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Comparative growth and yield of channel catfish and channel × blue hybrid catfish fed a full or restricted ration

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Abstract

Growth and yield (kg ha^{-1}) of the channel catfish (*Ictalurus punctatus*, Rafinesque, 1818) and the channel × blue hybrid catfish [*I. punctatus* female × *I. furcatus* (Lesueur, 1840) male], which shared the Jubilee strain of channel catfish as the maternal parent, were compared in sixteen 0.1 ha earthen ponds (14 852 fish ha^{-1}) during the April to November growing season. Each fish genetic group was fed a commercially formulated 32% protein feed daily to apparent satiation or at 80% of the mean daily satiation ration. Net yield and individual weight were higher for channel × blue hybrid catfish compared with channel catfish and for fish fed a full ration compared with a restricted ration. When fed a full ration, the channel × blue hybrid catfish grew faster from May to September than did the purebred channel catfish because the hybrid catfish consumed a greater percentage of its body weight at each feeding. Net yield within each fish genetic group was lower when feed ration was restricted. The per cent reduction in net yield in response to feed restriction was similar for each fish genetic group.

Keywords: channel catfish, channel × blue hybrid catfish, feed restriction, growth, yield

Introduction

The channel × blue hybrid catfish [*Ictalurus punctatus* (Rafinesque, 1818) female × *I. furcatus* (Lesueur, 1840) male] was stocked by 2.1% of all foodsize catfish operations in the United States in 2003 (United States Department of Agriculture 2003). Producers increasingly are interested in the channel × blue hybrid catfish because its performance is reported to be superior to that of purebred channel catfish. Greater resistance to *Edwardsiella ictaluri* infection (Wolters, Wise & Klesius 1996), higher tolerance to low dissolved oxygen (DO) concentration (Dunham, Smitherman & Webber 1983) and faster growth (Dunham, Brummett, Ella & Smitherman 1990; Bosworth, Wolters, Silva, Chamul & Park 2004) has been reported for the channel × blue hybrid catfish. However, the channel × blue hybrid catfish has not performed consistently better than the purebred channel catfish. Jiang, Daniels, Pine and Chappell (2008) reported no difference in growth and yield in earthen ponds for two strains of channel catfish compared with their respective hybrid. Because performance of the channel × blue hybrid catfish is affected by parental strain (Dunham, Smitherman & Goodman 1987), individual comparisons between the purebred and hybrid catfish must be performed for commercial strains of channel catfish to provide data to guide decisions on selecting the appropriate fish to stock.

Practical feed recommendations call for feeding catfish over a 20–30-min period to apparent satiation (Robinson, Manning & Li 2004). Restricting feed ration is one strategy considered by fish farmers to economize in a high feed cost environment because feed comprises 50% or more of total variable costs for producing food size catfish (Ligeon, Dunham, Jolly, Crews, Argue, Liu, Yant, Benfrey & Gagalac 2004). Feed restriction was accomplished by limiting daily feeding to a maximum ration or suspending feeding for one or more days each week. Limiting daily feed ration to 60–90 kg ha^{-1}day^{-1} resulted in 10.1–19.4% less net production of channel catfish (Li & Lovell 1992; Munsiri & Lovell 1993; Robinson, Li & Manning 2000). Net production and amount of feed fed did not differ significantly ($P > 0.05$) when channel catfish were fed 6 days week^{-1} instead of 7 days week^{-1} even though net production was 299 kg ha^{-1} lower and 1341 kg ha^{-1} less feed was fed (Li, Robinson & Bosworth 2005). Feeding channel catfish fewer than 6 days week^{-1} lowered net production and feed fed even further (Kim & Lovell 1995; Li, Manning, Robinson & Bosworth 2004; Reigh, Williams & Jacob 2006; Green, Perschbacher & Ludwig 2009). In addition to reduced growth, short-term feed restriction also reduced fillet yield, visceral fat-somatic index and hepatosomatic index (Bosworth & Wolters 2005). Much research on the effect of feed restriction has been conducted with channel catfish, but little information on its effects on the channel × blue hybrid catfish is available.

The objective of this study was to compare growth and yield of channel catfish (CC treatment) and channel × blue hybrid catfish (C × B treatment) that shared a common maternal strain and were fed a full or restricted feed ration.

Materials and methods

Sixteen 0.1 ha earthen ponds located at the Harry K. Dupree Stuttgart National Aquaculture Research Center, Stuttgart, AR, USA, were used for this study, which had a completely randomized design in a 2 × 2 factorial arrangement. Factors tested were genetic group of fish (CC or C × B) and full feed ration (FF) or restricted feed ration (RF).

Ponds were filled with well water in early March 2008. Salt (2268 kg ha^{-1}) was added to each pond to ensure that chloride concentration exceeded 100 mg L^{-1}. On 16 June, one application of 9.1 kg ha^{-1} of triple superphosphate fertilizer (0–46–0) was made to each pond to stimulate an algal bloom; the granular fertilizer was dissolved in pond water before application. Well water was added to ponds as required to replace losses to evaporation and seepage.

Ponds were stocked with fingerling channel catfish or channel (female) × blue (male) hybrid catfish, both from the 2007 year class. The Jubilee strain of channel catfish was used as the maternal parent for both pure-line and hybrid fingerlings; the D&B strain of blue catfish was used as the paternal parent for production of the hybrids. At stocking, the mean individual weight of each genetic group of fingerling was determined by weighing five counted samples (47–174 fish sample^{-1}). The number of fish stocked per pond (mean = 14 852 fingerlings ha^{-1}) was calculated by dividing the total weight of fingerlings stocked by the mean individual weight. Channel × blue hybrid catfish fingerlings (mean = 64.1 g fish^{-1}) were stocked into ponds on 13 March 2008. A prolonged period of inclement weather impeded access to fingerling ponds and delayed stocking of the CC fingerlings (mean = 73.3 g fish^{-1}) until 8 April 2008. The larger CC fingerling was stocked intentionally in an attempt to match the estimated size of C × B fingerlings. The CC fingerlings were allowed 3 weeks after stocking to acclimate to pond conditions. During the acclimation phase, all fish were fed a 32% protein floating feed.

The FF and RF treatments were implemented beginning 28 April 2008. Channel catfish and channel × blue hybrid catfish in each replicate FF treatment pond were fed as much 32% protein floating feed, as they would consume in 20 min and the quantity was recorded. The mean feed consumption for each genetic group in the FF treatment was calculated each day and then multiplied by 0.8 to calculate that day's RF treatment feed ration for each genetic group. The calculated daily RF treatment feed ration was applied to all replicate ponds within each genetic group. The daily feed rate expressed as a percentage of biomass was calculated for each pond as the daily feed ration divided by the estimated fish biomass on that day. Daily fish biomass was estimated by interpolation for each pond based on stock out, sample, harvest and mortality data.

Fish in each pond were sampled by seine net on five occasions during the experiment to monitor growth. Fish growth was sampled first on 6 May 2008. At least 200 randomly selected fish per pond were weighed on each sample date. Groups of 15–25 fish were counted into a tared bucket of water, weighed to the nearest 0.01 kg (Model MSI-6000, Measurement Systems International, Seattle, WA, USA), and returned to the pond. Fish were not fed the day before and the day of sampling.

Dissolved oxygen concentration and water temperature in each pond was monitored continuously by a galvanic oxygen sensor (Type III, Oxyguard, Birkerød, Denmark) and thermister (Model 109, Campbell Scientific, Logan, UT, USA) connected to a datalogger (Model CR206, Campbell Scientific). Each pond was equipped with an electric paddlewheel aerator (5.6 kW ha^{-1}; Big John Aerators, Quinton, AL, USA) that was activated when DO concentration declined below 4.25 mg L^{-1}.

Water samples were collected from ponds between 07:00 and 08:00 hours with a 90 cm column sampler (Boyd & Tucker 1992). Samples were collected biweekly from mid-May to mid-June and weekly thereafter. They were placed in a cooler on ice and transported to the laboratory where analyses began immediately. Sample pH was measured electrometrically. Nitrite-nitrogen (NO_2-N, diazotization), nitrate-nitrogen (NO_3-N, cadmium reduction), total ammonia-nitrogen (TAN, salicylate method) and soluble reactive phosphorus (ascorbic acid method) were analysed using flow injection analysis according to the manufacturer's instructions (FIAlab 2500, FIAlab Instruments, Bellevue, WA, USA). Chlorophyll *a* was extracted in 2:1 chloroform:-methanol from phytoplankton filtered from samples using a 0.45 μm pore size glass fibre filter, and concentration in the extract was determined by spectroscopy (Lloyd & Tucker 1988).

Ponds were harvested from 17 to 20 November 2008. Each pond was seined twice to capture as many fish as possible. One replicate pond per treatment was harvested each day. Each pond was drained after seining and any remaining fish were collected and weighed *en masse*. The total weight of fish harvested in each pond was recorded. The number of fish harvested per pond was the quotient of the total fish biomass divided by the mean individual weight. Feed conversion ratio (FCR) was calculated for each pond as the total quantity of administered feed divided by the sum of the net total yield. At least 150 fish were selected at random from each pond and weighed individually and a random sub-sample of 10 fish from this group was collected for determination of body compositional indices and muscle composition by selecting every 15th fish during individual weighing. Body compositional indices included the following measures:

$$\text{Hepatosomatic index (HSI)} = \text{liver mass} \times 100/\text{fish mass}$$

$$\text{Intraperitoneal fat (IPF) ratio} = \text{intraperitoneal fat mass} \times 100/\text{fish mass}$$

$$\text{Muscle ratio (MR)} = \text{skin-off fillet yield with ribs} \times 100/\text{fish mass}$$

Muscle samples from the above procedure were frozen for the later determination of proximate composition according to the standard methods [Association of Official Analytical Chemists 2000; American Oil Chemists Society (AOCS) 2009]. Frozen muscles were sectioned and passed through an industrial meat grinder. Ground sections were pooled for each fish and thoroughly mixed. This process was repeated two additional times before aliquots being taken for analysis. Briefly, protein ($N \times 6.25$) was determined by the Dumas method using a LECO nitrogen analyzer (FP428, LECO, St Joseph, MI, USA). Total energy was determined by isoperibol bomb calorimetry (Parr1281, Parr Instrument, Moline, IL, USA). Muscle lipid was determined by gravimetric quantification following petroleum ether extraction (AOCS 2009; method AM 5-04) in an ANKOM XT15 lipid extractor (ANKOM Technology, Macedon, NY, USA).

Fish production data were analysed by mixed models analysis of variance, mixed models repeated measures analysis of variance with compound symmetry covariance structure and linear regression analysis using SAS version 9.1.3 (SAS Institute, Cary, NC, USA). Differences among least squares means were evaluated using the DIFF option with the Tukey adjustment of *P* values in SAS. Per cent data were arcsin transformed before data analysis (Sokal & Rohlf 1995). Fish growth was evaluated in two ways because of the differences in size between genetic groups at stocking. Firstly, fish growth was evaluated by regression analysis of natural logarithm-transformed data between the 6 May and 24 September 2008 growth samples, a period when fish in all treatments were growing rapidly. Secondly, the regression equation proposed by Jobling (1983) with modifications for channel catfish by Silverstein, Wolters and Holland (1999) was used for the current experiment to compare the intercept, *a*, which represents the $\log_e$ specific growth rate at unit size. The RANK and GLM procedures (SAS version 9.1.3) were used to analyse the values of *a* derived for each treatment. Differences were declared significant at $\alpha = 0.05$.

Results

Production variables were affected independently ($P < 0.05$) by fish genetic group and feed ration (Table 1). Mean gross (12 047 kg ha^{-1}) and net (11 095 kg ha^{-1}) yields from ponds stocked with the channel × blue hybrid catfish (C × B treatment) were greater than those (9964 and 8876 kg ha^{-1} respectively) from ponds stocked with channel catfish

Table 1 Least squares mean and standard error (SE) gross and net yields (kg ha^{-1}), fish weight (kg fish^{-1}), survival (%), total feed (kg ha^{-1}), feed conversion ratio (FCR) and the intercept, *a*, for channel catfish (CC) or channel × blue hybrid catfish (C × B) grown in ponds from March/April–November

Genetic group	Feed ration	Gross yield	Net yield	Fish weight	Survival	Total feed	FCR	Intercept *a**
Main effects								
CC	FF	10 566	9478	0.76	93.1	13 758	1.45	2.28
	RF	9361	8274	0.65	96.7	11 181	1.35	2.16
C × B	FF	13 010	12 059	0.87	100.0	18 322	1.52	2.32
	RF	11 084	10 130	0.81	92.4	14 840	1.47	2.26
Pooled SE		280	274	0.03	2.5	306	0.03	0.03
Main effects means								
Genetic group	CC	9964	8876	0.71	95.1	12 469	1.40	2.22
	C × B	12 047	11 095	0.84	96.6	16 581	1.49	2.29
Feed ration	FF	11 788	10 769	0.82	97.0	16 040	1.49	2.30
	RF	10 223	9202	0.73	94.7	13 010	1.41	2.21
Pooled SE		198	194	0.02	1.8	216	0.02	0.02
ANOVA, $P > F$								
Genetic group		<0.001	<0.001	0.001	0.556	<0.001	0.004	0.023
Feed ration		0.001	<0.001	0.009	0.381	<0.001	0.010	0.013
Genetic group × feed ration		0.222	0.210	0.405	0.031	0.165	0.404	0.269

*Calculated from $\log_e G_w = a - 0.371 \times \log_e W_m$, according to Silverstein *et al.* (1999).
Fish in the FF treatment ponds were fed as much floating feed (32% protein) as they would consume in 20 min and those in RF treatment ponds were fed 80% of that day's mean FF feed consumption by genetic group ($N = 4$).

(CC treatment). Average individual weight of C × B (0.84 kg fish^{-1}) also was greater than that of CC (0.71 kg fish^{-1}). The intercept value, *a*, was greater for the C × B (2.29) than for the CC (2.22). The FCR for the CC treatment (1.40) was less than that for the C × B treatment (1.49). Likewise, gross and net yields (11 788 and 10 769 kg ha^{-1} respectively) from ponds fed the full ration (FF treatment) were greater than those (10 223 and 9202 kg ha^{-1} respectively) from ponds fed the restricted ration (RF treatment). Moreover, fish fed the full ration were larger (0.82 kg fish^{-1}) at harvest than fish fed the restricted ration (0.73 kg fish^{-1}). The intercept value, *a*, for fish fed the full ration (2.30) was greater than for those fed the restricted ration (2.21). The FCR for the RF treatment (1.41) was lower than for the FF treatment (1.49). No significant interaction was detected for any production variable between genetic group and feed ration treatments except for survival, which likely was an artifact of the analysis and reflected the opposite directions of the data trend between fish genetic groups.

Although the fish genetic group × feed ration interaction was not significant for production variables, examination of differences among specific genetic group × feed ration least squares means can be informative (Littell, Milliken, Stroup, Wolfinger & Schabenberger 2006). There was strong evidence that gross and net yields for the C × B-FF treatment ($P = 0.0002$ and $P = 0.0001$ respectively) differed from those for the CC–FF treatment. However, there was only some evidence ($P = 0.0809$) of a difference in mean individual weight at harvest between the C × B-FF and CC–FF treatments despite the fish in the C × B-FF treatment being 14.5% larger. There was no evidence that the intercept values, *a*, differed ($P = 0.3260$) between the C × B-FF and CC–FF treatments. In addition, there was no evidence of differences between the C × B-RF and CC–FF treatments for gross ($P = 0.5755$) and net ($P = 0.3726$) yields, individual weight at harvest ($P = 0.6983$), and the intercept value, *a* ($P = 0.8411$). Within the CC treatment, there was some evidence for a difference in gross ($P = 0.0440$) and net ($P = 0.0392$) yields and mean individual weight at harvest ($P = 0.0655$) between the RF and FF treatments, but not for the intercept value, *a*, ($P = 0.8411$).

The percentage of fish ≥ 0.68 kg fish^{-1}, considered a minimum market size by many processing plants, averaged 75.2%, 68.4%, 64.3% and 49.3% for the C × B-FF, CC–FF, C × B-RF and CC–RF treatments, respectively, at harvest. At a slightly lower market size, fish ≥ 0.54 kg fish^{-1} comprised 92.7%, 86.8%, 86.5% and 77.2% of the C × B-FF, C × B-RF, CC–FF and CC–RF treatment fish populations respectively.

Fish grew rapidly in all treatments until late September when growth slowed. Mean weight did not differ among treatments at the May sample. In September, fish in the C × B treatment (0.78 kg fish^{-1}) were larger than those in the CC treatment (0.59 kg fish^{-1}). Similarly, fish in the FF treatment (0.73 kg fish^{-1}) were larger than those in the RF treatment (0.65 kg fish^{-1}). Regression analysis showed that fish growth from May to late September was faster in the C × B-FF treatment ($R^2 = 0.980$) than in the CC–FF treatment ($R^2 = 0.978$). By late September, fish in the C × B-FF treatment averaged 0.82 kg fish^{-1}, larger than fish in the CC–FF treatment, which averaged 0.64 kg fish^{-1}. Growth rate during the late September to November period differed only between genetic groups; fish in the CC treatment (2.0 g day^{-1}) grew faster than fish in the C × B treatment (1.0 g day^{-1}). Results of regression analysis showed no significant difference in fish growth between the CC–FF ($R^2 = 0.943$) and C × B-FF ($R^2 = 0.912$) treatments when calculated from May to November.

Throughout the experiment, C × B consumed more feed, as a percentage of biomass, than CC. Mean daily feed consumption (% biomass) was significantly greater (12–45% higher) for C × B-FF than for CC–FF from May through mid-June, with the exception of 1 week in May. Fish in the C × B-FF treatment continued to consume 5–10% more feed daily (% biomass) from mid-June through mid-September, but the differences were not statistically significant. After that, fish in the CC–FF treatment consumed 11–593% more feed daily (% biomass); a significant difference was detected only during 1 week in October.

Mean daily feed consumption (% biomass) by fish in the FF treatment was inversely related to mean individual weight (Fig. 1). Feed consumption ranged from 3.3% to 3.7% biomass day^{-1} for fish of 0.1 kg average weight to 1.5–1.6% biomass day^{-1} for fish that average 0.6–0.7 kg. Regression analysis showed that for similar sized fish, C × B consumed more feed (% biomass day^{-1}) than CC as indicated by the absence of a difference between slopes, but a greater intercept for the C × B. Additionally, the C × B consumed more total feed (16 581 kg ha^{-1}) than the CC (12 469 kg ha^{-1}). Fish in the FF treatment consumed a mean of 16 040 kg ha^{-1} feed during this experiment, greater than the 13 010 kg ha^{-1} feed consumed by fish in the RF treatment. Daily feed consumption increased in FF treatment ponds through early August and began to decrease during the later half of September as pond water temperature declined (Fig. 2). Mean daily feed consumption exceeded 110 kg ha^{-1} only during August for the CC–FF treatment and from July through September for the C × B-FF treatment. Maximum daily feed consumption by fish in the CC–FF (196 kg ha^{-1}) and C × B-FF (218 kg ha^{-1}) treatments occurred during

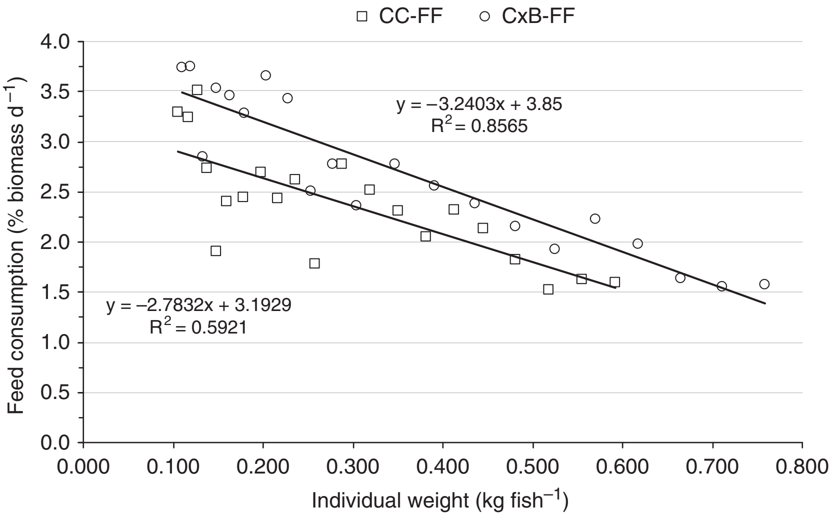

Figure 1 Mean daily feed consumption (% biomass day^{-1}) in relation to mean individual fish weight for channel catfish (treatment CC–FF) and channel × blue hybrid catfish (treatment C × B-FF) grown in earthen ponds. Fish were fed as much floating feed (32% protein) as they would consume in 20 min.

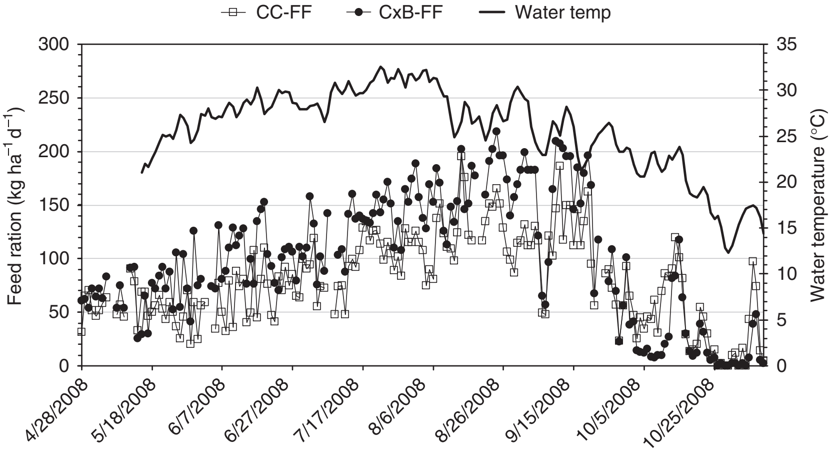

Figure 2 Mean daily feed consumption (kg ha^{-1}day^{-1}) by channel catfish (CC–FF) and channel × blue hybrid catfish (C × B-FF) stocked in 0.1 ha earthen ponds at 14 852 fish ha^{-1} and fed as much floating feed (32% protein) as they would consume in 20 min. Water temperature in all ponds was measured continuously by data loggers.

August. Feed conversion ratio differed between the CC and C × B treatments, and between the FF and RF treatments (Table 1).

Feed ration affected mean TAN concentration, which was significantly greater for the FF (2.58 mg L^{-1}) compared with the RF treatment (0.97 mg L^{-1}). Chlorophyll *a* concentration was significantly greater in C × B (229.4 mg m^{-3}) than in CC (115.8 mg m^{-3}) ponds. There were no other significant differences between main effects water quality means and there was no interaction between main effects. Least squares mean water quality variable concentration ranges were 0.78–3.00 mg NH_4-N L^{-1} (SE = 0.46), 0.21–0.28 mg NO_2-N L^{-1} (SE = 0.06), 0.72–2.01 mg NO_3-N L^{-1} (SE = 0.64), 0.001–0.008 mg PO_4-P L^{-1} (SE = 0.003) and 106.3–256.8 mg m^{-3} chlorophyll *a* (SE = 40.6).

Liver size (HSI) in CC was larger than that of the C × B, but was unaffected by feed ration (Table 2). The amount of body fat [intraperitoneal fat (IPF)] differed by both fish genetic group and feed ration without interaction. The C × B or fish fed the full ration exhibited more IPF than CC or fish fed the restricted ration. Muscle ratio of C × B was greater than that of CC, but was not influenced by feed ration.

Fillet dry matter and protein content (fresh-weight basis) did not differ by genetic group or feed ration (Table 3). Fillet lipid content was influenced independently by genetic group and feed ration. Fillets from CC or fish fed the full ration contained more lipid than those of C × B or fish fed the restricted ration. Greater energy (cal g^{-1}) also was found in the fillets of fish fed the full ration when compared with those of fish fed the restricted ration; however, fillet energy content did not differ between genetic groups.

Discussion

Water quality was not affected by genetic group, except for mean chlorophyll *a* concentration, which was greater in ponds stocked with C × B. Although more feed was fed to C × B (16 581 kg ha^{-1} compared with 12 469 kg ha^{-1} for CC) and to fish in the FF treatment, feed input to all ponds was high. Dissolved inorganic nitrogen and soluble reactive phosphorus concentrations were adequate to sustain high algal productivity as indicated by the chlorophyll *a* concentrations. There was a weak relationship ($R^2 = 0.333$) between mean chlorophyll *a* concentration and total feed input. Thus, the difference in total feed input may have contributed to the difference between genetic groups in chlorophyll *a* concentration. Another explanation or contributing factor may be difference between the genetic groups' habitat preferences. We observed that CC ponds tended to be muddy in appearance compared with C × B ponds, which had visible phytoplankton blooms. Fisher, Eder and Aragon (1999) reported that in a small impoundment channel catfish and blue catfish occupied significantly different habitats. Channel catfish preferred shallower water (littoral) habitats and blue catfish preferred midwater (pelagic) habitats. Although no reports of habitat preference were found in the literature for the C × B, its habitat preference likely is intermediate to those of its parental species.

Table 2 Hepatosomatic index (HSI, %), intraperitoneal fat (IPF, %) ratio, and muscle ratio (%) least squares means and standard error (SE) for channel catfish (CC) or channel × blue hybrid catfish (C × B) grown in ponds from March/April–November

Genetic group	Feed ration	HSI*	IPF ratio†	Muscle ratio‡
Main effects				
CC	FF	1.66	3.23	53.1
	RF	1.73	2.40	52.9
C × B	FF	1.27	4.27	55.9
	RF	1.23	3.50	56.5
Pooled SE		0.05	0.15	0.7
Main effect means				
Genetic group	CC	1.70	2.82	53.0
	C × B	1.25	3.89	56.2
Feed ration	FF	1.46	3.75	54.5
	RF	1.48	2.95	54.7
Pooled SE		0.03	0.11	0.5
ANOVA, $P>F$				
Genetic group		<0.001	<0.001	0.001
Feed ration		0.809	<0.001	0.789
Genetic group × feed ration		0.290	0.245	0.597

*Hepatosomatic index (HSI) = (liver mass/fish mass) × 100. Pond averages were based on 10 fish pond^{-1}.

†Intraperitoneal fat (IPF) ratio = (intraperitoneal fat mass/fish mass) × 100. Pond averages were based on 10 fish pond^{-1}.

‡Muscle ratio = (fillet yield with ribs/fish mass) × 100. Pond averages were based on 10 fish pond^{-1}.

Fish in full fed (FF) treatment ponds were fed as much floating feed (32% protein) as they would consume in 20 min and those in restricted feed (RF) treatment ponds were fed 80% of that day's mean satiation feed consumption by genetic group ($N = 4$).

Table 3 Fillet composition for channel catfish (CC) or channel × blue hybrid catfish (C × B) grown in ponds from March/April–November

Genetic group	Feed ration	Dry matter (%)	Protein (%)*	Lipid (%)*	Energy (cal g^{-1})*
Main effects					
CC	FF	27.9	16.6	8.8	1801
	RF	26.4	16.9	6.5	1543
C × B	FF	26.4	16.6	6.5	1627
	RF	25.1	16.7	5.1	1508
Pooled SE		0.01	0.3	0.8	61
Main effect means					
Genetic group	CC	27.1	16.7	7.7	1672
	C × B	25.7	16.6	5.8	1568
Feed ration	FF	27.1	16.6	7.7	1714
	RF	25.7	16.8	5.8	1543
Pooled SE		0.01	0.2	0.6	43
ANOVA, $P>F$					
Genetic group		0.174	0.741	0.032	0.123
Feed ration		0.163	0.577	0.039	0.012
Genetic group × feed ration		0.903	0.793	0.824	0.338

*Fresh-weight basis.

Fish in full fed (FF) treatment ponds were fed as much floating feed (32% protein) as they would consume in 20 min and those in restricted feed (RF) treatment ponds were fed 80% of that day's mean satiation feed consumption by genetic group ($N = 4$).

Total ammonia-nitrogen concentration was the only water quality variable affected by feed ration. The higher TAN concentration in the FF treatment resulted from the significantly greater total quantity of feed fed to fish in this treatment. Results from other pond studies are mixed and likely depend on experiment conditions. Some authors report that in response to full versus restricted feeding or to increased stocking rate TAN increases as feed daily feed input increases (Robinson, Li, Manning, Mischke & Bosworth 2004; Southworth, Stone & Engle 2006), but other authors report no relationship (Li *et al.* 2004, 2005).

Fish genetic group and feed ration affected fish production variables significantly, but there was no interaction between the main effects in this experiment. Overall, gross and net yields and individual weight at harvest were greater and FCR was higher for C × B compared with CC and for FF compared with RF. In other comparisons between channel catfish strains and C × B in pond culture, FCR does not differ (Bosworth *et al.* 2004; Jiang *et al.* 2008) or it is lower for C × B (Li, Robinson, Manning, Yant, Chatakondi, Bosworth & Wolters 2004); however, the significantly greater C × B survival may have influenced this latter result.

Net fish yield was higher when fish were fed as much as they would consume in 20 min. Fish in the C × B-FF treatment consumed 33% more feed than fish in the CC–FF treatment, which resulted in 27% more net yield and 14.5% larger fish. Despite the higher feed consumption by C × B, FCR did not differ significantly between these two treatments and averaged 1.49. At harvest, 75.2% and 68.4% of fish in the C × B-FF and CC–FF treatments, respectively, exceeded 0.68 kg fish^{-1}. Fish larger than 0.54 kg fish^{-1} comprised 92.7% and 86.5% of the population in the C × B-FF and CC–FF treatments respectively. Thus, depending on the processor requirements, 25–32% of the fish population could require further growth to attain a marketable size when 64–73 g fish are stocked in grow-out ponds in the spring.

Growth and yield comparisons reported previously between C × B and CC that shared a common maternal strain do not show a consistent performance advantage for either fish. Jiang *et al.* (2008) hybridized two strains of CC [Harvest Select-5 and National Warmwater Aquaculture Center 103 (NWAC103) strains] with blue catfish (D&B strain) and found that neither hybrid outperformed its corresponding CC strain when fish were stocked at 12 500 fish ha^{-1}. However, the Harvest Select-5 strain and hybrid outperformed the NWAC103 strain and hybrid, but the differences were attributed in part to greater initial weights for the Harvest Select-5 strain and hybrid. Bosworth *et al.* (2004) reported that net yield and mean individual weight of a C × B hybrid (channel catfish Norris strain female × blue catfish Dycus Farm strain male) were 29.2% and 29.3% greater ($P<0.05$), respectively, than those for the Norris strain of channel catfish, but that these differences likely were affected by the difference in initial weight. Growth, as indicated by the intercept value, *a*, did not differ among the channel catfish strains and hybrids in either of these studies. In a pond study stocked at 17 000 fish ha^{-1}, Dunham, Umali, Beam, Kristanto and Trask (2008) reported that the yield of a hybrid (channel catfish NWAC103 strain female × blue catfish Rio Grande × Auburn, D&B and Craft strains male) was 65.8% greater than that of the NWAC103 strain, and this difference was attributed to the lower survival of the NWAC103 strain. However, compared with the NWAC103 strain, the mean final weight of the hybrid was 12.2% greater. Yant, Smitherman and Green (1976) found that net yield and mean individual weight of channel × blue hybrid catfish (unidentified strain) were 15.0% and 13.0% greater, respectively, than for channel catfish (unidentified strain). Differences in fish strain, stocking rate, initial fish size, feed protein content and experiment duration may explain differences in the results of these studies and the current study (Dunham *et al.* 1987, 1990; Silverstein *et al.* 1999; Silverstein, Bosworth, Waldbieser & Wolters 2001).

Fish in the C × B-FF treatment grew more rapidly from May through September than those in the CC–FF treatment because the C × B consumed more feed on a daily basis. At any given size over the range of fish sizes observed in this experiment, the C × B consumed a higher percentage of its body weight as feed. The higher daily feed consumption by C × B from mid-May through mid-June gave them a growth advantage that persisted through September. In late September through the end of the experiment feed consumption by both genetic groups decreased, likely in response to the autumnal decline in water temperature. However, the larger decline in C × B feed consumption compared with CC is unexplained. Continued CC feeding activity during this period resulted in its faster growth and a mean individual weight at harvest that did not differ from the C × B.

Restricting feed to 80% of the satiation ration in the present experiment resulted in smaller fish and lower net yield and a lower FCR. The effect of feed restriction on growth and yield has been reported previously for CC, but not for C × B. While no reports of the response of C × B to feed restriction were found in the literature, their response in the present study was similar to that of CC. Studies on feed restriction involve either withholding feed for one or more days each week (Li *et al.* 2004, 2005; Green *et al.* 2009) or feeding daily at a reduced rate (Li & Lovell 1992; Munsiri & Lovell 1993; Robinson *et al.* 2000). The latter studies are appropriate for comparison to the present experiment because fish were fed daily. Channel catfish fed 69–90% of the satiate feed (32% protein) amount grew 81–92% as large and yielded 83–88% as much biomass as fish fed to satiation, but they converted feed more efficiently (Li & Lovell 1992; Munsiri & Lovell 1993; Robinson *et al.* 2000). Several factors may explain the differences in response among these studies. The experimental diets used in the three CC studies were formulated to evaluate ingredient quality and quantity, whereas in the present study a commercially formulated diet was used. Feed was restricted to a constant percentage of the satiate feed rate throughout the present study, but only beginning at about the mid-point and as a varying per cent of the satiate feed rate of the CC studies. Differences in fish size at harvest, the feed allowance at satiation and study duration also may explain differences among the studies.

Consistent with previous findings, fillet protein content in CC or the C × B was not different between fish fed to satiation or 80% of satiation. Both Robinson *et al.* (2000) and Munsiri and Lovell (1993) found muscle protein level generally insensitive to feeding regime or dietary protein level. Only a change in dietary protein quality, from low to medium, significantly increased muscle protein content in the latter study. Additionally, no change in muscle content was observed in that study when protein quality in the diets was increased from medium to high.

Results from the current study confirm that muscle lipid level typically is sensitive to feed ration in catfish and increases from restricted to satiation feeding. In contrast to Munsiri and Lovell (1993), however, protein and moisture content of the muscle were not inversely related to muscle lipid or feeding regime, but rather echoed the trend observed by Li and Lovell (1992). This may be related to the magnitude of difference between satiation and restricted feeding between studies. Restricted feeding was more severe in Munsiri and Lovell (1993) at about 70–73% of satiation and less severe in Li and Lovell (1992) at about 75–80% of satiation, based on the descriptions and feed data provided in those works.

Several studies have found that the magnitude of feed restriction – based on days fed per week, amount fed per day or amount fed per water area – influences the magnitude of change in body indices and muscle composition among catfish studies. Li, Robinson, Bosworth, Oberle and Lucas (2009) found 81% of satiation (the $\leq$ 110 kg ha^{-1} day^{-1} treatment) made no difference in either body indices or fillet composition of channel catfish in a multiple-batch cropping system when compared with fish fed to satiation; we also found liver size and muscle ratio unaffected by feeding regime at 80% of satiation feeding. Li *et al.* (2005) observed that missing more than 2 days per week feeding was required before visceral and muscle fat differed from those of full fed treatments. Not until feeding is more severely restricted, to 60–64% of satiation, for example, do body indices and muscle composition differ from satiation in single-batch (Li & Lovell 1992) or multiple-batch (Li *et al.* 2009) production systems. Finally, the greater muscle energy levels due to satiation, as opposed to restricted feeding in the current study are consistent with the greater muscle lipid content from the same treatments.

Body fat (IPF) ratio in catfish tends to be a more sensitive indicator of feeding regime. Fish fed a restricted ration typically exhibit less IPF than those fed to satiation, whereas HSI and muscle ratio seldom differ, at modest levels of feed restriction (Munsiri & Lovell 1993; Robinson *et al.* 2000) and our results are no different. On the other hand, IPF ratio, HSI and muscle ratio differed between catfish genetic groups and were inversely related. Specifically, CC exhibited larger livers, smaller fillets and less body fat, whereas C × B exhibited smaller livers, larger fillets and more body fat. Several authors report that compared with various stains of channel catfish, hybrids have greater fillet yield and/or visceral fat (Argue, Liu & Dunham 2003; Bosworth *et al.* 2004; Li *et al.* 2004; Jiang *et al.* 2008). While few data exist comparing liver size in different catfish strains under different feeding strategies, feeding studies in moronids (Rawles & Gatlin III 1998), for example, suggest that HSI is a sensitive indicator of both taxonomic and nutritional differences in feeding trials.

Like Bosworth, Wolters, Wise and Li (1998), we found muscle protein and moisture did not differ by genetic group, but muscle lipid was higher in channel catfish when compared with the hybrid. While Li *et al.* (2004) also found greater muscle lipid, muscle (fillet) protein and moisture were lower in the channel catfish relative to the hybrid. Hence changes in body indices and muscle composition in channel catfish and hybrid of the current study are consistent with trends noted previously in literature when satiation feeding is compared with modest restricted feeding.

The composition of growth data along with the observed feed conversions suggest that better feed efficiency (lower FCR) resulted from conservation of dietary protein for muscle, use of lipid for energy, with less accumulation of lipid in body depots when feed was moderately restricted. Similar trends in diet utilization have been observed in other species. For example, McGoogan and Gatlin III (1998) observed nonlinear, sigmoidal relationships between digestible protein/energy intake and body indices, feed efficiency (inverse sigmoid), whole body protein and whole body energy in red drum *Sciaenops ocellatus*. As intake decreased from 26 to 20 g digestible protein/100 g body weight – the plateau range of the intake curves – muscle ratio and whole body protein remained fairly constant while feed efficiency increased and IPF and whole body energy decreased. We also found both muscle ratio and protein remained constant, but IPF as well as muscle lipid and energy decreased when feeding was moderately restricted. Moreover, these trends were unaffected by differences in feed consumption or partitioning of dietary lipid between peritoneal cavity or muscle in the two strains of catfish tested. Hence, our results support the conclusions of Dumas, France and Bureau (2009) and current models of fish composition with respect to growth: that protein contents are comparable and constant across species, while the other components of composition (lipid, moisture, ash and energy) vary in a similar pattern among species as fish grow.

In summary, the net yield of channel × blue hybrid catfish is greater than that of the purebred channel catfish when both fish shared the Jubilee stain of channel catfish as the maternal parent. The channel × blue hybrid catfish in this study grew more quickly from May through September because it consumed a higher percentage of its body weight at each feeding. However, channel × blue hybrid catfish feed consumption declined more than that for channel catfish as water temperatures decreased, which allowed superior channel catfish growth during the late September to November period. Restricting feed to 80% of the satiate ration resulted in significantly lower growth and production for the channel × blue hybrid catfish and purebred channel catfish. Feeding daily to apparent satiation was necessary to achieve maximum fish size and production in this study.

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