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Interpopulation crossbreeding of farmed and wild African catfish *Clarias gariepinus* (Burchell 1822) in Indonesia at the nursing stage

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Abstract – Introduced African catfish *Clarias gariepinus* (Burchell 1822) have been cultivated in Indonesia since 1985 and have made a significant contribution to aquaculture production. Unfortunately, the rapid development of catfish farming was not accompanied by proper genetic improvement of broodstock and this led to poor production performances. A method that can potentially provide rapid improvement in the genetic quality of broodstock is the crossbreeding technique. The present study evaluated growth and survival performances up to 81 days post-hatching (nursing stage) of reciprocal interpopulation crossbreeds generated from five existing introduced African catfish populations in Indonesia, i.e. from Indonesia, Egypt, Kenya, the Netherlands and Thailand. Artificial spawning was applied to form five purebred populations and 20 crossbreed populations. There were significant differences in body length growth (specific growth rate – SGR), survival rate (SR) and number of over-size fish (OS) averages. The Egypt female × Netherlands male (EN) crossbreed showed the best performance with cumulative SGR, SR, and OS of 9.69 ± 0.03%, 63.98 ± 6.75% and 0.22 ± 0.04%, respectively. The result also revealed a correlation between the OS and the SR; the higher the OS, the lower the SR. This correlation tended to be weak at the sequential nursing stages. Our study suggested that the EN crossbreed has high potential to improve offspring quality in the near future.

Keywords: African catfish / interpopulation crossbreed / growth variation / survival

Introduction

In Indonesia, clariid catfish farming began in the 1970s using a local species, *Clarias batrachus* (Linnaeus 1758). At first, farmers collected the offspring from the wild and reared fish in backyard hatcheries. With the introduction of the African catfish, *Clarias gariepinus,* in 1985, fish farmers replaced the local species because the new introduced species had superior performance, including faster growth, higher disease resistance, higher fecundity, and easier reproduction in captivity, which guaranteed mass production of offspring (Sunarma 2004). The success of clariid catfish species has led to rapid development of catfish aquaculture in Indonesia and has increased national production on average by 40% per year from 91 000 tons in 2007 to 337 000 tons in 2011 (MMAF 2013). The success of catfish production has mostly been the result of small-scale fish farming with typical cultivation techniques, such as natural spawning and nursing and grow-out stage at an outdoor plastic-based pond (Sunarma et al. 2014). Although an economic success story, production on a small scale has also potentially led to introduced-catfish escape into the natural environment, which could threaten local catfish by competition for food and other resources. In several cases, fishermen have had catches of large size African catfish (>10 kg) in rivers, despite little abundance of the juveniles were found. Indeed, there are no reports on the impact of invasive introduced-catfish on the local catfish in Indonesian waters.

However, the rapid development of catfish farming did not coincide with efforts to produce good quality broodstock as well as offspring for the fish farmers. Nurhidayat et al. (2003) reported inbreeding depression of introduced catfish in Indonesia after an 18-year farming period, using a fluctuating asymmetry predictor that indicated evidence of poor genetic quality. The growth decline allegedly related to a lack of maintenance of genetic quality and genetic degradation in farmed strains (Dunham et al. 2001), as reported in African catfish in Thailand (Wachirachaikarn et al. 2009).

Given the evidence of genetic vulnerability for introduced African catfish in Indonesia, genetic improvement efforts have

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Table 1. Introduced African catfish populations in Indonesia used in the study.

Population	Country of origin and delivery time	Domestication history
Indonesia	Taiwan (1985)	The population was introduced and has been cultivated in Taiwan since 1975 (Huang et al. 2005). In Indonesia, mass production was started more than 30 years ago and has been intergeneration backcrossed since 2000
Egypt	Egypt (2005)	There is no available information on the domestication history. Production has been reported since 1996 and increased significantly in 2005 (El-Naggar 2008).
Kenya	Kenya (2011)	Directly collected from the natural habitat, characterized as the wild population
Netherlands	The Netherlands (2011)	The population was introduced to the Netherlands from South Africa in 1974 (Holcik 1991) and has been mass selected for growth (Fleuren 2008).
Thailand	Thailand (2002)	The population originated from introduced populations to Vietnam from Central Africa in 1974 (Na-Nakorn and Brummett 2009). Introduced to Thailand in 1987; significant contribution to aquaculture production (Wachirachaikarn et al. 2009)

been made since the 2000s by government agencies and the private sector, either based on former introduced populations from 1985 or newly reintroduced populations of the same species in 2002 and 2008 from Thailand, in 2005 from Egypt, and in 2011 from Kenya and the Netherlands. Recently, Indonesia had five different populations of African catfish introduced that supposed each population has its own genetic superiorities. Based on the domestication history, the Indonesia, Thailand and Netherlands populations – especially the Netherlands population – have been exposed to the specific cultivation environment for a longer period in an environment that is extremely different from the natural habitat, compared to the Egypt and Kenya populations. This is particularly true concerning the Kenya population, which can be characterized as a wild population that inhabits a natural habitat. In general, this domestication history is thought to change the heterozygosity and fitness of each population.

The availability of varied genetic populations of African catfish in Indonesia has made it possible to develop a breeding program in order to establish genetically better quality strains for aquaculture purposes, either using selection, crossbreeding or other techniques. Among the applied selective breeding methods, crossbreeding has been used in a range of species to achieve better performance in progenies, the production of sterile fish, as well as a first stage in selective breeding through the establishment of the base population (Bartley et al. 2001; Gjedrem 2005). These include *Heterobranchus longifilis* (Nguenga et al. 2000), guppy *Poecilia reticulata* (Nakadate et al. 2003), Chinook salmon *Oncorhynchus tshawytscha* (Bryden et al. 2004), Pacific blue shrimp *Penaeus stylirostris* (Goyard et al. 2008), silver perch *Bidyanus bidyanus* (Guy et al. 2009), common carp *Cyprinus carpio* (Zak et al. 2007; Nielsen et al. 2010), and tilapia *Oreochromis niloticus* (Neira et al. 2016; Thoa et al. 2016).

In the present study, we evaluated interpopulation crossbreed performance based on the five different populations of introduced African catfish in Indonesia in order to achieve a suitable crossbreed for better production.

Materials and methods

Broodstocks used in the experiment were sourced from the collection of the National Freshwater Aquaculture Center, Sukabumi, Indonesia and consisted of five populations, namely Indonesia, Egypt, Kenya, the Netherlands and Thailand populations (Table 1). Three males and three females of each population were induced to spawn using Ovaprim (Syndel Laboratories) for reciprocal interpopulation crossbreeding. Fertilization was conducted artificially to form 20 crossbreed and five purebred populations. To simplify terminology, the first letters of each population name were used as different combination crossing notations between dam and sire; for instance, IE represents the crossbreed between female Indonesia × male Egypt, while II and EE represent Indonesia and Egypt purebred, respectively.

Four days after hatching (dah) larvae were reared up to 81 dah at three nursing stages, i.e. 21, 28 and 28 days at stages 1, 2, and 3, respectively. At stage 1, larvae were stocked at a density of 15 fish L^{-1} in 100 L aquaria at the first nursing stage, fed on tubificid worms for the first 7 days, a combination of tubificid worms and artificial feed (protein content 40%, size 0.1–0.3 mm) for the next 7 days, and continued with the same artificial feed for the remaining 7 days. Tubificid worms were provided at all times (*ad libitum*), while artificial feed was given as much as the fish could consume (*at satiation*), at feeding rates of four times per day. Since the fish fed on artificial feed, the water was changed almost 100% every two days. At the end of rearing, the fish were harvested and sorted based on body length. The over-size fish were culled and not used at the next nursing stage to avoid high cannibalism. The over-size

Table 2. Specific growth rate (SGR), survival rate (SR), coefficient of variation (CV) and over-size fish (OS) of interpopulation crossbreeds of introduced African catfish at stage 1 (first 21 days of rearing).

Crossbreed	SGR (%)	SR (%)	CV (%)	OS (%)
II (control)	25.59 ± 0.13	69.53 ± 11.21	8.54 ± 0.98	0.90 ± 0.33
EE	25.43 ± 0.09	55.02 ± 10.06	9.48 ± 1.67	2.25 ± 1.06
KK	25.76 ± 0.04	50.24 ± 6.46	8.74 ± 0.49	1.98 ± 0.68
NN	25.74 ± 0.37	77.91 ± 6.04	9.19 ± 1.67	0.82 ± 0.33
TT	25.82 ± 0.23	61.36 ± 9.61	10.37 ± 0.89	1.27 ± 0.42
IE	25.71 ± 0.17	66.47 ± 0.87	9.75 ± 1.28	1.24 ± 0.29
IK	25.64 ± 0.26	74.24 ± 1.35	10.35 ± 2.20	0.71 ± 0.16
IN	25.49 ± 0.34	83.53 ± 1.37	8.95 ± 1.28	0.37 ± 0.05
IT	25.10 ± 0.22	87.00 ± 5.24	9.78 ± 0.25	0.35 ± 0.17
EI	25.26 ± 0.04	76.80 ± 8.40	8.35 ± 0.85	0.69 ± 0.28
EK	26.05 ± 0.28	74.13 ± 2.62	6.90 ± 0.93	0.81 ± 0.41
EN	25.41 ± 0.06	91.96 ± 2.82	12.83 ± 2.79	0.22 ± 0.04
ET	25.66 ± 0.23	75.04 ± 6.88	7.39 ± 0.34	0.82 ± 0.45
KI	25.24 ± 0.01	94.00 ± 3.59	8.79 ± 0.39	0.17 ± 0.09
KE	25.87 ± 0.54	64.24 ± 4.08	9.42 ± 1.28	1.27 ± 0.11
KN	25.16 ± 0.07	82.64 ± 2.66	10.47 ± 0.43	0.08 ± 0.08
KT	25.40 ± 0.11	76.02 ± 3.80	10.74 ± 1.84	0.58 ± 0.03
NI	25.46 ± 0.39	60.13 ± 4.17	8.14 ± 0.41	1.21 ± 0.10
NE	25.19 ± 0.08	62.69 ± 5.38	9.14 ± 0.18	1.26 ± 0.44
NK	25.40 ± 0.10	73.62 ± 6.56	8.90 ± 0.84	0.54 ± 0.17
NT	25.31 ± 0.28	82.00 ± 2.77	9.79 ± 0.78	0.36 ± 0.06
TI	25.35 ± 0.37	88.16 ± 5.48	11.18 ± 1.56	0.38 ± 0.24
TE	25.32 ± 0.16	77.91 ± 3.16	9.09 ± 0.79	0.43 ± 0.07
TK	25.46 ± 0.20	79.33 ± 4.62	9.59 ± 0.48	0.59 ± 0.27
TN	25.99 ± 0.60	77.51 ± 6.33	9.55 ± 0.43	0.57 ± 0.09

Data are presented as mean ±SD, in triplicate. Survival and over-size fish analyzed log transformed but presented numerically. Not significantly different ($p > 0.05$) to controls. I = Indonesia, E = Egypt, K = Kenya, N = Netherlands, T = Thailand. Crossbreed notations represent dam and sire of population names.

fish were identified as those with body length about 2 times the mean population body length (Baras and Jobling 2002).

At stage 2, the fish were stocked at a density of 8 fish L^{-1} in 100 L aquaria and given artificial feed (protein content 40%, size 0.1–0.3 mm) for the first week, and continued with artificial feed (protein content 39–41%, size 0.5–0.7 mm) for the remaining three weeks. The feed was applied *at satiation* at a feeding rate of four times per day. After four weeks, the fish were harvested and sorted based on body length. Like at stage 1, the over-size fish were culled and were not used at the next nursing stage.

At the third stage, fish were stocked at a density of 4 fish L^{-1} in 100 L aquaria. Artificial feed (protein content 39–41%, size 0.5–0.7 mm) was given *at satiation* at a feeding rate of three times per day for the first week, and continued with artificial feed (protein content 39–41%, size 0.7–1.0 mm) until the end of rearing. To maintain good water quality, almost 100% water was replaced every two days at stages 2 and 3.

The total body length (TL) measured from 30 samples of fish was used to calculate the specific growth rate (SGR) and the coefficient of variation (CV) during the rearing period. Survival and the number of over-size fish were counted from each aquarium and used to identify its degree of correlation at each rearing stage. The SGR and the CV were calculated as per Bhujel (2008). The SGR (%) of TL at the final rearing stage was expressed as $100 \times (\text{LnTL1} - \text{LnTL0})/T$, where TL1 = body length at 81 dah (mm), TL0 = body length at 4 dah (mm), and T = time period (days). The cumulative SR (%) was expressed as $100 \times (\text{SR1\%} \times \text{SR2\%} \times \text{SR3})$, where SR1%, SR2% and SR3% were survival rates at stages 1, 2, and 3, respectively. The CV (%) was expressed as $100 \times (\text{sd1} + \text{sd2} + \text{sd3})/(\text{x1} + \text{x2} + \text{x3})$, where sd and x are the standard of deviation and average of total length, respectively, at stages 1, 2 and 3. The average of OS was expressed as $100 \times (\text{OS1} + \text{OS2} + \text{OS3})/(\text{N1} + \text{N2} + \text{N3})$, where OS and N are the number of over-size fish and number of live fish, respectively, at each final rearing stage.

The normal distribution was assessed using the Kolmogorov-Smirnov test. SR and OS data that were not normally distributed were log transformed. One-way analysis of variance (ANOVA) was conducted to analyze the effect of crossbreed on each trait, and the means were compared using Dunnett's test ($p < 0.05$) with the Indonesia population as the control. The SR and the OS relationship was calculated by a Pearson test.

Results

There were significant differences in survival rates (SR) (50.24–94.00%) and over-size fish (OS) (0.08–2.25%) at stage 1, but no populations were significantly different compared to the existing Indonesia (II) purebred population (Table 2).

Table 3. Specific growth rate (SGR), survival rate (SR), coefficient of variation (CV) and over-size fish (OS) of interpopulation crossbreeds of introduced African catfish at stage 2 (second 28 days of rearing).

Crossbreed	SGR (%)	SR (%)	CV (%)	OS (%)
II (control)	2.39 ± 0.30	40.52 ± 6.78	13.74 ± 1.16	4.82 ± 1.69
EE	3.67 ± 0.17*	43.07 ± 4.71	17.97 ± 0.49	3.60 ± 0.46
KK	3.05 ± 0.14	50.66 ± 8.17	15.98 ± 2.27	3.35 ± 2.17
NN	2.99 ± 0.33	51.33 ± 3.30	20.02 ± 4.55	2.01 ± 0.27
TT	3.08 ± 0.12	51.77 ± 15.35	17.28 ± 2.53	3.30 ± 1.25
IE	3.04 ± 0.10	53.61 ± 15.89	15.59 ± 0.63	2.86 ± 1.03
IK	3.46 ± 0.25	66.39 ± 5.94	18.28 ± 1.31	1.38 ± 0.25
IN	3.07 ± 0.37	63.33 ± 8.29	12.22 ± 0.35	1.25 ± 0.20
IT	3.63 ± 0.21*	31.61 ± 6.98	17.70 ± 2.76	4.02 ± 1.34
EI	3.42 ± 0.23	90.88 ± 4.96*	16.00 ± 1.69	0.32 ± 0.06*
EK	3.46 ± 0.22	87.75 ± 0.70*	17.06 ± 2.64	1.50 ± 0.95
EN	3.50 ± 0.26	34.10 ± 2.63	14.48 ± 1.40	5.76 ± 1.58
ET	3.22 ± 0.26	66.22 ± 13.22	14.21 ± 0.56	1.23 ± 0.52
KI	2.86 ± 0.55	56.55 ± 2.26	16.24 ± 1.52	1.83 ± 0.70
KE	3.03 ± 0.41	77.35 ± 7.85*	16.22 ± 1.18	1.71 ± 0.42
KN	3.25 ± 0.30	48.84 ± 4.49	14.89 ± 0.49	2.22 ± 0.28
KT	2.94 ± 0.07	59.04 ± 2.69	25.96 ± 5.66*	1.49 ± 0.26
NI	2.67 ± 0.21	44.48 ± 16.06	17.53 ± 1.20	2.60 ± 1.56
NE	3.36 ± 0.50	62.19 ± 4.47	16.60 ± 3.27	1.32 ± 0.11
NK	3.06 ± 0.39	55.78 ± 6.90	20.00 ± 1.85	1.53 ± 0.36
NT	3.26 ± 0.22	39.29 ± 9.01	20.74 ± 5.34	2.82 ± 0.91
TI	2.95 ± 0.19	38.51 ± 9.37	16.33 ± 2.06	3.51 ± 0.65
TE	3.14 ± 0.12	36.33 ± 4.07	18.30 ± 0.44	3.15 ± 0.50
TK	3.16 ± 0.21	66.35 ± 8.65	15.83 ± 2.02	1.14 ± 0.24
TN	2.91 ± 0.33	47.75 ± 7.20	17.69 ± 1.24	2.41 ± 0.37

Data are presented as mean ±SD, in triplicate. Survival and over-size fish analyzed log transformed but presented numerically. * In same column shows significant difference ($p < 0.05$) to controls. I = Indonesia, E = Egypt, K = Kenya, N = Netherlands, T = Thailand. Crossbreed notations represent dam and sire of population names.

At stage 2, specific growth rate (SGR), SR, coefficient of variation (CV) and OS showed significant differences (Table 3). The Egypt (EE) purebred and the Indonesia-Thailand (IT) crossbreed populations obtained better SGR than the II population, in a significant manner. The Egypt-Indonesia (EI), Egypt-Kenya (EK) and Kenya-Egypt (KE) populations showed higher SRs than the II population, also significantly. The Kenya-Thailand (KT) and the EI populations exhibited more CV and less OS than the II population, respectively. At stage 3, the SR and OS showed significant differences between populations but only the SR of the Netherlands (NN) purebred population demonstrated differences to the II population (Table 4).

Further analysis that combines all stages of rearing showed all twenty generated crossbreeds at the nursing stage had varied growth performance when compared to the existing Indonesia (II) purebred population (Table 2). Comparative testing showed that the SGRs of twelve crossbreeds, including three purebreds, were significantly different from the II purebred populations. The Egypt-Netherlands (EN) and Thailand-Kenya (TK) crossbreeds had the highest and lowest growth rates, respectively. The SR at the nursing stage of all populations showed more varied values (2.10–63.98%) than its growth rate, and most of them indicated the same or lower rates compared to the II purebred. However, the EN crossbreed showed the highest and greatest survival (63.98%).

The CV values among populations were not significantly different. These values for all populations (12.47–16.97%) were characterized by a moderate range (Benhaïm et al. 2011). Although the uniformity of body size was moderate, in any crossbreed population there were individuals of larger size (over-size) than the closest size to the average population. The average number of over-size (OS) fish was significantly different among populations in a range of 0.22–2.86%. The EN crossbreed achieved the lowest OS and was significantly different to the II purebred. In addition, there were no other populations, either purebreds or crossbreeds, that were significantly different to the II purebred. The OS ranges at stages 1, 2 and 3 were 0.08–2.25%, 0.32–5.76%, and 0.02–6.61%, respectively. We found that the OS values were obviously correlated with the SR at each rearing stage, and the correlation tended to be weak as the nursing stage was advanced, i.e. correlation coefficient at stage 1 = 0.930 ($p < 0.01$), at stage 2 = 0.803 ($p < 0.01$), and at stage 3 = 0.776 ($p < 0.01$). Cumulatively, the correlation coefficient of OS to the SR was 0.819 ($p < 0.01$).

Discussion

In this study, interpopulation crossbreeding made use of the different introduction history of African catfish to Indonesia, i.e. farmed and wild population backgrounds, country of origin, and time of delivery. More diverse genetic sources of African catfish would be expected to contribute to an increase

Table 4. Specific growth rate (SGR), survival rate (SR), coefficient of variation (CV) and over-size fish (OS) of interpopulation crossbreeds of introduced African catfish at stage 3 (third 28 days of rearing).

Crossbreed	SGR (%)	SR (%)	CV (%)	OS (%)
II (control)	3.77 ± 0.18	76.66 ± 10.01	15.05 ± 2.19	3.08 ± 1.58
EE	3.46 ± 0.19	65.33 ± 10.65	16.83 ± 1.25	0.05 ± 0.00
KK	3.38 ± 0.19	55.75 ± 9.45	12.49 ± 0.72	5.16 ± 2.01
NN	4.28 ± 0.12	39.99 ± 7.64*	14.26 ± 0.65	4.70 ± 1.29
TT	3.70 ± 0.28	72.34 ± 5.70	13.72 ± 0.13	2.35 ± 0.73
IE	3.58 ± 0.02	73.91 ± 8.11	12.76 ± 0.78	2.28 ± 0.71
IK	3.10 ± 0.42	82.25 ± 3.68	13.90 ± 0.56	1.11 ± 0.06
IN	3.79 ± 0.28	78.08 ± 7.39	13.81 ± 0.99	1.01 ± 0.28
IT	3.90 ± 0.21	65.12 ± 14.40	13.60 ± 0.79	4.17 ± 1.33
EI	3.24 ± 0.18	77.50 ± 8.14	13.15 ± 0.66	0.02 ± 0.01
EK	3.27 ± 0.48	64.08 ± 8.00	15.18 ± 0.77	0.03 ± 0.01
EN	4.08 ± 0.25	83.49 ± 6.72	13.99 ± 1.32	0.02 ± 0.01
ET	3.37 ± 0.29	78.75 ± 2.46	12.59 ± 1.56	0.02 ± 0.00
KI	4.07 ± 0.54	81.17 ± 6.89	16.57 ± 2.00	0.99 ± 0.56
KE	3.41 ± 0.09	94.83 ± 2.46	16.60 ± 4.17	0.36 ± 0.18
KN	4.10 ± 0.09	55.25 ± 14.37	17.58 ± 1.39	4.51 ± 1.54
KT	3.77 ± 0.05	70.58 ± 10.30	13.74 ± 1.77	1.45 ± 0.56
NI	3.88 ± 0.21	56.13 ± 8.77	15.09 ± 1.38	6.09 ± 2.35
NE	4.20 ± 0.46	69.49 ± 2.75	15.62 ± 1.45	3.10 ± 1.18
NK	3.93 ± 0.42	72.88 ± 6.81	14.09 ± 1.30	1.29 ± 0.35
NT	4.27 ± 0.30	66.08 ± 5.05	16.70 ± 1.63	2.98 ± 0.76
TI	4.02 ± 0.09	76.17 ± 2.32	12.20 ± 0.47	1.97 ± 0.06
TE	4.04 ± 0.04	64.67 ± 3.09	15.17 ± 1.26	2.87 ± 0.38
TK	3.28 ± 0.12	84.33 ± 1.42	13.32 ± 1.81	0.80 ± 0.21
TN	4.16 ± 0.42	47.00 ± 4.27	16.02 ± 0.50	6.61 ± 1.28

Data are presented as mean ± SD, in triplicate. Survival and over-size fish analyzed log transformed but presented numerically. * In same column shows significant difference ($p < 0.05$) to controls. I = Indonesia, E = Egypt, K = Kenya, N = Netherlands, T = Thailand. Crossbreed notations represent dam and sire of population names.

in the genetic variation of catfish, which in turn has an impact on improved growth and other fitness related traits (Bartley et al. 2001), as reported in tilapia (Bentsen et al. 1998) and giant freshwater prawn *Macrobrachium rosenbergii* (Thanh et al. 2010). The results of this experiment showed the improvement of growth, survival and number of over-size fish on crossbreed populations, compared to the Indonesia purebred population and other purebred populations.

The EN crossbreed generated the highest growth and survival, and the lowest number of over-size fish. This showed the prominent consistency of the EN crossbreed compared to the II purebred and other crossbreeds. The crossbreed of African catfish introduced to Thailand did not show any differences in body weight, total length and survival rates at 5 and 14 weeks (Wachirachaikarn et al. 2009). These authors used African catfish that have been cultivated since 1987, without any new introduced populations. This is different from African catfish in Indonesia in this research, in which several new catfish populations were introduced (Table 1). The EN crossbreed showed the best results because it is a cross between a wild population that was domesticated to an aquaculture system (Egypt population) and a genetically improved population (the Netherlands population). The Kenya population as the wild population, has not been farmed properly, and this may contribute to low performance as indicated by the lower growth and survival compared to other purebred populations. Meanwhile, the Thailand and Indonesia populations, despite being well farmed, were thought to be less well selected than the Netherlands population (Table 1). Our results coincide with those for crossbreeds of tilapia (Bentsen et al. 1998), Pacific blue shrimp (Goyard et al. 2008), silver perch (Guy et al. 2009), and giant freshwater prawn (Thanh et al. 2010). However, crossbreeds of the farmed population and wild population did not always produce better performance than their parents, as reported in brook trout *Salvelinus fontinalis* (Granier et al. 2011) and Chinook salmon (Bryden et al. 2004).

Cumulative survival showed that the EN crossbreed had the highest and most significant difference compared to the Indonesia purebred population. Generally, cumulative survival in this research was mostly <30% and nine crossbreeds achieved better survival than the Indonesia population. Higher survival of crossbreeds than their parents was shown in Pacific blue shrimp (Goyard et al. 2008) and common carp (Nielsen et al. 2010), but no significant effect was reported in Rohu carp *Labeo rohita* (Gjerde et al. 2002), and Chinook salmon (Bryden et al. 2004), and decreased survival was found in pink salmon *Oncorhynchus gorbuscha* (Gilk et al. 2004).

Our present experiment showed different performances of reciprocal crossbreeds. The DE crossbreed demonstrated survival and number of over-size fish significantly lower than the EN crossbreed. Similar results were also found in growth rates of the IT, EK, and TE crossbreeds compared to their reciprocals, but this was not found in the other crossbreeds and their reciprocals. In several fish crossbreeds, the different breeding schemes, i.e. one population acting as a sire or as a dam, can produce different performances, such as those found

Table 5. Specific growth rate (SGR), cumulative survival rate (SR), coefficient of variation (CV) and over-size fish (OS) average of interpopulation crossbreeds of introduced African catfish at the nursing stage.

Crossbreed	SGR (%)	SR (%)	CV (%)	OS (%)
II (control)	9.22 ± 0.08	22.81 ± 7.94	13.99 ± 1.45	2.39 ± 0.80
EE	9.53 ± 0.01*	7.10 ± 2.58	16.46 ± 0.92	2.32 ± 0.55
KK	9.36 ± 0.05	9.22 ± 3.45	12.97 ± 0.97	2.86 ± 1.26
NN	9.66 ± 0.01*	11.58 ± 1.97	15.01 ± 1.26	1.75 ± 0.39
TT	9.51 ± 0.04*	12.85 ± 5.09	14.23 ± 0.64	2.03 ± 0.22
IE	9.42 ± 0.02	22.71 ± 13.66	13.14 ± 0.49	1.88 ± 0.44
IK	9.38 ± 0.03	32.03 ± 7.41	14.72 ± 0.43	0.97 ± 0.07
IN	9.45 ± 0.03	37.24 ± 12.43	12.96 ± 0.54	0.73 ± 0.08
IT	9.58 ± 0.08*	14.08 ± 1.59	14.24 ± 0.19	2.00 ± 0.29
EI	9.31 ± 0.04	13.52 ± 1.89	13.41 ± 0.20	2.09 ± 0.44
EK	9.55 ± 0.03*	30.36 ± 5.60	14.86 ± 1.03	0.90 ± 0.07
EN	9.69 ± 0.03*	63.98 ± 6.57*	14.00 ± 0.98	0.22 ± 0.04*
ET	9.40 ± 0.06	27.89 ± 8.89	12.47 ± 0.98	0.82 ± 0.18
KI	9.40 ± 0.02	41.36 ± 4.65	15.74 ± 1.12	0.78 ± 0.31
KE	9.39 ± 0.04	34.65 ± 12.11	15.73 ± 2.79	1.27 ± 0.14
KN	9.53 ± 0.12*	20.81 ± 8.62	16.37 ± 0.88	1.37 ± 0.11
KT	9.37 ± 0.02	26.41 ± 8.21	16.27 ± 0.76	0.98 ± 0.07
NI	9.32 ± 0.11	15.19 ± 10.42	14.90 ± 0.73	2.35 ± 0.52
NE	9.62 ± 0.06*	16.81 ± 2.32	15.29 ± 1.72	1.55 ± 0.42
NK	9.47 ± 0.04*	21.67 ± 7.29	14.93 ± 0.42	0.95 ± 0.06
NT	9.64 ± 0.04*	16.09 ± 2.45	16.97 ± 1.31	1.48 ± 0.33
TI	9.44 ± 0.06	21.24 ± 5.64	13.01 ± 0.57	1.54 ± 0.15
TE	9.52 ± 0.01*	13.97 ± 3.03	15.30 ± 0.93	1.60 ± 0.17
TK	9.29 ± 0.09	33.98 ± 7.15	13.57 ± 1.19	0.79 ± 0.16
TN	9.66 ± 0.07*	15.93 ± 5.74	15.75 ± 0.44	2.01 ± 0.24

Data are presented as mean ± SD, in triplicate. Survival and over-size fish analyzed log transformed but presented numerically. * in same column shows significant difference ($p < 0.05$) to controls. I = Indonesia, E = Egypt, K = Kenya, N = Netherlands, T = Thailand. Crossbreed notations represent dam and sire of population names.

in crossbreeds of tilapia (Lutz et al. 2010), brook trout (Granier et al. 2011; Crespel et al. 2012), and blunt snout bream *Megalobrama amblycephala* (Luo et al. 2014). This reciprocal effect may be associated with a parental effect and genetic linkage between sex genes and performance genes (Crespel et al. 2012).

Fish survival at stages 1 and 3 was higher than at stage 2. Lower survival at stage 2 was in line with a higher number of over-size fish. Although the dynamics of African catfish cannibalism occur more frequently during the first 2 weeks of age (Adamek et al. 2011), larval rearing at stage 1 for 3 weeks in the present study succeeded in achieving survival >50%. In another separate test using an outdoor based-plastic pond system, survival for 21 days of larval rearing was 18–42% (Sunarma et al. 2013). At stage 2, after seven weeks of consecutive rearing, lower survival was in line with a higher number of over-size fish that led to high cannibalism. Over 7 weeks of rearing, the level of mortality due to cannibalism can reach 50–90% (Adamek et al. 2011). High cannibalism, as the main cause of high mortality, was also reported in fat snook *Centropomus parallelus* juveniles (Corrêa and Cerqueira 2007). At stage 3, after 11 weeks of consecutive rearing, survival could be increased with larger seed size. As fish grow bigger, cannibalism tends to decline because the prey fish can swim faster to avoid predators.

The correlation between the survival rate and cannibalism can be indicated by the strong correlation between the survival rate and the number of over-sized fish. The more over-size fish, the lower the survival rate. However, the number of over-sized fish was not represented on the coefficients of variation in our study. This may be because the over-sized fish can actively escape when sampling was performed. The number of over-size fish can definitively be determined on sorting of the fish population at the end of rearing. Over-size fish can arise because of aggression and cannibalism that occur naturally in African catfish. Aggression or attack behavior may cause other fish to be wounded and weakened, encouraging cannibalism (Mukai et al. 2013). At the larval stage, cannibalism in African catfish started at about 8 days post-fertilization and the larvae could prey on their neighbors that had the same size (Appelbaum and Kamler 2000). Larvae that become predators usually grow faster than the other fish and thus larger size may increase the chances of preying on other fish and becoming more dominant in competing for food. These natural behaviors of African catfish should be taken into account regarding the possibility of introduced-catfish escape into the natural environmental, especially from small-scale fish farms. The larger larvae size of African catfish than local catfish (Lenormand et al. 1998) could potentially eliminate local catfish either by competition for food or through predation.

The CV of total length in this research (12.47–16.97%) was in the moderate range according to Benhaïm et al. (2011). The CV of body weight in African catfish can reach 13–26% by 15 days of age (Baras and d'Almeida 2001) and 41–51% after 7 weeks of larva rearing (Adamek et al. 2011). Volckaert and Hellemans (1999) reported a low CV of body length in African catfish of 6.7–11.9 and 4.5–8.1 at one month and nine months of age, respectively, by removing over-size fish that prey on their siblings to reduce cannibalism. Generally, the CV of the phenotypic variation in fish is 20–30% (Gjedrem and Baranski 2009). However, the CV does not seem to be particularly useful in describing of size variability in fish involved in cannibalism (Appelbaum and Kamler 2000).

This research also indicates that the growth rate of the purebred Indonesia population is lower than that of any other purebred populations, both farmed populations, i.e. Netherlands and Thailand populations, and natural populations, i.e. Egypt and Kenya populations. It reveals a decrease in the genetic quality of African catfish that have been used widely in Indonesia, as that has been reported in Asian cultured tilapia strains (Bentsen et al. 1998). The Netherlands population grew better than other populations, possibly associated with better selection, like that reported in brook trout (Granier et al. 2011) and Atlantic salmon *Salmo salar* (Morris et al. 2011).

Conclusion

This study showed that interpopulation crossbreeding between female Egypt and male Netherlands populations produced an EN crossbreed that had the best growth rate, highest survival, and lowest number of over-size progeny. Our work also suggests that the EN crossbreed shows the most suitable performances to improve offspring quality of catfish in the near future for grow-out farmers in Indonesia.

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