Genotype-Environment Interactions For Growth, Survival, Sexual Dimorphism and Seinability For Different Genetic Types of Channel Catfish (Ictalurus punctatus) ♀ X Blue Catfish (I. furcatus) ♂ Cultured In Three Environments

by

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Abstract

For this study, eight genetic types of channel catfish (Ictarulus punctatus) female x blue catfish (I. furcatus) male hybrids were reared in three environments: a low density pond, a high density pond and an in-pond raceway for a period of five months and were fed to satiation. MR X DB, KS X DB, KR X RG and KS X RG ranked in the top group in all three environments for adjusted body weight ($P<0.05$). 103KS X RG ranked in the top group for the pond environments, but had the lowest adjusted body weight in the in-pond raceway. Genotype X environment, sex X environment and genotype X sex X environment interactions were observed ($P<0.05$). Fish in the low density pond and the in-pond raceway were of similar size, yet the sexual dimorphism was different in these two environments.

There were genotype- environment interactions observed for survival ($P<0.05$). 103 KS X RG had higher survival rates than the other genetic types in the low density environment and in-pond raceway while KR X RG had the highest value for the high density pond with a survival of 88.7%. MS X RG and MR X DB performed poorly for survival in all the environments.

No genetic differences were observed among the 8 genetic types within each environment for seinability ($P>0.05$). However, when sires were pooled, hybrids from D&B males were easier to catch than those from RG males in the in-pond raceway only.

Significant genotype-environment interactions existed, therefore suggesting that multiple breeding programs are needed for the multiple culture systems to genetically design hybrids specific for each one. However there was a high probability that selecting the top performer in

one environment would result in selecting a genetic type that would perform well in other environments. The results obtained also suggest that in many cases general combining ability exists in channel catfish dams and selection for general combining ability for growth in channel catfish can increase hybrid catfish performance in multiple environments.

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INTRODUCTION

The increase in demand for fish and reduced ocean fish catch has caused fish prices to rise 10-12% per year and increased investments in aquaculture to boost fish supply worldwide (FAO 2013). In the case of the United States (US), major portion of aquaculture is the production of catfish with about 92% of the sales produced in Mississippi, Alabama, Arkansas and Texas (Hanson and Sites 2014). The industry was valued at $423 million in 2012, and now about 30-50% of the US catfish production was from the culture of the channel catfish (Ictalurus punctatus*)* (female) x blue catfish, (I. furcatus) (male) hybrids (Brune et al. 2003; Dunham et al. 2014). The state of Alabama has about 150 farmers involved in the production of catfish, which has a large impact on the state's economy (Hanson and Sites 2014).

Traditional pond systems produce 4,500 – 5,500 kg/ha of ictalurid catfish with a maximum of 7,000kg/ha. Farms are now capable of producing more than 10,000 kg/ha (Steven et al. 2007). Thus, efficient production and sustainable techniques are being developed that improve upon the traditional pond production methodology (Brown et al. 2011).

Despite the catfish industry being the largest aquaculture industry in the US, it is in crisis. Catfish production peaked at 300 million kg in 2003 then contracted to 226, 127, 138 and 150 million kg in 2007, 2008, 2011 and 2013, respectively (NASS 2012; Hanson and Sites 2014) due to increased feed and fuel prices, the recession and increased imports.

The catfish industry is at an important turning point in its history as two innovative changes are occurring, both of which are key for the survival, subsequent recovery and growth of

this industry. One key is the implementation of more efficient and productive culture systems such as in- pond raceways (Brown et al. 2011) and split-pond partitioned aquaculture systems (Brune et al. 2012). These systems utilize intensification elements that prove to be more controllable and efficient than traditional ponds (Brown et al. 2011), which can allow the doubling or tripling of production while improving feed conversion efficiency (low FCR). The other is the wide spread implementation of the hybrid between channel catfish, Ictalurus punctatus, females and blue catfish, I. furcatus, males (hybrid) which exhibits heterosis for several traits (Dunham et al. 2008). The hybrid is an important component for easier adoption of improved culture systems (Brown et al. 2011; Brune et al. 2012), and may in fact, be the key to these new systems working as they require fish with accelerated growth and disease resistance to function properly.

Of the 50 ictalurid catfish hybrids that have been evaluated, only the hybrid between female channel catfish and male blue catfish showed better growth rates compared to the parent species when cultured in earthen ponds (Dunham and Smitherman 1984). This hybrid is improved (15-20%) for feed conversion (Yant et al. 1976; Li et al. 2004), growth (especially at high densities, 20- 100%; Giudice 1966; Yant et al. 1976; Dunham et al. 1987; Dunham et al. 1990; Dunham and Brummett 1999; Argue et al. 2003; Li et al. 2004; Dunham et al. 2008; Brown et al. 2011), bacterial disease resistance (Ella 1984; Wolters et al. 1996; Dunham et al. 2008; Arias et al. 2012) and survival (10 – 100%, Ella 1984, Dunham and Brummett 1999; Li et al. 2004), but not viral disease resistance (Plumb and Chappell 1978).

Additionally, the hybrid exhibits heterotic tolerance of low oxygen (50- 100%; Dunham et al. 1983), harvest by seining (50-100%; Yant et al.1976; Chappell 1979; Dunham and Argue 1998), angling vulnerability (100%; Tave et al. 1981; Dunham et al. 1986) and carcass yield

(10%; Yant 1975; Chappell 1979; Huang et al. 1994, Argue et al. 2003, Bosworth et al. 2004, Li et al. 2004, Bosworth et al. 2012) and has more uniform growth and body shape (Yant et al. 1976; Brooks et al. 1982a; Brooks et al. 1982b; Dunham et al. 1982a) compared to the commonly grown channel catfish. Body composition and flavor of channel catfish and hybrids are similar (Huang et al. 1994). This is the most powerful example of genetic improvement in farmed fish in the world in regards to number of traits improved and potential economic impact (Dunham 2011).

The channel-blue hybrid catfish is the best genetic type for US catfish culture. Strain of parent species affects the level of heterosis/performance observed in hybrids (Dunham et al. 1987; Dunham et al. 2014a; Dunham et al. 2014b) and likely hybrid performance can be improved by selection for combining ability (Bosworth and Waldbieser 2014).

General combining ability (GCA) is an average performance of an individual in a particular series of crosses. The genetic basis of GCA is additive genetic variance and additive x additive gene interaction. On the other hand, specific combining ability (SCA) is a performance of a parent under consideration in a specific cross, representing deviation from GCA. The genetic basis of SCA is dominance, genetic variance and all types of gene interaction. Theoretically, the hybrid performance could be improved due to additive effects from selected parent species or from heritable specific combining ability (dominance, over-dominance and epistatic effects) or both from selected parents.

Genotype-environment (GE) interactions can be prevalent for hybrid catfish (Dunham et al. 1990). With the advent of new culture systems for hybrid catfish, assessment of GE interactions is critical for the design of effective breeding programs to improve hybrid catfish.

Potentially, blue catfish and channel catfish could be selected for combining ability and increase hybrid performance of their progeny.

In general, genotype-environment interactions are more likely to occur in aquaculture with increasing genetic distance among the genetic groups being evaluated and with increasing differences in environment, especially culture unit and feed type (reviewed by Dunham 2011). GE interactions are usually minimal among strains and select lines (Gjerde 2006; Pongthana et al. 2010), slightly more prevalent among intraspecific crossbreeds and parents (Bentsen et al. 1998) and most common when comparing polyploids, transgenics, species and interspecific hybrids (Dunham et al. 1990; Xie et al. 2007; Dunham 2011; Cheng et al. 2014).

Genetic stock that performs better in one set of environmental conditions might not be the best performing genotype in another set of environmental conditions. Therefore do programs for genetically improving CB hybrids need to be conducted for specific environments since catfish are now cultured in upwards to 4 environments; traditional ponds with single or multi-cropping, in-pond raceways and split ponds or will the best fish developed in one environment be the best hybrid for all culture environments? GE interactions must be evaluated before improved stocks can be recommended for a variety of farm conditions (Dunham et al. 1990).

The specific objectives were to measure genotype-environment interactions for growth, survival, sexual dimorphism and seinability for different genetic types of hybrid catfish grown in a low density pond, a high density pond and an in-pond raceway, and to identify the best performing genetic type of hybrid under these culture conditions.

MATERIALS AND METHODS

Experimental fish

Five lines of channel catfish females were hybridized with 2 lines of, D&B (DB) and Rio Grande (RG), of blue catfish males in various combinations in June of 2012. Channel catfish lines were Kansas random (KR), Marion random (MR), Marion select (MS, selected for 8 generations for increased body weight), Kansas select (KS, selected for 8 generations for increased body weight) and 103KS (an F2 generation cross between NWAC-103 and KS). Ancestry of these fish can be found in Dunham and Smitherman (1984). NWAC-103 was selected for growth for 2 generations and originated from a fast growing strain, Uvalde. These fish were maintained at the EW Shell Fisheries Research Center, Auburn University, Alabama.

Spawning and incubation

In general, artificial spawning procedures were those of Kristanto et al. (2009) and Su et al. (2013). Channel catfish females were implanted with luteinizing hormone releasing hormone analog (LHRHa) administered intramuscularly as a single dose, 100 µg/kg body weight, posterior and ventral to the dorsal fin. Each female was held individually in black or white spawning bags that were secured with clothes line pins to the edges of flow-through troughs receiving reservoir water. Thirty-six hours after implantation, the spawning bags were checked every four hours for the presence of eggs. Ovulating females that were releasing eggs were anesthetized with 100 mg/L tricaine methanesulfonate (MS-222) and 100 ppm sodium

bicarbonate. Anesthetized females were then dried with a towel to remove excess water and hand stripped of the eggs into a 30.5 cm pan coated with vegetable oil.

Sperm from male blue catfish was collected by surgically removing the anterior section of the testes. The testes were cleaned, dried and weighed to the nearest 0.1g. They were then placed on a white plastic tray with a 0.85% saline solution and were macerated to release the sperm. Sperm was then stored in 15ml tubes at 4°C. It was distributed over the eggs at 2.5ml of sperm to 100g of eggs. The sperm was activated by the addition of freshwater while gently swirling the eggs. Then the pans were placed in troughs with flowing freshwater for 15 minutes to harden the eggs. Once hardened, forming an egg mass, they were transferred into baskets secured in paddle-wheel troughs for agitation and incubation.

Hatching troughs used were made of fiberglass and were 2.4m long, 0.61m wide and 0.25m deep. A series of paddles attached to a shaft were suspended along the length of the trough with enough space between the paddles to accommodate wire mesh baskets. The masses were continually aerated by the paddlewheel and water temperature was 26 – 31°C with a flow rate of 4L/min. Prophylactic treatments of 100 ppm formalin and 32 ppm copper sulphate were administered to prevent fungus and bacteria, beginning 8 hours after fertilization. Copper sulphate treatments were terminated when the eggs were at the eyed-stage. These treatments were given statically for 15 minutes, 3 times per day. Yolk sac fry were siphoned, enumerated and transferred to fry rearing troughs.

Fry culture

The fry were reared in 2.5 m long, 30 cm wide and 25 cm deep fiberglass rearing troughs. A water flow of about 3L/min at a temperature between 24 and 30°C were maintained. After the

yolk sac was absorbed, about 3 days after hatch, the fry were fed floating commercial powdered feed containing 56 % protein feed, 4 times a day at a rate of 4-5 % of their body weight. Small diameter pelleted feed was used as the fry size increased. When the fry were 2cm each, they were moved to rearing ponds, and fed with 36% protein (BB pellets) catfish feed.

In the months of March and April 2013, the fingerlings were seined from 6 different ponds and were given a VIE mark. They were then stocked back into their respective ponds, for multiple rearing (Moav and Wohlfarth 1973; Dunham et al. 1982b; Dunham 2011) to equalize body weights to begin the stocker phase of this experiment. In July 2013, the fingerlings were seined from the ponds, weighed, heat branded and stocked communally so that each genetic group was represented in each experimental unit to minimize the environmental factor (Brummett 1986; Dunham and Brummett 1999; Wohlfarth and Moav 2014). Each fish was heat branded using the technique of Moav et al. (1960) to differentiate the genetic groups at harvest.

Experimental units

The fingerlings were raised in 3 different environments; in-pond raceway, a high density pond and a low density pond. The ponds each had a surface area of 0.04-ha with an average depth of 1m. Water levels were maintained by periodic addition of water compensating for loss in seepage and evaporation.

The raceway was rectangular shaped, built from treated lumber and suspended between walkways of a floating pier, having the dimensions, 1.2 m deep, 1.2m wide, 5.9m long, for a total volume of 8.5m^3. It was constructed of a semi-rigid, high density polyethylene plastic. A set of air lift pumps located at the head end of the raceway circulated pond water into the raceway. It had an approximately 4% slope along its length to assist the movement of fish waste. The

raceway was located in a 10-ha pond containing 11 additional in-pond raceways. Table 1 below shows the stocking densities for the three environments and Table 2 shows the stocking numbers and initial weights for each of the genetic groups in each environment.

Table 1. The stocking densities of the different genetic types of channel (Ictarulus punctatus) female x blue (I. furcatus) male catfish hybrids cultured in a low density pond, a high density pond and an in-pond raceway

Environments	Density
Low density pond	15000 fish/ha (1.5 fish/ m^3)
High density pond	113000 fish/ha (11.3 fish/m^3)
In-pond raceway	393 fish/m^3

Table 2. The stocking numbers and mean initial body weights (g) of the different genetic types of channel (Ictarulus punctatus) female x blue (I. furcatus) male catfish hybrids cultured in a low density pond, a high density pond and an in-pond raceway

		Low density Pond		High density Pond		In-pond Raceway	
Genetic type[1]	Brand	No.	Wt (g)	No.	Wt (g)	No.	Wt (g)
103KS X DB	0L	75	41.1	1146	32.4	500	42.1
MR X DB	1L	75	46.4	377	42.5	443	41.3
KS X DB	1R	75	42.4	983	40.3	400	40.8
KR X DB	2L	75	43.6	500	43.7	318	41.5
103KS X RG	6L	75	34.1	366	32.9	500	51.0
MS X RG	6R	75	61.9	362	56.9	406	58.2
KR X RG	7L	75	40.0	399	40.9	370	39.0
KS X RG	7R	75	39.9	387	47.0	400	48.6

[1]Blue catfish sires were D&B (DB) and Rio Grande (RG). Channel catfish lines were Kansas random (KR), Marion random (MR), Marion select (MS, selected for 8 generations for increased body weight), Kansas select (KS, selected for 8 generations for increased body weight) and 103KS (an F2 generation cross between NWAC-103 and KS).

Feeding regime

Feed used in the experiment was a 32% crude protein, floating catfish pellet. Fingerlings that were cultured in the raceway were fed daily in the morning while those in earthen ponds were fed in the afternoon. Feed was applied by hand throughout the experimental period. Fish were fed to satiation. Approximately, 8 days of feeding were missed because of severe weather and heavy rain.

Water quality

Dissolved oxygen (DO) and water temperature were measured daily. DO was measured early morning over the rearing period. Water temperature and dissolved oxygen were measured using the YSI model 55 DO meter. Electrical spray type aerators were provided only on the days that the dissolved oxygen was critically low (<3mg/L) during August – December. On these days, aerators were operated from 2200 to 0600hrs.

Treatment

Mortality was observed during the first week after stocking in the in-pond raceway and the high density pond. The causative agent of this mortality was Flavobacterium columnare, columnaris. Treatment was affected with 2mg/L of potassium permanganate (KMnO4) in pond water. There were no observed mortalities in the low density pond throughout the experimental period, although survival was less than 100% at harvest.

Harvesting and data collection

After a grow-out period of 4 months, the 2 earthen ponds were harvested with a 30m seine. Seining was done in the morning (around 0800hrs) when the temperatures were lowest.

The ponds were prepared for seining by reducing the water level approximately 50% the previous night. After two seine hauls, the remaining fish were caught by completely draining the pond and capturing them with dip nets.

For the in- pond raceway, a net was used to harvest. It was carefully placed at the far end of the raceway, ensuring it touched the raceway bottom and the raceway was seined 5 times.

The day following harvesting from each environment, total weights and numbers for each genetic group were recorded. Data on sex and individual weight were taken for all fish harvested for each seine haul.

Statistical Analysis

Experimental data were analyzed for statistical significance using ANOVA and LSD for differences in treatment means (SAS 9.3, SAS Institute Inc. NC, USA).

Body weight

Final mean individual body weights were analyzed using three-way analysis of variance (ANOVA) at the significance level ($P \leq 0.05$). A three–way ANOVA model was used as below;

$$y_{ijk} = \mu + G_i + S_j + E_k + (GE)_{ik} + (SE)_{jk} + (GS)_{i,j} + (GSE)_{i,jk} + \epsilon_{ijkl}$$

Where, μ: overall mean body weight; y_{ijkl}: final body weight;

G: main effect of genetic type of hybrids; i=1,2,3,... 8;

S: main effect of gender; j=F or M;

E: environment; k=1,2, and 3;

ϵ: random error.

Adjusted final body weight

Final body weight was adjusted with regression to correct for the effects of initial body weight according to the methods of Dunham et al. (1982b; 2014a).

Adjusted final body weight= Individual body weight – 3.0 ($X - \bar{X}$)

Where X: initial mean body weight of a genetic type of hybrid in an environment; $\bar{X}$: grand mean body weight of all genetic type of hybrids in an environment. The regression coefficient 3.0 was derived by previous research with fish and catfish fingerlings (Wohlfarth 1977; Dunham et al. 1982b)

Multiple comparisons on the means of final body weight and adjusted body weight were performed using Tukey-Kramer procedure with two/three-way analysis of variance (ANOVA) at the significant level ($P \leq 0.05$) (SAS 9.3). Equal variance, independent and normal distribution of residuals were checked using Bartlett's Test, QQ-plot and residuals plots. When assumption of homogeneity of variance was violated, data were transformed using Box-Cox transformation and the ANOVA was performed on the transformed data.

Survival

Different genetic types of hybrids had different survival in the three environments. To determine influence of the main factors such as genetic type of hybrids, sex, initial mean body weight, final mean body weight, adjusted mean body weight and environments on the survival of the genetic type of hybrids, a logistic model was used as given below.

$$U = \mu + G_i + S_j + E_k + y_i + I + (GE)_{ik} + (SE)_{jk} + (GS)_{i,j} + (GSE)_{i,jk} + \epsilon_{ijkl}$$

Where U: either 1 (survival) or 0 (death); μ: overall survival percentage; y*i*: either the final body weight or adjusted final body weight. *I*: average initial body weight

Goodness of fit was checked using a Hosmer-Lemeshow test. INFLUENCE and IPLOTs were used for regression diagnostics.

Seinability

Seinability in regards to percentage of fish caught in the first haul was analyzed using Tukey's one degree of freedom F-test for additivity (Tukey 1949). The data structure was one observation per cell with two main factors. The model used is given below:

$Y_{ij} = \mu. + G_i + E_j + D\, G_i E_j + \epsilon_{ij.}$

Where, Y_{ij}: First seine haul percentage of a genetic type of hybrid in an environment;

μ: overall mean seinability;

G: main effect of genetic type of hybrid; *i*=1,2,3,... 8;

E: main effect of environment; *j*=1 (high density pond), 2 (low density pond), and 3 (raceway);

D: a real-valued parameter to be estimated.

ϵ: random error.

Means of genetic types with common sires (RG or DB) or common dams pooled by ancestry (M, K or 103KS were used as replicates (2-4) to evaluate sire and dam effects on certain traits. Means were compared with a t-test at $P<0.05$. Additionally, hybrids produced by select females were compared to their corresponding controls with an unpaired t-test at $P<0.05$. Males and females of the same genetic type in the same environment were compared with an unpaired t-test at $P<0.05$.

RESULTS

Final Body weight

Table 3 shows the final body weights of the test fish in the 3 environments; in-pond raceway, low density and high density ponds, their pooled mean final body weights and the relative rank of the genetic types in each environment. Sex (S), genetic type (G), environment (E) and their interactions; sex x environment (S X E), sex x genetic type (S X G) and genetic type x environment (G X E) were all significant ($P < 0.05$) for final body weight (Table 4). The interaction effect (S X E, S X G and G X E) demonstrated that genetic types and gender responded differently to the variation in environmental conditions.

The genetic type sum of squares was 6.7 times higher than the genetic type x environment (G X E) interaction, and was 24 times that of sex x genetic type (S X G), the sum of squares for environment was 46.8 times greater than the gender x environment interaction. This shows that genotype and environment accounted for the majority of the variability followed by the G X E interaction.

MS X RG and KS X RG performed better ($P < 0.05$) in the low density pond compared to the other genetic types, with a mean body weight of 0.253 and 0.235 kg, respectively. MS X RG had the highest body weight in the high density pond environment. The genetic types KR X DB, KR X RG, 103 KS X DB and 103 KS X RG had the lowest body weights ($P <0.05$). MS X RG, KS X RG and MR X DB had the highest ($P<0.05$) in the in-pond raceway. 103KS XDB had the lowest unadjusted final body weight in all 3 environments ($P<0.05$).

In the low density pond, females had a higher body weight ($P < 0.05$) compared to males and the same trend was observed in the in-pond raceway, where the females were 1.2 times larger ($P < 0.05$) than the males. There were no differences ($P>0.05$) in mean body weight between males and females cultured in the high density pond.

Table 3. Mean final body weights (kg), pooled body weights (kg) and the standard deviation (SD) of different genetic types of channel (Ictarulus punctatus) female x blue (I. furcatus) catfish male hybrid cultured in a low density pond, a high density pond and an in-pond raceway.

	Mean final body weights ± Standard Deviation			
Genetic type[1]	Low density	High density	Raceway	Pooled data
103KS x DB	$0.110^{h} \pm 0.054$	$0.101^{e} \pm 0.045$	$0.131^{e} \pm 0.066$	$0.113^{f} \pm 0.057$
MR X DB	$0.184^{cde} \pm 0.083$	$0.145^{bc} \pm 0.071$	$0.209^{ab} \pm 0.112$	$0.183^{b} \pm 0.100$
KS X DB	$0.186^{cde} \pm 0.097$	$0.139^{cd} \pm 0.056$	$0.179^{c} \pm 0.070$	$0.153^{c} \pm 0.070$
KR X DB	$0.177^{cde} \pm 0.091$	$0.103^{e} \pm 0.050$	$0.145^{de} \pm 0.090$	$0.127^{de} \pm 0.077$
103KS X RG	$0.136^{fg} \pm 0.055$	$0.109^{e} \pm 0.040$	$0.146^{de} \pm 0.019$	$0.135^{d} \pm 0.070$
MS X RG	$0.253^{a} \pm 0.122$	$0.176^{a} \pm 0.080$	$0.217^{a} \pm 0.111$	$0.203^{a} \pm 0.105$
KR X RG	$0.202^{bcd} \pm 0.097$	$0.104^{e} \pm 0.045$	$0.130^{ef} \pm 0.069$	$0.122^{de} \pm 0.068$
KS X RG	$0.235^{ab} \pm 0.119$	$0.155^{b} \pm 0.070$	$0.224^{a} \pm 0.097$	$0.191^{ab} \pm 0.094$
Grand Mean	$0.181^{b} \pm 0.101$	$0.124^{a} \pm 0.060$	$0.163^{c} \pm 0.090$	0.145 ± 0.081

[abcdefg] Means within the same column followed by the same letter are not significantly different (P = 0.05, Tukey multiple range test).

[1]Blue catfish sires were D&B (DB) and Rio Grande (RG). Channel catfish lines were Kansas random (KR), Marion random (MR), Marion select (MS, selected for 8 generations for increased body weight), Kansas select (KS, selected for 8 generations for increased body weight) and 103KS (an F2 generation cross between NWAC-103 and KS).

Table 4. The interaction of sex (S), genetic type (G) and environment (E) on the final body weight (kg) of the different genetic types of channel (Ictarulus punctatus) female x blue (I. furcatus) male catfish hybrids cultured in a low density pond, a high density pond and an in-pond raceway

Source	DF	Type III SS	Mean Square	F Value	Pr > F
S	1	4.15391938	4.15391938	19.77	<.0001
G	7	98.95680124	14.13668589	67.29	<.0001
E	2	74.61536216	37.30768108	177.59	<.0001
S*E	2	1.59183144	0.79591572	3.79	0.0227
G*E	14	14.63281313	1.04520094	4.98	<.0001
S*G	7	3.71727871	0.53103982	2.53	0.0135

Comparing sex differences for body weight within a genetic type within an environment, there were 24 possible comparisons (Table 5). 103KS X DB females were larger ($P<0.05$) than their males in the low density pond, but not in the other environments ($P>0.05$). MR X DB females were larger ($P<0.05$) than their males in the high density pond, nearly so in the low density pond, but not ($P>0.05$) in the raceway. KR X DB females were larger ($P<0.05$) than their males in the in-pond raceway, but not in the other environments ($P>0.05$). KR X RG females were larger ($P<0.05$) than their males in the high density pond and the low density pond, but males were larger than females ($P<0.05$) in the raceway.

Table 5. Final body weight (kg), and standard deviation (SD) by sex of the genetic types of channel (Ictarulus punctatus) female x blue (I. furcatus) catfish male hybrid cultured in a low density pond, high density pond and an in-pond raceway Percent sexual dimorphism = mean of male-mean of female divided by mean of the female X 100

Genetic type[1] Sex % Sexual Dimorphism	Low density pond	High density pond	Raceway	Pooled data
103KS x DB				
Female	0.135 ± 0.047*	0.104 ± 0.047	0.137 ± 0.064	0.117 ± 0.056
Male	0.100 ± 0.053	0.098 ± 0.040	0.127 ± 0.068	0.110 ± 0.057
%	-28.6	-5.0	-7.1	
MR X DB				
Female	0.204 ± 0.084	0.156 ± 0.082*	0.213 ± 0.106	0.194 ± 0.099
Male	0.167 ± 0.080	0.138 ± 0.062	0.206 ± 0.110	0.175 ± 0.100
%	-15.0	-12.5	-3.0	
KS X DB				
Female	0.191 ± 0.093	0.141 ± 0.056	0.178 ± 0.065	0.154 ± 0.064
Male	0.181 ± 0.103	0.137 ± 0.057	0.181 ± 0.076	0.152 ± 0.069
%	-5.3	-2.5	1.5	
KR X DB				
Female	0.179 ± 0.074	0.112 ± 0.051	0.173 ± 0.107*	0.138 ± 0.083
Male	0.176 ± 0.100	0.098 ± 0.047	0.134 ± 0.080	0.121 ± 0.073
%	-1.0	-9.1	-23.5	
103KS X RG				
Female	0.165 ± 0.045	0.111 ± 0.043	0.146 ± 0.070	0.135 ± 0.063
Male	0.168 ± 0.051	0.106 ± 0.037	0.146 ± 0.083	0.135 ± 0.074
%	1.1	-4.5	0.0	
MS X RG				
Female	0.244 ± 0.105	0.172 ± 0.089	0.220 ± 0.100	0.197 ± 0.098
Male	0.262 ± 0.139	0.182 ± 0.083	0.215 ± 0.118	0.208 ± 0.111
%	8.3	5.9	2.5	
KR X RG				
Female	0.225 ± 0.087*	0.106 ± 0.045	0.120 ± 0.040*	0.125 ± 0.063
Male	0.178 ± 0.102	0.102 ± 0.05	0.136 ± 0.080	0.121 ± 0.069
%	-21.7	3.9	13.3	
KS X RG				
Female	0.244 ± 0.126	0.150 ± 0.068	0.220 ± 0.091	0.188 ± 0.093
Male	0.225 ± 0.113	0.161 ± 0.071	0.230 ± 0.103	0.194 ± 0.095
%	-4.2	6.7	4.5	
Grand Total	0.181 ± 0.101	0.124 ± 0.060	0.163 ± 0.090	0.145 ± 0.081

* Means of male and female are different (unpaired t-test, P<0.05).

[1]Blue catfish sires were D&B (DB) and Rio Grande (RG). Channel catfish lines were Kansas random (KR), Marion random (MR), Marion select (MS, selected for 8 generations for increased body weight), Kansas select (KS, selected for 8 generations for increased body weight) and 103KS (an F2 generation cross between NWAC-103 and KS).

Adjusted final body weights

Sex, genetic type, environment, environment x genetic type, environment by sex, and sex by genetic type were found to have significant effects for adjusted final body weight (Table 6). Mean adjusted final body weights of males and females in the high density pond and in-pond raceway, were not significantly different (P>0.05) while those in the low density environment were significantly different (P<0.05) from each other.

In the low density environment, KS X RG had the highest observed adjusted body weight, 0.247 kg, but had only significantly higher (P<0.05) adjusted final body weight, than 103KS X DB. 103KS X DB had the lowest (P<0.05) mean final body weight at 0.118 kg. When pooling by sire type, hybrids produced by RG males, 0.204 kg were not larger (P>0.05) than those from DB males, 0.167 kg despite the 22.1% observed difference. When pooling dams of common ancestry, hybrids from K females 0.196 kg were larger (P<0.05) than those from 103KS females (0.142 kg).

KS X DB, MR X DB and 103KS X RG had the largest adjusted body weights (P<0.05) in the high density pond. However, the means were much closer than in the low density pond and KR X DB had the smallest (P<0.05) genetic type. When pooling by sire or dam type, there were no significant differences (P>0.05).

KS X RG and MR X DB had higher mean adjusted body weights ($P<0.05$), 0.213 kg and 0.220 kg respectively, than all genetic types except MS X RG, KR X RG and KS X DB in the in-pond raceway. 103KS X RG had the lowest ($p<0.05$) body weight at 0.127 kg. When pooling by sire type, hybrids produced by RG males were not larger ($P>0.05$) than those from DB males. When pooling dams of common ancestry, hybrids from K females, 0.181 kg, and M females, 0.199 kg, were larger ($P<0.05$) than those from 103KS females, 0.133 kg.

Table 6. Adjusted final body weights (kg), pooled body weights (kg) and the standard deviations (SD) of different genetic types of channel (Ictarulus punctatus) female x blue (I. furcatus) catfish male hybrid cultured in a low density pond, a high density pond and an in-pond raceway

	Mean adjusted body weights ± Standard deviation			
Genetic type[1]	Low density Pond	High density Pond	Raceway	Pooled data
103KS x DB	0.118^{ef} ± 0.054	0.121^{bc} ± 0.045	0.139^{d} ± 0.066	0.130^{c} ± 0.055
MR X DB	0.177^{abcd} ± 0.083	0.135^{abc} ± 0.077	0.220^{a} ±0.112	0.190^{ab} ±0.103
KS X DB	0.191^{abc} ± 0.097	0.136^{ab} ± 0.056	0.191^{ab} ± 0.07	0.170^{ab} ±0.067
KR X DB	0.180^{abc} ± 0.091	0.089^{d} ± 0.049	0.150^{cd} ± 0.09	0.060^{c} ± 0.086
103KS X RG	0.165^{abcd} ± 0.055	0.128^{abc} ± 0.040	0.127^{e} ± 0.079	0.150^{c} ± 0.069
MS X RG	0.200^{abcde}± 0.122	0.124^{c} ± 0.086	0.177^{bc} ± 0.111	0.160^{c} ± 0.106
KR X RG	0.204^{ab} ± 0.097	0.126^{bc} ± 0.045	0.171^{abc}± 0.069	0.160^{b} ± 0.066
KS X RG	0.247^{a} ± 0.119	0.132^{bc} ± 0.070	0.213^{a} ± 0.097	0.190^{a} ± 0.098
Grand Total	0.184^{a} ± 0.097	0.125^{b} ± 0.057	0.165^{c} ± 0.089	0.147± 0.099
C X RG	0.204^{1} ± 0.034	0.128^{2} ± 0.003	0.172^{3} ± 0.035	
C X DB	0.167 ± 0.033	0.121 ± 0.022	0.175 ± 0.037	
103KS X B	0.142 ± 0.033	0.125 ± 0.005	0.133 ± 0.008	
M X B	0.189 ± 0.016	0.130 ± 0.008	0.199 ± 0.034	
K X B	0.196 ± 0.013	0.121 ± 0.022	0.181 ± 0.027	

[abcdefg] Means within the same column followed by the same letter are not significantly different (P = 0.05, Tukey multiple range test).

[1]Blue catfish sires were D&B (DB) and Rio Grande (RG). Channel catfish lines were Kansas random (KR), Marion random (MR), Marion select (MS, selected for 8 generations for increased

body weight), Kansas select (KS, selected for 8 generations for increased body weight) and 103KS (an F2 generation cross between NWAC-103 and KS).

[2] Sire effects were not significant ($P>0.05$) and hybrids from pooled K dams were larger ($P<0.05$) than hybrids from pooled 103KS dams (t-test)

[3]There were no significant ($P>0.05$) pooled sire or dam effects (t-test).

[4]Sire effects were not significant ($P>0.05$) and hybrids from pooled K dams and pooled M dams were larger ($P<0.10$) than hybrids from pooled 103KS dams (t-test)

Table 7. Type III sum of squares (SS) and mean square for the effects of sex (S), genetic type (G) and environment (E) and their interaction on the adjusted final body weight (kg) of the different genetic types of channel (Ictarulus punctatus) female x blue (I. furcatus) male catfish hybrids cultured in a low density pond, a high density pond and an in-pond raceway

Source	DF	Type III SS	Mean Square	F Value	Pr > F
S	1	2.84811030	2.84811030	17.48	<.0001
G	7	31.94870183	4.56410026	28.01	<.0001
E	2	77.40497171	38.70248586	237.54	<.0001
S*E	2	1.28244869	0.64122434	3.94	0.0196
G*E	14	42.22335993	3.01595428	18.51	<.0001
S*G	7	2.98516900	0.42645271	2.62	0.0107

Survival

The mean survival (%) of the different genetic types of channel X blue hybrids in the three environments are presented in Table 8. Genetic type, environment and genetic type x environment interaction accounted for a significant proportion of variance in survival ($P<0.05$). 103KS X RG had the highest ($P<0.05$) survival rates in the low density pond. KR X RG had higher ($P<0.05$) survival rate than KS X RG; with MS X RG and MR X DB having significantly lower rates ($P<0.05$) in the high density pond. Other genetic types had lower survival rates, and were significantly different from KS X RG. For the in-pond raceway, 103 KS X RG again had

the highest ($P<0.05$) survival rate. MR X DB and MS X RG had significantly lower survival rates ($P<0.05$) while KS X DB. KS X RG had the second lowest survival (Table 8).

Table 8. The survival (%) of the different genetic types of channel (Ictarulus punctatus) female x blue (I. furcatus) male catfish hybrids cultured in a low density pond, a high density pond and an in-pond raceway environments

Genetic type[1]	Low density Pond	High density Pond	Raceway	Pooled Survival
103KSXDB	82.7[b]	43.7[f]	70.0[c]	62.7[d]
MRXDB	53.7[d]	28.9[g]	35.9[f]	39.5[e]
KSXDB	72.0b[c]	65.5[d]	59.3[e]	65.6[d]
KRXDB	80.0[b]	67.4[c]	68.0[b]	71.8[b]
103KSXRG	84.0[a]	45.6[e]	79.0[a]	69.5[bc]
MSXRG	49.3[e]	33.1[g]	22.4[g]	34.9[f]
KRXRG	77.3[bc]	88.5[a]	64.6[d]	76.8[a]
KSXRG	80[b]	71.6[b]	55.3[e]	68.9[d]

[abcdef] Means within the same column followed by the same letter are not significantly different (P = 0.05, Tukey multiple range test).

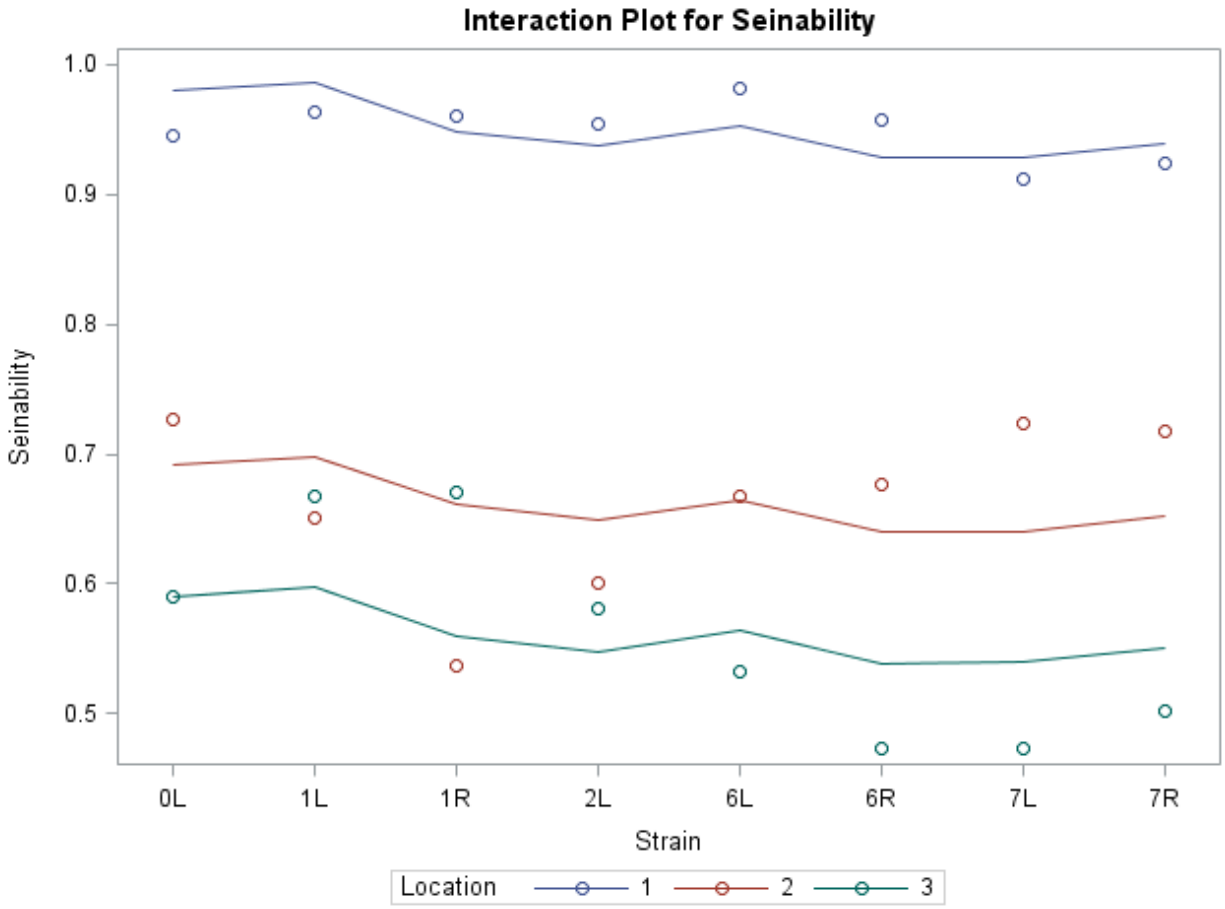
[1]Blue catfish sires were D&B (DB) and Rio Grande (RG). Channel catfish lines were Kansas random (KR), Marion random (MR), Marion select (MS, selected for 8 generations for increased body weight), Kansas select (KS, selected for 8 generations for increased body weight) and 103KS (an F2 generation cross between NWAC-103 and KS)

Seinability

Environment had a significant effect on seinability ($P<0.05$, Fig. 1) with fish being more difficult to catch in this environment. No differences were found among genetic types within any

of the environments ($P>0.05$, Table 9). However, a sire effect ($P<0.05$) was found for the in-pond raceway with hybrids produced by RG males more difficult to capture.

Fig. 1 The seinability of the different genetic types of channel (Ictarulus punctatus) female x blue (I. furcatus) male catfish hybrids cultured in a low density pond, a high density pond and an in-pond raceway environments



Where Location 1= High density pond, Location 2 = Low density pond, Location 3 = In-pond raceway

Brand 0L = 103 KS X DB, 1L = MR X DB, 1R = KS X DB, 2L = KR X DB, 6L = 103 KS X RG, 6R = MS X RG, 7L = KR X RG, 7R = KS X RG

Table 9. The seinability of the different genetic types of channel (Ictarulus punctatus) female x blue (I. furcatus) male catfish hybrids cultured in low density pond, high density pond and in-pond raceway

Genetic type[1]	Low density Pond	High density Pond	Raceway
103KSXDB	0.726	0.946	0.590
MRXDB	0.651	0.963	0.667
KSXDB	0.537	0.961	0.671
KRXDB	0.600	0.954	0.581
103KSXRG	0.667	0.982	0.532
MSXRG	0.676	0.958	0.473
KRXRG	0.724	0.912	0.473
KSXRG	0.717	0.927	0.502
C X DB	0. 628	0. 955	0.628*
C X RG	0. 698	0.945	0.493
M X B	0. 665	0.961	0.570
103KS X B	0.700	0.964	0.560
K X B	0.644	0.939	0.550

[1]Blue catfish sires were D&B (DB) and Rio Grande (RG). Channel catfish lines were Kansas random (KR), Marion random (MR), Marion select (MS, selected for 8 generations for increased body weight), Kansas select (KS, selected for 8 generations for increased body weight) and 103KS (an F2 generation cross between NWAC-103 and KS)

*Sire effects were significant ($P<0.05$, paired t-test) for the low density pond.

DISCUSSION

Adjusted final body weight

Differences in the adjusted final body weight for the different genetic types of channel catfish female X blue catfish male hybrid were found in all three environments. Sex, genetic type and environmental effects, as well as all of their interactions were significant. If observed adjusted body weight is examined, KS X RG has the highest value in the low density pond, the in-pond raceway and is 4g from the highest value in the high density pond.

Statistically, MR X DB, KS X DB, KR X RG and KS X RG rank in the top group in all 3 environments. 103KS X RG ranked in the top group for the pond environments, but had the lowest adjusted body weight in the raceway. 103KS X DB was not different from the top group in the high density pond, but had the lowest weight in the other 2 environments. KR X DB was in the top group in the low density pond, but had the lowest weight in the high density pond. There was a 109, 53 and 68% difference between the genetic type with the largest and smallest weight in the low density pond, high density pond and in-pond raceway, respectively. Thus, choosing the correct genetic type of hybrid could mean a two-fold difference in production.

There was almost a significant sire effect on adjusted body weight in the low density pond as hybrids from the RG males had an observed weight that was 22% higher than that of DB males, but the difference was 6 and -2% for high density ponds and in-pond raceways. Dunham et al. (2014a) found large sire effects for growth rate of hybrids when using different strains, but

Bosworth and Waldbieser (2014) found minimal sire effects within the D & B strain of blue catfish on growth and carcass yield.

In previous studies, dam effects on hybrid growth performance were minimal (Jeppsen 1995; Dunham et al. 2014a), but observed differences in the current study were large in low density pond and in-pond raceway as hybrids from M and K dams were 33-50% larger than those from KS103 dams. However, in the high density pond, these dam effects were near zero.

Bosworth and Waldbieser (2014) examined combining ability in a single strain of blue catfish and channel catfish. Their data indicated that selection for body weight in channel catfish females should result in channel catfish that produce larger hybrids as dam general combining ability was high. However, hybrids produced by KS females selected for increased body weight for 4 generations were virtually identical in size compared to hybrids from KR females, the random control, which grew 55% slower than KS females (Jeppsen 1995), which would indicate no dam general combining ability for increased hybrid growth in Kansas channel catfish females, the opposite of the prediction of Bosworth and Waldbieser (2014) based on full-sib and half-sib analysis. In the current experiment, the results were variable and often in contrast to those of Jeppsen (1995) and, Bosworth and Waldbieser (2014).

KS X RG was 11, 5 and 25% larger than KR X RG in low density ponds, high density ponds and in-pond raceways, respectively, although the difference was not significant in the high density pond. In the case of KS X DB, this hybrid was 6, 152 and 82% larger than KR X DB in low density ponds, high density ponds and in-pond raceways, respectively, with the latter two differences being statistically significant. These results from Kansas females selected for body weight for 8 generations appear to support the results of Bosworth and Waldbieser (2014),

though not those of Jeppsen (1995), who used Kansas females selected for 4 generations. The additional 4 generations of selection appeared to impact the general combining ability.

The example of MS (also selected for 8 generations) is potentially confounded by sire effects. In the high density pond and the in-pond raceway, the MR X DB hybrid is actually larger than the hybrid from the selected females, MS X RG. The one environment where the observed mean of MS X RG is higher than that of MR X DB, MS X RG is aided by potentially positive sire effects. When examining the results of Jeppsen (1995), Bosworth and Waldbieser (2014) and those of the current study, there appears to be strain differences and genotype-environment interactions for combining ability, and combining ability can change with time as allele frequencies change.

Unadjusted final body weight also has relevance. Whether evaluation is done in a communal or separate setting, initial weight will have an impact on final weight. In the case of communal evaluation, the magnification effect can occur (Tave 1986), but the magnification effect has both environmental and genetic effects (Wohlfarth 1977; Dunham et al. 1982b). In the current study, the fish multiple reared (Dunham et al. 1982b) to try to obtain equal starting weights for all genetic types. However, fingerling size was unequal in some cases, and this could have had both environmental and genetic components, but these cannot be partitioned to explain the results of this study as the analysis for the fry to fingerling stage is incomplete.

Theoretically, when the growth was adjusted in the current experiment, genetic superiority at the fingerling stage could be partially negated as an impact, and some of the genetic advantage from fingerling to stocker stage is corrected for since the genetic and environmental impact on the magnification effect was not measured. Thus, analysis of the unadjusted final body weights can give additional genetic perspective since they will include any genetic advantage from the

fingerling stage and the complete genetic advantage of the stocker stage. Unfortunately, the unadjusted final body weights also include any environmental advantages from the fingerling stage, and environmental magnification effects from the stocker stage.

The results are slightly different when examining unadjusted final body weight compared to adjusted final body weight. In this case, MS X RG had the highest body weight in the pond environments instead of KS X RG, but KS X RG still had the highest value in the in-pond raceway.

Statistically, there was more spread among the genetic types as MS X RG was in the top group in each environment joined by KS X RG in two cases and MR X DB in the other. In contrast, after correction for initial body weight, there were 4-5 genetic types in the top group statistically. 103KS XDB was near the lowest unadjusted body weight in all 3 environments but only for 2 of 3 environments for adjusted body weight.

Genotype- environment interactions were observed in regards to sex. There were no significant differences found between males and females for final body weight in high density pond and the in-pond raceway, but there were differences in the low density environment. Jiang et al. (2008) also found one genetic type of hybrid (NWAC103) to be significantly different in total weight and length based on sex when channel catfish, blues and their hybrids were cultured in earthen ponds.

Dunham et al. (2014a) reported varying degrees of sexual dimorphism in channel X blue hybrid. Sexual dimorphism may be related to the size that the fish have reached. In the current experiment, fish in the low density pond and the in-pond raceway were of similar size, yet the

sexual dimorphism was different in these two environments so the type of environment as well as size may have impacts on when sexual dimorphism is seen and its extent.

Females were larger than males in 5 of the 6 cases when sexual dimorphism for body weight was significant. This is an opposite result for most but not all genetic types of hybrids evaluated by Dunham et al. (2014a), and compared to those of Bosworth and Waldbieser (2014) for which males were larger than females. One possible explanation is that the fish in the current study were harvested at a smaller size, and the faster growth of males compared to females may not occur until the fish reach larger sizes.

Size variability in the current study also contrasts with some earlier research. Dunham et al. (1982b) reported that the existence of body weight variability in catfish hybrids was mostly influenced by the male parent, and that channel catfish female X blue catfish male hybrids had a coefficient of variation for body weight of about 10 – 30%, which was less compared to channel catfish. In all 3 environments, variability for body weight was quite high with a coefficient of variation for most groups of approximately 50%. High variability might indicate high stocking density at fry phase (Macaranas et al. 1997; Jiang et al. 2008). Possibly variability was induced during the multiple rearing phase when feed was restricted for some groups. The culture environment apparently did not promote additional variability as the variability in the low density environment was similar to the two high density environments, the high density pond and in-pond raceway.

Survival

Previous studies of channel catfish when cultured in in-pond raceway reported survival rates that ranged between 85.2 to 88% (Wilcox 1998), 81.8% for catfish fry cultured for 90 days

(Carpenter 2001) and between 67 – 83% for channel catfish cultured in earthen ponds (Brown et al. 2011). Survival in the current study was similar to their findings.

Genotype- environment interactions were observed for survival. 103 KS X RG had higher survival rates than the other genetic types in the low density environment and in-pond raceway while KR X RG had the highest value for the high density pond with a survival of 88.7%. MS X RG and MR X DB performed poorly in all the environments. Across environments, hybrids from KR dams had the top two survival rates.

Woods (1994) concluded that in general when channel catfish genetic types were compared for survival the Kansas genetic type was well suited for high density culture, where they showed higher survival rates and growth rates compared to other genetic types. Dunham and Smitherman (1984) also concluded that Kansas strain channel catfish had relatively high disease resistance and Marion strain channel catfish has poor disease resistance. It appears these intraspecific dam effects impact disease resistance and survival in hybrids, and perhaps general combining ability will be high for bacterial disease resistance.

Genotype-environment interactions were observed for both growth and survival in the current study. High mortalities after stocking because of high water temperatures have been found to play an important role in infection rates (Tang, 1996). The experiment was initiated in warm water temperatures and the fish experienced significant handling stress. These factors likely contributed to the mortality caused by columnaris. Stressors such as oxygen depletion and disease have been identified to contribute to the genotype x environment interaction (Brummett, 1980; Ella 1984; Dunham et al., 1986). Disease problems are associated with high stocking densities that could accentuate the G X E interaction.

Seinabilty

Seinability or harvestibility is an undervalued trait. This is an important trait especially in multi-batch production systems since channel x blue catfish hybrids are easier to harvest, thus, there would be less numbers of large fish that remain in the pond and competition for food and production costs would be lower. Fish cannot be sold if they are not captured and still in the culture system. Harvesting can be a significant cost. Fish that are missed and are left in the culture system can reach too large of a size, their FCR becomes worse, they can prevent smaller fish from eating adversely affecting production and FCR and the longer they are in culture, the chance of loss due to disease or predation increases.

The environment had the largest impact on harvestibility by seine. The observed harvestability was lowest in the in-pond raceways. Theoretically, the fish in this environment should be the most harvestable. This illustrates that proper technique needs to be learned to effectively harvest fish in these systems.

No genetic differences were observed among the 8 genetic types within each environment for seinability. However, when sires were pooled, hybrids from D&B males were easier to catch than those from RG males for the in-pond raceways. A genotype-environment interaction occurs though, as there were no sire effects in the other environments. Additionally, there were no pooled dam effects on seinability.

A few possible explanations exist for this genotype-environment interaction in regards to sires. Hybrid catfish tend to swim mid-water to near the surface of the pond (Dunham and Argue 1998), but perhaps RG sired hybrid catfish show less of this behavior. Hybrids from RG blue

catfish sires may only be able to express their superior escapability in the environment of poor seining technique.

CONCLUSION

In the current studies, genetic differences for growth, survival and seinability were found among different genetic types of hybrids. The least amount of differences were found for seinability except there was a major negative impact of RG blue catfish sires for the in-pond raceway. This could impact decisions on what type of hybrid to use in environments that are difficult to harvest.

In regards to body weight, significant genotype-environment interactions existed. This would indicate the necessity of testing the performance of the genetic types of hybrids in multiple culture systems to identify which is the best genotype of hybrid for specific culture system. This also suggests that multiple breeding programs are needed for the multiple culture systems to genetically design hybrids specific for each one.

This is important, but is not critical as if you chose the largest hybrid from the low density environment, it would also be among the largest in the other culture systems. The largest genetic types in the high density pond were also in the top group of genetic types in the other environments. Thus, the genotype-environment interactions have a significant impact, but they do not radically change the rankings. Without adjusting the body weights the same conclusion will be reached.

Genotype-environment interactions were also identified for survival. However, the hybrids from the M dams had lower survival in all environments, so elimination of poor surviving genetic types in one environment would lead to a correct conclusion and elimination in other

environments. The genetic type with the best survival, those from KR dams, was not the fastest growing hybrid.

This complicates identification of the best genetic type of hybrid for all culture systems, and may require selective breeding to change combining abilities so that the highest survival and growth are found in the same genetic type. Additionally, the results obtained suggest that in many cases general combining ability exist in channel catfish dams and selection for general combining ability for growth in channel catfish can increase hybrid catfish performance in multiple environment.

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APPENDIX

Table 10. The logistic regression of the survival of the genetic types of channel (Ictalurus punctatus) female x blue (I. furcatus) male catfish hybrids cultured a low density pond using the heckman model.

Parameter	DF	Estimate	Standard Error	t Value	Approx. Pr > |t|
W.Intercept	1	1.444793	0.026376	54.78	<.0001
W.G 103ks x db	1	0.208699	0.024288	8.59	<.0001
W.G MR X DB	1	0.069848	0.032002	2.18	0.0291
W.G KS X DB	1	0.067237	0.025627	2.62	0.0087
W.G KR X DB	1	0.067715	0.027142	2.49	0.0126
W.G 103ks x rg	1	0.122174	0.024271	5.03	<.0001
W.G MS X RG	1	0.010885	0.037101	0.29	0.7692
W.G KR X RG	1	0.042197	0.024468	1.72	0.0846
W.G KS X RG	0	0			
W.S Female	1	-0.049140	0.013420	-3.66	0.0003
W.S Male	0	0			
_Sigma.W4	1	0.132372	0.004584	28.88	<.0001
U. Intercept	1	0.841621	0.164980	5.10	<.0001
U.G 103ks x db	1	0.099453	0.237323	0.42	0.6752
U.G MR X DB	1	-0.656754	0.220055	-2.98	0.0028
U.G KS X DB	1	-0.258780	0.225698	-1.15	0.2516
U.G KR X DB	1	-2.242946E-8	0.260856	-0.00	1.0000
U.G 103ks x db	1	0.152837	0.239767	0.64	0.5238
U.G MS X RG	1	-0.858333	0.219464	-3.91	<.0001
U.G KR X RG	1	-0.091752	0.230187	-0.40	0.6902
U.G KS X RG	0	0			
_Rho	1	-6.738895E-8	0.407075	-0.00	1.0000

G = Genetic type, S = sex

Table 11. The logistic regression of the survival of the genetic types of channel (Ictalurus punctatus) female x blue (I. furcatus) male catfish hybrids cultured in the high density pond using the heckman model.

Parameter	D	Estimate	Standard Error	t Value	Approx Pr > |t|
W4.Intercept	1	-1.498805	0.036917	-40.60	<.0001
W.G 103ks x db	1	-0.247230	0.035392	-6.99	<.0001
W.G MR X DB	1	-0.042456	0.057275	-0.74	0.4585
W.G KS X DB	1	-0.059265	0.021482	-2.76	0.0058
W.G KR X DB	1	-0.237016	0.022295	-10.63	<.0001
W.G 103ks x rg	1	-0.198821	0.036966	-5.38	<.0001
W.G MS X RG	1	0.075977	0.051463	1.48	0.1399
W.G KR X RG	1	-0.229481	0.026792	-8.57	<.0001
W.G KS X RG	0	0			
W.S Female	1	0.018037	0.010255	1.76	0.0786
W.S Male	0	0			
_Sigma. W	1	0.247996	0.003593	69.02	<.0001
U. Intercept	1	0.570298	0.067622	8.43	<.0001
U.G 103ks x db	1	-0.728439	0.077174	-9.44	<.0001
U.G MR X DB	1	-1.126242	0.096118	-11.72	<.0001
U.G KS X DB	1	-0.308516	0.078810	-3.91	<.0001
U.G KR X DB	1	-0.171443	0.093458	-1.83	0.0666
U.G 103ks x rg	1	-0.680098	0.094251	-7.22	<.0001
U.G MS X RG	1	-1.006096	0.096039	-10.48	<.0001
U.G KR X RG	1	0.628577	0.106459	5.90	<.0001
U.G KS X RG	0	0			
_Rho	1	-0.000000577	0.284150	-0.00	1.0000

G = Genetic type, S = sex

Table 12. Survival analysis of the genetic types of channel (Ictalurus punctatus) female x blue (I. furcatus) male catfish hybrids cultured in a high density pond using the logistic model

Parameter		DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept		1	0.2491	0.0380	42.9098	<.0001
G	103KS X DB	1	-0.5017	0.0641	61.3109	<.0001
G	MR X DB	1	-1.1487	0.1055	118.6090	<.0001
G	KR X DB	1	0.1700	0.0681	6.2366	0.0125
G	103KS X RG	1	0.3920	0.0987	15.7745	<.0001
G	MS X RG	1	-0.4244	0.0985	18.5554	<.0001
G	KS X RG	1	-0.9505	0.1039	83.6940	<.0001
G	KR X RG	1	1.7888	0.1410	160.9943	<.0001

Note: G = Genetic type

Table 13. Survival analysis of the genetic types of channel (Ictalurus punctatus) female x blue (I. furcatus) male catfish hybrids cultured the in-pond raceway using the logistics model

Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	0.3090	0.0382	65.4429	<.0001
G 103KS x DB	1	0.5287	0.0926	32.6020	<.0001
G MR X DB	1	-0.8891	0.0939	89.6568	<.0001
G KS X DB	1	0.0653	0.0960	0.4617	0.4968
G KR X DB	1	0.6360	0.1147	30.7371	<.0001
G 103KS X RG	1	1.0159	0.1025	98.2760	<.0001
G MS X RG	1	-1.5508	0.1099	199.0416	<.0001
G KR X RG	1	0.2922	0.1016	8.2723	0.0040

Note: G = Genetic type

Table 14. ANOVA output for seinability by 1st seine of the different genetic types of channel (Ictalurus punctatus) female x blue (I. furcatus) male catfish hybrids cultured in a low density pond, a high density pond and an in-pond raceway

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Genetic type	7	0.01015329	0.00145047	0.30	0.9441
Environment	2	0.65133358	0.32566679	66.52	<.0001

Table 15. Sexual dimorphism analysis of the genetic types of channel (Ictalurus punctatus) female x blue (I. furcatus) male catfish hybrids cultured in a low density pond

	W2 LSMEAN	G	LSMEAN Number
A	244.814	F	1
B	183.101	M	2

LS-means with the same letter are not significantly different

Table 16. Sexual dimorphism analysis of the genetic types of channel (Ictalurus punctatus) female x blue (I. furcatus) male catfish hybrids cultured in a high density pond

	W2 LSMEAN	G	LSMEAN Number
A	1026.96	F	1
B	917.52	M	2

LS-means with the same letter are not significantly different