Agriculture and Natural Resources 50 (2016) 351–356

Contents lists available at ScienceDirect

Agriculture and Natural Resources

journal homepage: http://www.journals.elsevier.com/agriculture-and-natural-resources/

Original Article

Growth and survival of a diallel cross for five strains of climbing perch (*Anabas testudineus* Bloch, 1792) in Thailand

Nitikorn Piwpong,* Jarunee Chiayvareesajja, Sommai Chiayvareesajja

Department of Aquatic Science, Faculty of Natural Resources, Prince of Songkla University, Hat Yai, Songkhla 90112, Thailand

ARTICLE INFO

Article history:
Received 18 August 2015
Accepted 4 May 2016
Available online 24 December 2016

Keywords:
Anabas testudineus
Absolute growth rate
Crossbred
Genetic improvement
Heterosis

ABSTRACT

A complete diallel cross experiment was conducted with five strains of climbing perch (*Anabas testudineus*) representing three wild populations collected from main river basins in Thailand and two farm populations in southern Thailand. Growth performance was recorded from 794 individually tagged progeny of the 24 different strain combinations after a grow-out period of about 130 d in an earthen pond. Least squares means of body weight at harvest and absolute growth rates were computed for each strain combination. The Chumphon strain showed the highest growth performance (81.1 ± 1.1 g). The Surat Thani × Chumphon (the first strain represents the sire) showed the highest survival (65.4 ± 25.50%) among the purebreds and the crossbreds. The domesticated gene pool had much better growth in aquaculture than the wild gene pool. The correlation between the least squares means of body weight and the survival rates in the 24 strain combinations was 0.51 ($p < 0.05$). The mean heterosis of all crossbreds across traits was negative (−10.2 ± 22.7%). Heterosis appeared to decrease when different gene pools were crossed. This suggests that there may be outbreeding depression. The advantage of crossbred performance was clearly not shown in the study.

Copyright © 2017, Kasetsart University. Production and hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Introduction

Climbing perch (*Anabas testudineus*) is an excellent fish for growing in shallow and seasonal ponds and thus has been an affordable source of animal protein for developing countries, such as India, Bangladesh, Malaysia, Vietnam and Thailand (Sarkar et al., 2005; Kim and Hoan, 2009; Alam et al., 2010; Zalina et al., 2011). This species is sought after due to its air breathing ability and tolerance of adverse environmental conditions such as being able to aestivate (Alam et al., 2010). The climbing perch is commercially important and its value in Thailand was USD 19.13 million in 2010 (Information Technology Center, 2012). However, captive stocks have recently been established; therefore breeding programs for the species are required to improve its performance (Komanpririn et al., 2010).

Crossbreeding aimed at producing superior hybrids resulting from heterosis is widely practiced in plant and animal breeding programs (Falconer and Mackay, 1996; Bryden et al., 2004). Crossbreeding to exploit heterosis is relatively common in the culture of fish such as carp (*Cyprinus carpio*; Bakos and Gorda, 1995; Hulata, 1995). In addition, a number of traits have been shown to exhibit heterosis in Pacific blue shrimp (*Penaeus* (*Litopenaeus*) *stylirostris*; Goyard et al., 2008), rainbow trout (*Salmo gairdneri*; Ayles and Baker, 1983), Chinook salmon (*Oncorhynchus tshawytscha*; Bryden et al., 2004) and tilapia (*Oreochromis niloticus*; Bentsen et al., 1998; Lozano et al., 2011). In particular, diallel crossing has also been employed to establish a genetically diverse synthetic base population prior to initiating a breeding program (Bentsen et al., 1998).

The objective of this study was to examine the growth and survival performance of purebred wild and farmed strains of climbing perch in Thailand and their crossbreds.

Materials and methods

Experimental fish

Five strains—three from wild populations and two from hatchery stocks—of climbing perch were collected during April 2012 to January 2013 (Table 1). The hatchery stocks have been maintained in two hatcheries located in the southern Thailand for approximately 10 years. The wild strains were collected from

* Corresponding author.
E-mail address: piwpong@yahoo.com (N. Piwpong).

http://dx.doi.org/10.1016/j.anres.2016.05.001
2452-316X/Copyright © 2017, Kasetsart University. Production and hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Table 1
Details of climbing perch germplasm collections.

Strain ID	Strain name	Origin
N	Nakhon Phanom	Wild population collected from rice field in Nakhon Phanom province, Mekong River basin.
P	Phetchaburi	Wild population collected from a natural fish pond in Phetchaburi province, Chao Phraya River basin.
K	Nakhon Si Thammarat	Wild population collected from swamp in Amphoe Pak Phanang, Nakhon Si Thammarat province, a peninsular Thailand area.
C	Chumphon	Hatchery population, Chumphon Aquaculture Genetics Research and Development Center, broodstock originated from a fish farm in Nakhon Si Thammarat province in 2005 and improved growth rate by mass selection for four generations.
S	Surat Thani	Hatchery population, Amporn Farm, broodstock originated from three fish farms in Nakhon Si Thammarat, Phatthalung and Samut Prakan province for established base population in 2004. The deliberately selected population has been improved through mass selection for better growth rate (one generation/yr for 10 generations).

Nakhon Phanom, Phetchaburi and Nakhon Si Thammarat which represented three geographic areas: the Mekong River basin, the Chao Phraya River basin, and a peninsular Thailand area, respectively. These three geographic areas possess distinct genetic differences of conspecific fish species as reported by Sekino and Hara (2000), Na-Nakorn et al. (2004) and Hidayat and Senanan (2010). About 1000 juveniles of each wild strain were collected and transported to Amporn farm, a private fish farm in Surat Thani province, and quarantined for approximately 1 yr in separate cages of 15 m^2, with a density of 60–70 individuals/m^2.

Breeding of the tested strains

Breeding occurred during July to September 2013. A diallel cross and a hierarchical mating design with two or three dams per sire were performed. Each single-pair mating was performed in a 40 cm^2 × 50 cm^2 polystyrene box with a water depth of 30 cm. The broodstocks were injected with LH–RH analogue (trade name, Suprefact) at doses of 20 μg/kg for females and 10 μg/kg for males, together with 5 mg/kg domperidone. The detail of breeders contributing progeny is given in Table 2. However, to establish a broad genetic base population for further breeding programs, missing strain combinations due to unsuccessful mating were replaced by S × S crosses because the S strain can spawn all year round. Fourteen hours after the injection, the spawning boxes were examined for fertilized eggs and then the brood fish were removed. After that, the fertilized eggs were left to hatch out in each spawning box which took on average 24 h.

Newly hatched larvae were transferred to 1.0 m^2 × 1.0 m^2 polyethylene cages with a water depth of 0.5 m, which floated in a 400 m^2 earthen pond at a stocking density of 20 larvae/L for 10 d. After that, the fry was transferred to fine-mesh hapas (1.0 m^2 × 3.0 m^2, 1 m in depth) and were cultured for 38–68 d (48 ± 6.5 d). The feeding scheme was: rotifers (*Brachionus* sp.) were given to 3–10 day-old post-hatching larvae (of which the yolk-sac was almost fully absorbed) with a density of 100 rotifer individuals/mL/d; water flea (*Moina macrocopa*) were given to 8–15 day-old fry with a density of 10 water flea individuals/mL/d; artificial powder feed was given to 16–40 day-old fry twice a day; and small pellets containing 40% crude protein (Charoen Pokphand Feed Company, Ltd.) were given to 41–68 day-old fingerlings twice daily, until they reached a tagged size of 10–15 g (modified from Amornsakun et al., 2005).

Table 2
Number of breeders of climbing perch contributing progeny to each of the 24 strain combinations.

Sire strain	Dam strain				
	N	P	C	S	K
N	¾	1/2	1/3	1/1	2/3
P	2/3	5/8	1/2	2/6	2/4
C	3/6	2/4	2/6	2/6	1/3
S	2/5	1/3	2/6	14/22	2/6
K	2/5	2/3	0/0	2/4	3/6

Tagging

The fry (13.0 ± 6.9 g) were anesthetized in cold water at 3–4 °C for 1–2 min to avoid handling stress, and the body weight was recorded (initial weight). Then, the fish were individually tagged using hot branding and one dorsal fin spine was up-rooted if hot branding signs were not enough (Duerasor and Chiayvareesajja, 2013). Because tagged fish aggressively bit each other, each tagged fish was conditioned separately in a 600 mL plastic drinking water bottle without feeding, and 20 parts per million chlorinated water was completely changed every 3 d, for a 10 d healing period before stocking. In December 2013, 2873 tagged fingerlings representing 121 full-sib families were communally stocked in a 400 m^2 earthen pond at Amporn Farm.

Pond grow-out

The grow-out stocking density was 7 individuals/m^2. With such a low density, aeration was not required. Water exchange was undertaken at least twice a month or when required. Juvenile fish were fed with commercial catfish pellets containing 35% crude protein (Charoen Pokphand Feed Company, Ltd.), and a feed with a lower protein content (30%) was used during the last four grow-out weeks.

Data collection

After a rearing period of about 130 d, in May 2014, all fish were harvested and each individual body weight was recorded. The absolute growth rate [absolute growth rate = (harvest weight − initial weight)/number of rearing days] was calculated for each sex in each strain combination (Koolboon et al., 2014). The sex of fish was identified by external appearance wherever possible, and the immature fish whose sex could not be identified were recorded as “un-identified sex”. The survivors were enumerated and survival rates were calculated. Fish without a tag (due to tag loss) were discarded from the analyses. Correlation was estimated between least squares means of body weight and survival rates (Becker, 1992).

Data analysis

Heterosis was calculated using Equation (1) (Falconer and Mackay, 1996):

$$\text{Heterosis (H)} = \frac{\overline{X}_H - \overline{X}_P}{\overline{X}_P} \times 100 \quad (1)$$

where $\overline{X}_P$ = mean of parent and $\overline{X}_H$ = mean of crossbred.

The body weight was analyzed with the model using the lm function of the statistical software R version 3.1.3 (Sheather, 2009). Model I used is shown in Equation (2):

$$Y_{bcdfg} = \mu + W_b + D_c + S_d + C_f + e_{bcdfg} \quad (2)$$

where Y_{bcdfg} is the body weight of the gth individual; μ is the common mean; W_b is the fixed effect of the initial weight; D_c is the fixed effect of the grow-out period (measured in days); S_d is the fixed effect of dth sex (d = 1 for male, 2 for female and 3 for unidentified sex); C_f is the fixed effect of the fth strain combination (f = 1, 2, …, 24); and e_{bcdfg} is the random residual effect.

Gene pool performance

The domesticated gene pool (DD) consisted of the two farmed strains (C and S) and the reciprocal crossbreds. The wild gene pool (WW) consisted of the pure wild strains (N, P and K) and the reciprocal crossbreds. The crossbred gene pool (WD) consisted of the crossbreds between the domesticated gene pool and the wild gene pool, and the reciprocal crossbreds. The body weight and the survival rate of gene pools were analyzed using the model and the lm function in R. Model II was used and is shown in Equation (3):

$$Y_i = \mu + bX_i + e_i \quad (3)$$

where Y_i is the body weight or the survival rate of the ith gene pool; μ is the common mean; b is the regression coefficient of the dependent variable on the gene pool; X_i is the gene pool (DD, WW and WD) and e_i is the random residual effect. The MultcompView package of the R package was used for multiple comparisons of least squares means (Lenth, 2015).

Results

The harvest body weight for male, female and unidentified sex of all purebreds and crossbreds in climbing perch was 38.0 ± 19.0 g, 105.9 ± 48.9 g and 49.2 ± 32.2 g, respectively. The female body weight was significantly ($p < 0.01$) higher than the male and unidentified sex fish. The fixed effects of sex, initial weight, grow-out period and strain combinations in Model I were highly significant ($p < 0.01$). Likewise, the sex contributed greatly to significant growth trait. The proportion of the variation explained by Model I (coefficient of determination, R^2) was 0.66. The overall survival rate of the experimental fish was 54.7% including the tag-lost fish and reduced to 27.6% when tag loss was taken into account.

Growth performance

Males of the C strain showed the highest absolute growth rate (0.35 ± 0.20 g/d) which was not significantly ($p > 0.05$) different from the S strain and P × C, C × S and S × C crossbreds, but had a significantly ($p < 0.05$) larger absolute growth rate than those of the remaining purebreds and crossbreds. Similarly, for females, the C strain showed the highest growth rate (1.09 ± 0.31 g/d) which was not significantly ($p > 0.05$) different from the S strain and P × C, C × S, S × P and S × C crossbreds, but had a significantly ($p < 0.05$) larger absolute growth rate than those of the remaining purebreds and crossbreds (Table 3).

Table 3
Absolute growth rate of males and females and body weight of the 24 strain combinations of climbing perch reared in an earthen pond for 130 d. Means in the same column superscripted with different uppercase letters are significantly different ($p < 0.05$).

Strain	Male (g/d) mean ± SD	Female (g/d) mean ± SD	Body weight (g) mean ± SD
Purebred			
N × N	0.08 ± 0.04^{DE}[b]	0.31 ± 0.15^{FG}	25.1 ± 13.7^{J}
P × P	0.17 ± 0.15^{BCDE}	0.42 ± 0.12^{EFG}	53.3 ± 26.5^{DEFG}
C × C	0.35 ± 0.20^{A}	1.09 ± 0.31^{A}	107.7 ± 55.2^{A}
S × S	0.29 ± 0.13^{ABC}	1.03 ± 0.36^{AB}	91.8 ± 56.6^{ABC}
K × K	0.11 ± 0.04^{DE}	0.21 ± 0.10^{G}	29.0 ± 13.5^{IJ}
Crossbred			
N × P	0.08 ± 0.02^{DE}	0.32 ± 0.09^{FG}	36.9 ± 19.0^{FGHIJ}
N × C	0.08 ± 0.09^{DE}	0.44 ± 0.12^{EFG}	39.0 ± 22.4^{FGHIJ}
N × S	–[a]	–	25.4 ± 2.3^{J}
N × K	–	–	25.5 ± 7.7^{J}
P × N	0.18 ± 0.08^{BCDE}	0.42 ± 0.28^{EFG}	49.1 ± 29.5^{DEFGHI}
P × C	0.21 ± 0.10^{ABCDE}	0.81 ± 0.10^{ABCDE}	67.4 ± 46.6^{BCDE}
P × S	0.15 ± 0.05^{CDE}	0.63 ± 0.22^{CDEF}	73.2 ± 36.8^{ABCD}
P × K	0.11 ± 0.05^{DE}	–	38.1 ± 19.0^{FGHIJ}
C × N	–	0.42 ± 0.28^{EFG}	69.6 ± 33.5^{ABCD}
C × P	0.30 ± 0.11^{ABC}	0.58 ± 0.20^{DEFG}	57.1 ± 28.1^{CDEF}
C × S	0.23 ± 0.17^{ABCDE}	0.95 ± 0.49^{ABC}	73.3 ± 55.8^{BCDE}
C × K	0.10 ± 0.05^{DE}	0.51 ± 0.11^{EFG}	55.3 ± 28.9^{DEFG}
S × N	0.10 ± 0.03^{DE}	0.43 ± 0.15^{EFG}	41.3 ± 23.1^{EFGHIJ}
S × P	0.25 ± 0.21^{ABCD}	0.90 ± 0.38^{ABCD}	77.0 ± 55.8^{BCD}
S × C	0.33 ± 0.20^{AB}	0.97 ± 0.29^{ABC}	95.6 ± 47.6^{AB}
S × K	0.16 ± 0.06^{BCDE}	0.66 ± 0.27^{BCDEF}	54.7 ± 38.1^{DEFGH}
K × N	–	–	37.7 ± 34.2^{IJK}
K × P	0.06 ± 0.05^{E}	0.43 ± 0.19^{EFG}	35.3 ± 21.7^{GHIJ}
K × S	0.16 ± 0.10^{BCDE}	0.52 ± 0.28^{EFG}	62.2 ± 37.2^{CDEF}

[a] No data—probably because all fish died in each sex or unidentified sex fish.
[b] Duncan's new multiple-range test used for multiple comparisons.

The body weight and least squares mean of body weight gave a similar picture to the absolute growth rate. The C strain showed the highest body weight (107.7 ± 55.2 g) which was not significantly ($p > 0.05$) different from the S strain and P × S, C × N and S × C crossbreds, but had a significantly ($p < 0.05$) larger body weight than those of the remaining purebreds and crossbreds (Table 3). Based on least squares means of body weight, the C strain showed the highest body weight (81.1 ± 1.1 g) which was not significantly ($p > 0.05$) different from the S strain and P × C, C × S and S × C crossbreds, but had a significantly ($p < 0.05$) larger body weight than those of the remaining purebreds and crossbreds (Table 4).

Survival rate

The survival rates among the purebreds and the crossbreds varied considerably and ranged from 9.4% in the N × S (no SD because there was only one family in this cross) to 65.4 ± 25.5% in the S × C. Among the purebreds, the survival rates were low. The P strain was the best (37.5 ± 15.87%) and the N strain was the poorest (23.1 ± 14.12%). The survival rate of the S × C was significantly ($p < 0.05$) higher than those of N × N, N × P, P × N, P × C, P × K, C × N, C × K, K × N and K × S, but was not significantly ($p > 0.05$) different from those of the remaining purebreds and crossbreds (see details in Table 4).

The correlation between the least squares means of body weight and the survival rates in the 24 strain combinations was 0.51 and significantly ($p < 0.05$) different from zero. Growth and survival under the test conditions were positively correlated with each other. There was no trade-off between these two major components of production.

Table 4
Crossbreds of climbing perch in the diallel cross, number of recorded fish per crossbreds (n), least squares mean of body weight (LSM), heterosis of each crossbred estimated from the least squares mean (HBW), survival rate (SUR), heterosis of survival rate (HS), average heterosis (AH) between HBW and HS and gene pools (GP). Means ± SE in the same column superscripted with different uppercase letters are significantly different ($p < 0.05$).

Strain	n	LSM (g)	HBW (%)	SUR (%)	HS (%)	AH (%)	GP
Purebred							
N × N	28	29.9 ± 1.1^{I}	–	23.1 ± 14.12^{BC}	–	–	WW
P × P	94	47.9 ± 1.1^{DEFG}	–	37.5 ± 15.87^{ABC}	–	–	WW
C × C	44	81.1 ± 1.1^{A}	–	28.7 ± 15.11^{ABC}	–	–	DD
S × S	142	68.3 ± 1.0^{ABC}	–	36.6 ± 19.84^{ABC}	–	–	DD
K × K	45	33.7 ± 1.1^{HI}	–	23.3 ± 16.48^{ABC}	–	–	WW
Crossbred							
N × P	9	34.2 ± 1.2^{DEFGHI}	−12.1	15.6 ± 3.20^{BC}	−48.5	−30.3	WW
N × C	19	41.7 ± 1.1^{DEFGHI}	−24.9	25.1 ± 13.03^{ABC}	−3.0	−14.0	WD
N × S	3	35.1 ± 1.3^{BCDEFGHI}	−28.6	9.4[a]	−68.5	−48.6	WD
N × K	10	29.6 ± 1.1^{GHI}	−7.0	25.5 ± 21.25^{ABC}	10.1	1.6	WW
P × N	16	37.4 ± 1.1^{DEFGHI}	−4.0	23.3 ± 14.69^{BC}	−23.2	−13.6	WW
P × C	12	56.4 ± 1.1^{ABCDEFG}	−12.6	42.9 ± 60.60^{BC}	29.6	8.5	WD
P × S	44	52.4 ± 1.1^{CDEBCDEF}	−9.9	37.6 ± 30.99^{ABC}	1.5	−4.2	WD
P × K	14	37.9 ± 1.1^{DEFGHI}	−7.0	20.9 ± 16.09^{BC}	−31.1	−19.1	WW
C × N	13	47.2 ± 1.1^{BCDEFGHI}	−15.1	10.1 ± 12.96^{BC}	−60.9	−38.0	WD
C × P	23	51.6 ± 1.1^{CDEFG}	−20.0	20.4 ± 17.81^{ABC}	−38.5	−29.3	WD
C × S	25	58.1 ± 1.1^{ABCD}	−22.3	34.5 ± 55.45^{ABC}	5.6	−8.4	DD
C × K	12	48.8 ± 1.1^{BCDEFGH}	−15.1	17.7 ± 7.48^{BC}	−31.8	−23.5	WD
S × N	46	35.7 ± 1.1^{GHI}	−27.4	33.3 ± 14.40^{ABC}	11.5	−8.0	WD
S × P	17	50.9 ± 1.1^{BCDEFGH}	−12.4	32.1 ± 7.53^{ABC}	−13.4	−12.9	WD
S × C	72	74.5 ± 1.1^{AB}	−0.2	65.4 ± 25.50^{A}	100.3	50.1	DD
S × K	45	45.3 ± 1.1^{DEFGH}	−11.1	48.9 ± 9.87^{AB}	63.4	26.2	WD
K × N	8	29.9 ± 1.2^{EFGHI}	−5.9	14.3 ± 20.47^{C}	−38.2	−22.1	WW
K × P	23	35.0 ± 1.1^{FGHI}	−14.2	39.2 ± 11.23^{ABC}	29.0	7.4	WW
K × S	25	52.3 ± 1.1^{BCDEF}	2.6	19.3 ± 2.56^{BC}	−35.7	−16.6	WD

[a] no SD because of only one family in this cross.

Gene pool performance and heterosis

The least squares mean of the body weight of DD (70.5 ± 3.51 g) was significantly ($p < 0.05$) higher than the least squares means of body weight of WW and WD (35.0 ± 2.34 g and 47.0 ± 2.12 g, respectively). In addition, the survival rate of DD (41.3 ± 6.07%) was not significantly ($p > 0.05$) higher than the survival rates of WW and WD (24.7± 4.05% and 27.0 ± 3.66%, respectively). The DD performed much better in aquaculture than the WW.

The mean heterosis of all crossbred across traits was −10.2 ± 22.70 (Table 4). The means of average heterosis of DD and WW were 20.9 ± 41.29% and −12.7 ± 14.45%, respectively, and higher than the mean heterosis of WD which was −14.6 ± 20.85% (Table 5).

Discussion

The relatively low survival rate was probably caused by Gram-negative bacterial infection. The recorded survival rates were likely biased downwards because of the fish that has lost their tags (49.5%). However, tag loss was assumed to happen at random across strain combinations.

Sexual dimorphism in growth is very pronounced in climbing perch, with females growing significantly faster than males, as displayed in the body weight and absolute growth rate. This differential growth effect has been reported in many aquatic species, including silver barb (*Puntius gonionotus* Bleeker; Pongthana et al., 1999), Eurasian perch (*Perca fluviatilis*; Rougeot et al., 2002) and giant tiger prawn (*Penaeus monodon*; Gopal et al., 2010).

Table 5
Least squares mean (LSM) of climbing perch gene pools: domesticated gene pool (DD), wild gene pool (WW) and crossbred gene pool (WD) from Model II and means of average heterosis. Means ± SE in the same column superscripted with different uppercase letters are significantly different ($p < 0.05$).

Gene pool	LSM body weight (g)	LSM survival (%)	Mean of average heterosis (%)
DD	70.5 ± 3.51^{A}	41.3 ± 6.07^{A}	20.9 ± 41.29
WW	35.0 ± 2.34^{B}	24.7 ± 4.05^{A}	−12.7 ± 14.45
WD	47.0 ± 2.12^{C}	27.0 ± 3.66^{A}	−14.6 ± 20.85

The least squares mean was used to compare the growth performance of the purebreds and the crossbreds because of differences in the initial weights corrected by Model I. The farmed strains (S and C) showed higher growth than the wild strains (N, K and P). The domesticated gene pool performed much better in aquaculture than the wild gene pool. In addition, among the purebreds and the crossbreds, the C strain showed the highest growth performance, as indicated by the consistent results of the least squares mean and absolute growth rate. This shows the effectiveness of mass selection for domesticating and improving the growth rate (Ponzoni et al., 2010). There are cases in aquatic species in which truly domesticated and selected strains perform better over time under cultured environments due to their better adaptation to captive environments, for example, Nile tilapia (*O. niloticus*; Chiayvareesajja et al., 1999), Atlantic salmon (*Salmo salar*; Gjedrem et al., 2012) and white shrimp (*Litopenaeus vannamei*; Cuéllar-Anjel et al., 2012). Domestication has brought about gains in growth and survival.

The poor survival in the wild strains: may be explained by their inability to adapt to cultured environments (Thanh et al., 2009) whereas inbreeding may account for the poor survival of the farmed strains. Inbreeding affects traits related to fitness, such as survival and disease resistance (Nielsen et al., 2010). According to Komanpririn et al. (2010), the C strain was developed by crossing 30 males and 30 females of brood fish in the mass selection program. There is a considerable risk that the small effective population size has caused much higher inbreeding. This is in agreement with Hidayat and Senanan (2010) who indicated that the C strain had lower genetic diversity than wild strains. Mass selection suggested that rapid accumulation of inbreeding may have counteracted the response to selection (Bentsen and Olesen, 2002). However, it is

also accepted that with such low rates of inbreeding, natural and artificial selection would be able to counter any deleterious effects (Ponzoni et al., 2010). It should be noted that if it is assumed that tag loss occurred at random, the survival rate of each wild and farm strain was increased to 29.4, 47.7, 36.5, 46.5 and 29.6 for N × N, P × P, C × C, S × S, and K × K, respectively.

The S × C (65.4 ± 25.50%) strain combinations showed higher survival than the purebreds and the crossbreds, suggesting that this crossbred is more resistant to stress or pathogens or both than the purebreds and the crossbreds (Wachirachaikarn et al., 2009). It is noteworthy that the survival of the reciprocal crosses between the S strain and the C strain were different, where the S × C had higher survival than the C × S (34.5 ± 55.45%). Differences in reciprocal effects likely indicate maternal effects, sex-linked genes or cytoplasmic inheritance (Bentsen et al., 1998). This effect may justify the use of particular sire or dam lines for a more effective crossbreeding program, but this would need much more investigation because of the small sample size in the current study.

In general, breeding of genetically divergent strains results in heterosis, which is caused by overdominance or masking of the expression of deleterious genes that are particularly associated with overall fitness (Falconer and Mackay, 1996). However, crossbreeding of genetically distant strains may result in outbreeding depression caused by a break-down of favorable gene complexes accumulated during the adaptation process (Granier et al., 2011). None of the favorable heterosis of body weight was observed in this study, except for K × S, which was similar to the results of Refstie (1983), Horstgen-Schwark et al. (1986), Wachirachaikarn et al. (2009), and Pillai et al. (2011). The mean of average heterosis appeared to decrease when different gene pools were crossed, suggesting that there may be outbreeding depression in the F1 crosses. Nevertheless, in general terms, heterosis tended to be restored after fitness suffered a reduction from inbreeding in carp (*C. carpio*; Bakos and Gorda, 1995) and tilapia (*O. niloticus*; Bentsen et al., 1998).

In conclusion, crossbred performance must be significantly superior to the best purebreds to justify a crossbreeding program. This was clearly not the case in the current study. Indeed, crossbred performance was markedly worse, especially between the wild and farmed strains, so outbreeding depression (presumably due to local adaptation) is a real possibility. However, the statistically significant superior growth performance from strains and crosses containing genes from the farm population showed that progress has been made during domestication. This is very satisfying. Therefore, data from the current study will be exploited further to estimate the magnitude of additive genetic components that contributed to improved growth and survival performances in the pure and crossbred farm populations and provided a starting point for a selection program to improve the cultured stock of climbing perch in Thailand.

Conflict of interest statement

The authors declare that there are no conflicts of interest.

Acknowledgements

This study formed part of the first author's Ph.D. study. The experiment was partly funded by the Graduate School, Prince of Songkla University, Thailand. The authors would like to thank the Amporn farm staff—Mr Sahapat Duerasor and Mr Thanatat Uaewiwatsakul for their kind help in rearing the fish and supporting the experiment. Thanks are also expressed to Dr Akarapong Swatdipong and Dr Puttharat Baoprasertkul for reviewing the manuscript. We wish to thank Dr Sanga Leesanga for his valuable advice and for the fish samples from the Chumphon Aquaculture Genetics Research and Development Center, Department of Fisheries, Thailand.

References

Alam, J., Mustafa, G., Islam, M., 2010. Effects of some artificial diets on the growth performance, survival rate and biomass of the fry of climbing perch, *Anabas testudineus* (Bloch, 1792). Nat. Sci. 8, 36–42.

Amornsakun, T., Sriwatana, W., Promkaew, P., 2005. Some aspects in early life stage of climbing perch, *Anabas testudineus* larvae. Songklanakarin J. Sci. Technol. 27, 403–418.

Ayles, G.B., Baker, R.F., 1983. Genetic differences in growth and survival between strains and hybrids of rainbow trout (*Salmo gairdneri*) stocked in aquaculture lakes in the Canadian prairies. Aquaculture 33, 269–280.

Bakos, J., Gorda, S., 1995. Genetic improvement of common carp strains using intraspecific hybridization. Aquaculture 129, 183–186.

Becker, W.A., 1992. Manual of Quantitative Genetics, fifth ed. Academic Enterprises, Pullman: WA, USA.

Bentsen, H.B., Olesen, I., 2002. Designing aquaculture mass selection programs to avoid high inbreeding rates. Aquaculture 204, 349–359.

Bentsen, H.B., Eknath, A.E., Vera, M.S.P., et al., 1998. Genetic improvement of farmed tilapias: growth performance in a complete diallel cross experiment with eight stocks of *Oreochromis niloticus*. Aquaculture 160, 145–173.

Bryden, C.A., Heath, J.W., Heath, D.D., 2004. Performance and heterosis in farmed and wild chinook salmon (*Oncorhynchus tshawytscha*) hybrid and purebred crosses. Aquaculture 235, 249–261.

Chiayvareesajja, J., Rø, K.H., Eknath, A.E., Danting, J.C., Vera, M.P.D., Bentsen, H.B., 1999. Genetic variation in lytic activities of blood serum from Nile tilapia and genetic associations with survival and body weight. Aquaculture 175, 49–62.

Cuéllar-Anjel, J., White-Noble, B., Schofield, P., Chamorro, R., Lightner, D.V., 2012. Report of significant WSSV-resistance in the Pacific white shrimp, *Litopenaeus vannamei*, from a Panamanian breeding program. Aquaculture 368–369, 36–39.

Duerasor, S., Chiayvareesajja, J., 2013. Marking techniques for genetic improvement in climbing perch *Anabas testudineus* (Bloch, 1792). In: Proceedings of the 11th Academic Agriculture Naresuan Conference. Naresuan University, Phitsanulok, Thailand, pp. 502–509 [in Thai].

Falconer, D.S., Mackay, T.F.C., 1996. Introduction to Quantitative Genetics, fourth ed. Pearson Education Ltd, Harlow, UK.

Gjedrem, T., Robinson, N., Rye, M., 2012. The importance of selective breeding in aquaculture to meet future demands for animal protein: a review. Aquaculture 350–353, 117–129.

Gopal, C., Gopikrishna, G., Krishna, G., et al., 2010. Weight and time of onset of female-superior sexual dimorphism in pond reared *Penaeus monodon*. Aquaculture 300, 237–239.

Goyard, E., Goarant, C., Ansquer, D., et al., 2008. Cross breeding of different domesticated lines as a simple way for genetic improvement in small aquaculture industries: heterosis and inbreeding effects on growth and survival rates of the Pacific blue shrimp *Penaeus (Litopenaeus) stylirostris*. Aquaculture 278, 43–50.

Granier, S., Audet, C., Bernatchez, L., 2011. Heterosis and outbreeding depression between strains of young-of-the-year brook trout (*Salvelinus fontinalis*). Can. J. Zool. 89, 190–198.

Hidayat, S., Senanan, W., 2010. PCR-RFLP analysis of mitochondrial DNA to differentiate populations of climbing perch (*Anabas testudineus*) in Thailand. Burapha Sci. J. 15, 87–98.

Horstgen-Schwark, G., Fricke, H., Langholz, H.J., 1986. The effect of strain crossing on the production performance in rainbow trout. Aquaculture 57, 141–152.

Hulata, G., 1995. A review of genetic improvement of the common carp (*Cyprinus carpio* L.) and other cyprinids by crossbreeding, hybridization and selection. Aquaculture 129, 481–491.

Information Technology Center, 2012. Fisheries Statistics of Thailand 2010. Department of Fisheries, Ministry of Agriculture and Cooperatives, Thailand. Technical Paper No. 12/2012.

Kim, V.V., Hoan, V.Q., 2009. Intensive nursing climbing perch (*Anabas testudineus*) in hapas using pellet feed at different protein levels. J. Sci. Dev. 7, 239–242.

Komanpririn, K., Leesanga, S., Jul-a-dung, S., 2010. Genetic Improvement of Climbing Perch (*Anabas testudineus* Bloch, 1792) by Mass Selection. Aquatic Animal Genetics Research and Development Institute, Department of Fisheries, Ministry of Agriculture and Cooperatives, Thailand. Technical Paper No. 1/2010. [in Thai].

Koolboon, U., Koonawootrittriron, S., Kamolrat, W., Na-Nakorn, U., 2014. Effects of parental strains and heterosis of the hybrid between *Clarias macrocephalus* and *Clarias gariepinus*. Aquaculture 424–425, 131–139.

Lenth, R.V., 2015. Using lsmeans. https://cran.r-project.org/web/packages/lsmeans/vignettes/using-lsmeans.pdf, 30 December 2015.

Lozano, C., Gjerde, B., Bentsen, H.B., Dionisio, E.E., Rye, M., 2011. Estimates of strain additive genetic, heterosis and reciprocal effects for male proportion in Nile tilapia, *Oreochromis niloticus* L. Aquaculture 312, 32–42.

Na-Nakorn, U., Kamonrat, W., Ngamsiri, T., 2004. Genetic diversity of walking catfish, *Clarias macrocephalus*, in Thailand and evidence of genetic introgression from introduced farmed *C. gariepinus* genome. Aquaculture 240, 145–163.

Nielsen, H.M., Ødegård, J., Olesen, I., Gjerde, B., Ardo, L., Jeney, G., Jeney, Z., 2010. Genetic analysis of common carp (*Cyprinus carpio*) strains I: genetic parameters and heterosis for growth traits and survival. Aquaculture 304, 14–21.

Pillai, B.R., Mahapatra, K.D., Ponzoni, R.W., et al., 2011. Genetic evaluation of a complete diallel cross involving three populations of freshwater prawn (*Macrobrachium rosenbergii*) from different geographical regions of India. Aquaculture 319, 347–354.

Pongthana, N., Penman, D.J., Baoprasertkul, P., Hussain, M.G., Islam, M.S., Powell, S.F., McAndrew, B.J., 1999. Monosex female production in the silver barb (*Puntius gonionotus* Bleeker). Aquaculture 173, 247–256.

Ponzoni, R.W., Khaw, H.L., Nguyen, N.H., Hamzah, A., 2010. Inbreeding and effective population size in the Malaysian nucleus of the GIFT strain of Nile tilapia (*Oreochromis niloticus*). Aquaculture 302, 42–48.

Refstie, T., 1983. Hybrids between salmonid species. Growth rate and survival in seawater. Aquaculture 33, 281–285.

Rougeot, C., Jacobs, B., Kestemont, P., Melard, C., 2002. Sex control and sex determinism study in Eurasian perch, *Perca fluviatilis*, by use of hormonally sex-reversed male breeders. Aquaculture 211, 81–89.

Sarkar, U.K., Deepak, P.K., Kapoor, D., Negi, R.S., Paul, S.K., Singh, S., 2005. Captive breeding of climbing perch *Anabas testudineus* (Bloch, 1792) with Wova-FH for conservation and aquaculture. Aquacult. Res. 36, 941–945.

Sekino, M., Hara, M., 2000. Genetic characteristics and relationships of climbing perch *Anabas testudineus* populations in Thailand. Fish. Sci. 66, 840–845.

Sheather, S.J., 2009. A Modern Approach to Regression with R. Springer Science + Business Media, New York, NY, USA.

Thanh, N.M., Ponzoni, R.W., Nguyen, N.H., Vu, N.T., Barnes, A., Mather, P.B., 2009. Evaluation of growth performance in a diallel cross of three strains of giant freshwater prawn (*Macrobrachium rosenbergii*) in Vietnam. Aquaculture 287, 75–83.

Wachirachaikarn, A., Rungsin, W., Srisapoome, P., Na-Nakorn, U., 2009. Crossing of African catfish, *Clarias gariepinus* (Burchell, 1822), strains based on strain selection using genetic diversity data. Aquaculture 290, 53–60.

Zalina, I., Saad, C.R., Rahim, A.A., Christianus, A., Harmin, S.A., 2011. Breeding performance and the effect of stocking density on the growth and survival of climbing perch, *Anabas testudineus*. J. Fish. Aquat. Sci. 6, 834–839.