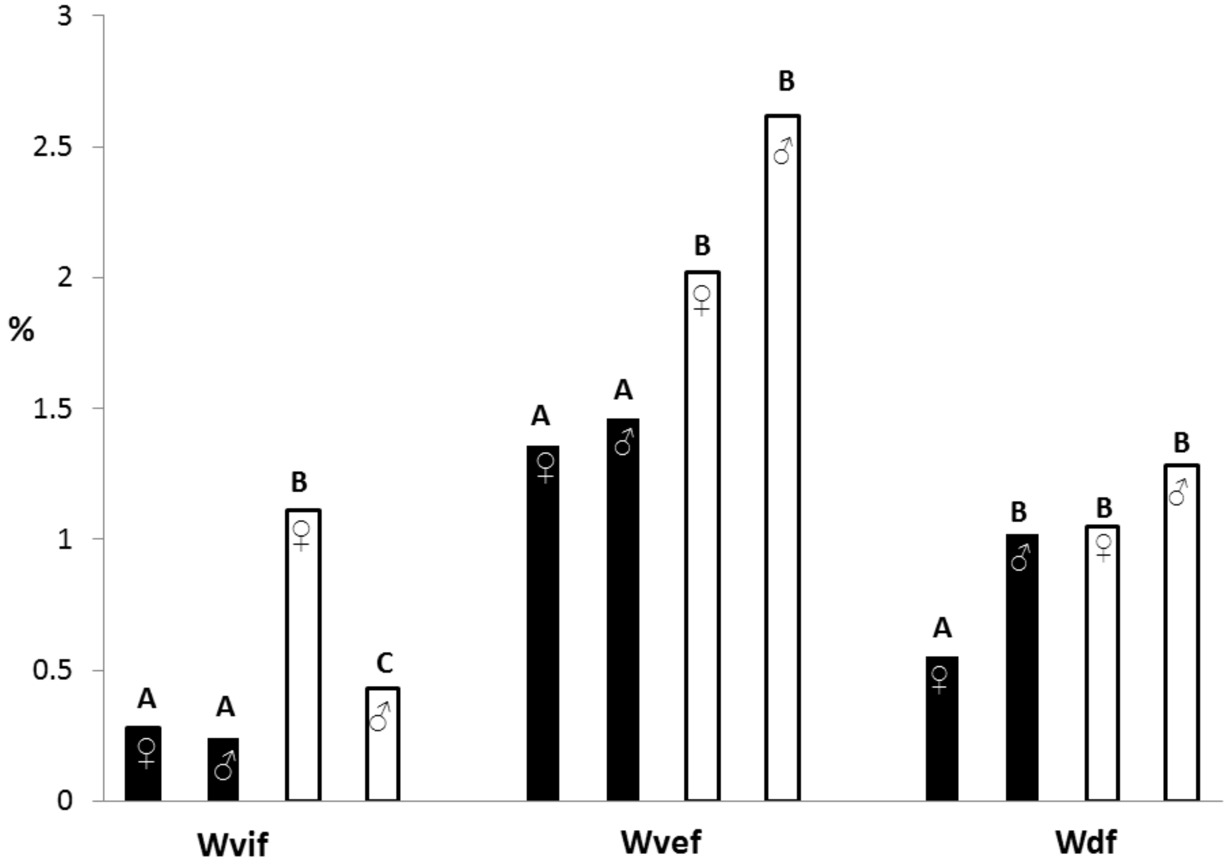

Table 1. Length-weight characteristics of 18-month-old catfish, *Silurus glanis*, (mean ± S.D.) from pond (flow-through system; n♀ = 14, n♂ = 11) and recycling system (RAS; n♀ = 18, n♂ = 9). TL = total length; SL = standard length; W = weight; NS = not significant

Culture system	sex	n	TL (mm)	SL (mm)	W (g)
Flow-through	F	14	645±33	581±30	2,117±376
	M	11	623±174	564±159	2,373±535
	significance		NS	NS	NS
RAS	F	18	655±37	595±37	2,460±512
	M	9	619±199	564±180	2,451 ±589
	significance		NS	NS	NS
Flow-through x RAS	F		NS	NS	NS
	M		NS	NS	NS

Table 2. Condition coefficients (mean ± S.D.) in 18-month-old catfish, *Silurus glanis*, reared in ponds (flow-through system; n♀ = 14, n♂ = 11) and in a recycling system (RAS; n♀ = 18, n♂ = 9). Ct = condition coefficient (whole fish); Cev = condition coefficient (eviscerated fish); NS = not significant

Culture system	sex	n	Ct	Cev
Flow-through	F	14	1.07±0.08	0.97±0.06
	M	11	1.05±0.28	0.97±0.26
	significance		NS	NS
RAS	F	18	1.14±0.11	1.04±0.09
	M	9	1.12±0.10	1.04±0.09
	significance		NS	NS
Flow through x RAS	F		NS	NS
	M		NS	NS

Table 3. Hepatosomatic (HSI) and gonadosomatic (GSI) indices and relative fecundity (RF; 10^3 eggs.kg^{-1}) in *Silurus glanis* cultured for 18 months. Data represent means ± SD from pond (flow through system; n♀ = 14, n♂ = 11) and recycling system (RAS; n♀ = 18, n♂ = 9). Note: NS = not significant, * p < 0.05, ** p < 0.01

system	sex	n	HSI	GSI	RF
Flow-through	F	14	1.11±0.31	3.86±2.01	16.65±1.56 (n=10)
	M	11	1.09±0.32	0.70±0.10	-
	significance		NS	**	-
RAS	F	18	1.11±0.29	1.55±1.47	18.04±5.15 (n=4)
	M	9	0.94±0.14	0.53±0.31	-
	significance		NS	*	-
Flow-through x RAS	F		NS	**	NS
	M		NS	NS	-