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Relative performance of two Nile tilapia (*Oreochromis niloticus* Linnaeus) strains in Egypt: The Abbassa selection line and the Kafr El Sheikh commercial strain

Nabil Ahmed Ibrahim[2], Mohamed Yahia Abou Zaid[2], Hooi Ling Khaw[1], Gamal Othman El-Naggar[2] & Raul W Ponzoni[1]

[1]The WorldFish Center, Penang, Malaysia

[2]Regional Research Center for Africa and West Asia, The WorldFish Center, Abu Hammad, Abbassa, Egypt

Correspondence: Dr R W Ponzoni, The World Fish Center, Jalan Batu Maung, 11960 Bayan Lepas, Penang, Malaysia. E-mail: r.ponzoni@cgiar.org

Abstract

The Abbassa selection line (developed by selective breeding) and the Kafr El Sheikh commercial strain (widely used in Egypt), both *Oreochromis niloticus*, were compared at two stocking densities (two and four fish m^{-2}). Harvest weight, length, depth, width and head length were recorded. The Abbassa line showed a superior harvest weight (28 per cent) over the Kafr El Sheikh strain. Males were heavier than females, but the between-sex difference was greater in the commercial than in the Abbassa line (39 and 31 per cent respectively). Females in the Abbassa line grew almost as fast as males in the commercial line. Both strains grew faster at the lower density, and the percentage reduction in harvest weight at the higher density was about the same for both strains (27 per cent). The advantage of the Abbassa line was 28 per cent at both densities. Both strains had a similar survival rate (approximately 80 per cent) during the grow-out period. We conclude that the Abbassa line is ready for release to the tilapia industry in Egypt. Further evidence is being sought in currently underway on-farm evaluations. Measures should be taken to ensure the long-term viability of the Abbassa line.

Keywords: Nile tilapia, strain comparison, harvest weight, survival rate, competition

Introduction

The importance of aquaculture production in Egypt has been increasing rapidly in the past decade, especially tilapia aquaculture, which accounts for about 55 per cent of the total aquaculture production in the country (FAO 2011). Egyptian tilapia aquaculture production has grown from 150,000 tonnes in the year 2000 to 390,000 tonnes in the year 2009, representing an annual increase of 25 per cent (FAO 2011). Egypt is the world's second largest tilapia producer (after China), but to meet the growing population needs for animal protein, it has to realize the potential to further increase tilapia aquaculture production. The strengthening of aquaculture's technological foundations has been identified in Egypt's aquaculture strategy (SADS 2030 2009) as an essential ingredient for its expansion. The development and effective use of genetically improved strains is one of the most powerful technologies at our disposal to achieve that end. Since 2002, scientists from the Central Laboratory for Aquaculture Research (CLAR) and from the WorldFish Center have been working at the Abbassa Regional Research Station on a genetic improvement programme for Nile tilapia. The results have been so encouraging (Khaw, Bovenhuis, Ponzoni, Rezk, Charo-Karisa & Komen 2009; Rezk, Ponzoni, Kamel, John, Dawood, Khaw & Megahed 2009) that it was decided that the Abbassa selection should be compared with breeding stock currently being used in industry.

In the present paper, we report on the favourable performance of the Abbassa selection line relative to Nile tilapia (*Oreochromis niloticus* Linnaeus) stock widely used in Egypt and perceived as one of the best performing in Egypt: the Kafr El Sheikh strain. We make recommendations about the use of the Abbassa selection line in industry and about the management of this valuable genetic resource.

Materials and methods

The environment

The strain comparison was carried out at the Regional Research Station of The WorldFish Center in Egypt. The research station is located in Abbassa, Abou Hammad, approximately 70 km northeast of Cairo and 80 km inland from the Mediterranean Sea. The average air temperature at Abbassa ranges from 4°C in winter to 40°C in summer, whereas the water temperature varies from 9°C to 34°C. Egypt is a climatically dry country with two distinctive seasons, usually referred to as the hot season (May–September), and the cold season (November–March). At Abbassa, the average annual rainfall is between 25 and 50 mm, and may occur only once in several years.

The fish

Two sources of Nile tilapia (*Oreochromis niloticus*) were used in the present strain comparison: the Abbassa selection line and a commercial strain from Kafr El Sheikh. The Abbassa selection line has recently been described in detail by Rezk *et al.* (2009) and by Khaw *et al.* (2009). The base population was established in 2002 by sampling four populations. Thereafter, a selective breeding programme has been conducted. Pedigree is maintained and replacements are chosen based on the estimated breeding values calculated using best linear unbiased procedures (BLUP). Harvest weight has been the trait receiving the greatest amount of attention, followed by survival rate. The mating of close relatives is avoided using the approach described by Ponzoni, Khaw, Nguyen and Hamzah (2010). The Kafr El Sheikh strain was obtained from the farm of Dr. Ismail Radwan who is the pioneer in introducing modern tilapia farming in Egypt. The original stock consisted of sampled wild fish with periodic replacement with new stock every three years from other sources to avoid inbreeding problems (Ismail Radwan, personal communication 2008). The reasons for its choice in the present strain comparison were that it is perceived by producers as one of the most productive strains in the tilapia industry in Egypt, and that it is the most widely used.

The experimental animals from both strains were produced by mass spawning. The dates of the main events from mating of the parents that produced the experimental progeny to the harvest of such progeny are specified in Table 1. In the case of the Abbassa selection line, the experimental progeny were generated by spawning 30 pairs both in 2008 and 2010. The fish from Kafr El Sheikh were obtained from the commercial hatchery of Dr. Ismail Radwan. This hatchery is located 160 km NW from Abbassa, in a location with the same climatic characteristics. Fry production in the hatchery is a continuous process on a daily basis. To get fry of the same age from both strains, we informed the hatchery manager the exact date when we produced the fry of the Abbassa selection line and requested that the required number of fry spawned on the same day be kept aside. The arrangement worked well and the Kafr El Sheikh fish were produced from the spawning of about 40 brood stock in both 2008 and 2010, and transferred to Abbassa 10–14 days after spawning. Thereafter, each strain was placed in a separate 12 m^3 tank (5000 fry per tank) and provided ground formulated feed of 27 per cent crude protein. The fish of both strains were healthy and active. The Kafr El Sheikh fish displayed no external signs of having suffered in any way because of the transfer. Stocking in

Table 1 Reproduction and management schedule

	Activities				
Year	Mating	Nursing	Tagging and stocking	Grow-out	Harvest
2008	April–May	May–June	22nd–26th June	July–December	1st–3rd December
2010	May–June	June–July	2nd–5th August	August–January 2011	12th–24th January 2011

ponds and harvesting took place at the same time for both strains so that differences in both age and duration of the grow-out period between them were minimized by design. In 2008, an estimate of weight at stocking was available from bulk weighing and counting five samples of not less than 50 fish each from each strain. The averages for the Abbassa and the Kafr El Sheikh strains were 4.0 and 3.8 g respectively. Individual weight at stocking was available only in 2010, when the average was 7.3 and 4.2 g for the Abbassa and the Kafr El Sheikh strains respectively.

Prior to stocking in ponds, all experimental fish were individually identified with Floy Tags® (plastic disc held by a thread with alphanumeric code, see Thodesen & Ponzoni 2004) in 2008, and with PIT Tags® (Passive Integrated Transponder, unique alphanumeric code read with a special purpose scanner) in 2010. Hereafter, we refer to these two types of identification as Floy and PIT tags, respectively.

Experimental design and data structure

The experiment was repeated with the same design in 2008 and 2010. In both years, there were 10 ponds of 100 m^2 each available. Five were randomly assigned to a lower stocking density (two fish m^{-2}), whereas the other five were assigned to a higher stocking density (four fish m^{-2}). Both strains were present in each pond. Fig. 1 is a schematic representation of the experimental design used in this trial, where pond is nested within year and stocking density, but pond and strain are cross-classified. The statistical model fitted follows from this design, and so does the choice of mean square for testing the significance of the different effects (see Results section). One hundred fish of each strain (200 fish in total) were stocked in low stocking density ponds, and 200 fish of each strain (400 fish in total), in the high density ponds.

The grow-out system

Following individual identification with Floy tags (in year 2008) or with PIT tags (in year 2010), the experimental fish grew out in the ponds schematically represented in Fig. 1. They were fed pelleted floating fish feed containing 27 per cent crude protein. The feeding frequency was twice daily at 1000 and 1400 h six days a week, whereas the amount fed was to apparent satiation (when the fish stopped eating and showed no interest in any further feed thrown to the pond).

Records

At harvest, the fish were sexed, weighed and in 2010 standard length, depth, width and head

Year 2008

Pond no. 1 Strains A and K Density 2	Pond no. 2 Strains A and K Density 4	Pond no. 3 Strains A and K Density 2	Pond no. 4 Strains A and K Density 4	Pond no. 5 Strains A and K Density 4
Pond no. 6 Strains A and K Density 2	Pond no. 7 Strains A and K Density 4	Pond no. 8 Strains A and K Density 2	Pond no. 9 Strains A and K Density 4	Pond no. 10 Strains A and K Density 2

Year 2010

Pond no. 11 Strains A and K Density 4	Pond no. 12 Strains A and K Density 4	Pond no. 13 Strains A and K Density 2	Pond no. 14 Strains A and K Density 2	Pond no. 15 Strains A and K Density 4
Pond no. 16 Strains A and K Density 2	Pond no. 17 Strains A and K Density 4	Pond no. 18 Strains A and K Density 4	Pond no. 19 Strains A and K Density 2	Pond no. 20 Strains A and K Density 2

Figure 1 Schematic representation of the experimental design of the strain comparison (A, Abbassa selection line; K, Kafr El Shiekh strain; Density 2, stocking density of 2 fish m^{-2}, 100 A and 100 K fish; Density 4, stocking density of 4 fish m^{-2}, 200 A and 200 K fish.

length were also recorded. Body width and depth were measured at the mid-side of the fish, where they were greatest (Fig. 2). Only the fish recovered with a tag were sexed.

Data analysis

Descriptive statistics were calculated using the MEANS procedure in SAS Institute (2008). Harvest weight, standard length, depth, width and head length were analysed using the MIXED procedure in SAS Institute (2008). As harvest weight was not normally distributed, we used the square root transformation, which was effective in restoring normality in this trait. The remainder body traits did not require transformation.

The statistical model fitted to harvest weight included the fixed effects of Year, Strain, Density, Sex, as well as all the two-way interactions; Pond nested within Year and Density, and Strain by Pond were fitted as random effects. Mathematically, the model may be written as:

$$\begin{aligned}\mathrm{Y}_{ijklmn} = {} & \mu + \mathrm{Yr}_i + \mathrm{Str}_j + \mathrm{Dens}_k + \mathrm{Sx}_l \\ & + (\mathrm{YrStr})_{ij} + (\mathrm{Yr\ Dens})_{ik} + (\mathrm{Yr\ Sx})_{il} \\ & + (\mathrm{Str\ Dens})_{jk} + (\mathrm{Str\ Sx})_{jl} \\ & + (\mathrm{Dens\ Sx})_{kl} + P_{ikm} + (\mathrm{Str}P)_{jm} \\ & + e_{ijklmn}\end{aligned}$$

where:

Y_{ijklmn} is the nth observation in the mth pond, the lth sex, the kth density, the jth strain and the ith year,

μ is the overall mean,

Yr_i is the effect of the *i*th year (i = 2008 or 2010),

Str_j is the effect of the *j*th strain (j = Abassa selection line or Kafr El Sheikh strain),

Dens_k is the effect of the *k*th stocking density (k = two or four fish m^{-2}),

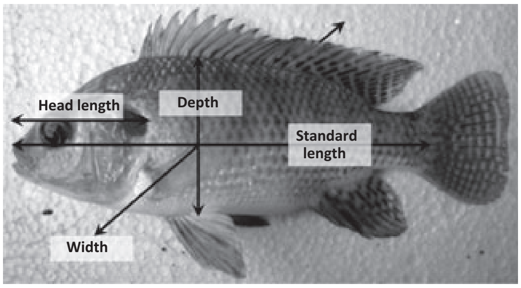

Figure 2 Definition of the fish body measurements.

Sx_l is the effect of the *l*th sex (l = female or male),

$(\mathrm{Yr\ Str})_{ij}$, $(\mathrm{Yr\ Dens})_{ik}$, $(\mathrm{Yr\ Sx})_{il}$, $(\mathrm{Str\ Dens})_{jk}$, $(\mathrm{Str\ Sx})_{jl}$ and $(\mathrm{Dens\ Sx})_{kl}$ are self-explanatory two-way interaction terms,

P_{ikm} is the random effect of the *m*th pond nested within the *k*th density and the *i*th year (m = 1, …, 20),

$(\mathrm{Str}\ P)_{jm}$ is the random effect of the interaction between strain and pond, and e_{ijklmn} is the random error term.

The model fitted to standard length, depth, width and head length was the same as for harvest weight, but omitting the Year effects and all interactions involving that effect (these additional body traits were only recorded in 2010).

Fish recovery rate was analysed using the GLIMMIX procedure in SAS Institute (2008). This variable was coded as ‘0’ (not recovered with identification at harvest) or ‘1’ (recovered with identification at harvest). A binomial distribution was assumed and the statistical model was fitted using the logit link function. The GLIMMIX procedure can fit both fixed and random effects. The model fitted was the same as for harvest weight, except that sex (and all interactions involving sex) was omitted (the sex was not known for fish that were not recovered). The least squares means were computed in the logit scale and back transformed from the logit scale to actual units using the inverse link option (ILINK) in GLIMMIX.

Results

Descriptive statistics

Table 2 shows the number of observations, the mean, minimum and maximum, standard deviation and coefficients of variation for the recorded traits. The coefficient of variation for harvest weight was greater (approximately twice) than for the other four body measurements. This is consistent with reports from other work where these characters were recorded (e.g. Nguyen, Khaw, Ponzoni, Hamzah & Kamaruzzaman 2007). Fish recovery rate was greater in 2010 than in 2008. As earlier described, this variable is computed from the number of fish stocked (tagged) and the number recovered at harvest with a tag (a Floy tag in 2008, a PIT tag in 2010). In both years, recovery rates result from the combined effect of tag losses and fish mortality. In 2008, tag losses were high,

Table 2 Number of observations (N), simple mean (μ), minimum and maximum, standard deviation (σ) and coefficient variation (CV,%) of harvest weight (g), standard length (cm), depth (cm), width (cm), head length (cm) and fish recovery rate

Variable	Year	N	μ	Min	Max	σ	CV
Harvest weight	2008	1418	106.43	24.0	256.0	40.69	38.23
	2010	2464	131.34	27.0	434.0	63.10	48.04
Standard length	2008						
	2010	2464	14.78	8.9	22.5	2.37	16.04
Depth	2008						
	2010	2464	5.78	3.0	9.4	1.14	19.67
Width	2008						
	2010	2464	2.71	1.5	5.6	0.52	19.32
Head length	2008						
	2010	2464	4.67	2.8	7.8	0.74	15.81
Fish recovery rate	2008	3000	0.47	0	1	0.50	105.64
	2010	3000	0.82	0	1	0.38	46.65

whereas in 2010 (with PIT tags), the retention rate was estimated at 97 per cent. Hence, recovery rate in this latter year was a good measure of survival rate, whereas that was not the case in 2008.

Body traits

Table 3 shows the results of the analysis of variance, whereas Tables 4a–e show the least squares means for the five body traits. All main effects were statistically significant for all traits, but Year could only be fitted to harvest weight. The Abbassa selection line outperformed the Kafr El Sheikh strain in all traits. Lower Density (two fish m^{-2}) resulted in heavier fish at the end of the grow-out period, whereas males were always heavier than females. The Year by Strain interaction was significant due to a scale effect (Table 4a), whereby the superiority of the Abbassa line was greater in 2010 than in 2008. The Year by Sex interaction was also significant due to the greater between-year differences in females.

Strain by Sex was significant in all traits except for depth. Proportionally, the between-sex difference was greater in the Kafr El Sheikh strain than in the Abbassa selection line. The Density by Sex interaction was significant for all traits except width (where it approached the significance level). The between-sex difference was greater at the lower density than at the higher density.

Fish recovery rate

This variable is discrete, taking values of ‘0’ or ‘1’ for not recovered or recovered fish (with a tag) at harvest respectively. Table 5 shows the results of the analyses of variance, whereas Table 6 shows the least squares means for fish recovery rate. All fixed effects were statistically significant with the exception of the Year by Strain and Strain by Density interactions, although in the former case the probability value approached significance (there were between-strain differences in the fish recovery rate in 2008, but not in 2010, Table 6). Year by Density was significant because fish recovery rate differed between densities in 2008, but not in 2010. The fish recovery rate was lower in the strain and in the density expected to produce the larger fish. Large, vigorous fish are more likely to lose a Floy tag than smaller, less vigorous fish, hence our conclusion that in 2008, the Abbassa selection line fish, and the fish at a density of two per m^2 lost their tag more frequently than those from the alternative strain or density. This in turn contributed to the lower fish recovery rate in those two classifications. In 2008, all the fish with lost tag were weighed. In all but two ponds, the fish with lost tag were heavier than those that had retained theirs. This supports the hypothesis that heavier fish lost the Floy tag more frequently than smaller fish, and that that contributed to the lower fish recovery rate in 2008 in the Abbassa selection line and in the lower density treatment. By contrast, in 2010, the retention of PIT tags was very high and tag losses negligible, hence recovery rate in that year was a measure of survival rate (Table 6, no significant between-strain and between-density differences).

Table 3 Analysis of variance of harvest weight ($g^{0.5}$), standard length (cm), depth (cm), width (cm), and head length (cm): Tests of fixed effects using the MIXED procedure in SAS Institute (2008)

	Harvest weight$^{0.5}$			Standard length			Depth			Width			Head length		
Effect	Den DF†	*F*-value	*P*-value	Den DF	*F*-value	*P*-value	Den DF	*F*-value	*P*-value	Den DF	*F*-value	*P*-value	Den DF	*F*-value	*P*-value
Year (Yr)	16	24.94	0.0001												
Strain (Str)	17	283.48	<.0001	8	271.52	<.0001	8	243.81	<.0001	8	127.29	<.0001	8	213.62	<.0001
Density (Dens)	16	79.99	<.0001	8	34.19	0.0004	8	37.04	0.0003	8	15.80	0.0041	8	33.29	0.0004
Sex (Sx)	3838	1133.35	<.0001	2441	526.19	<.0001	2441	537.83	<.0001	2441	343.72	<.0001	2441	408.72	<.0001
Yr*Str	3838	28.93	<.0001												
Yr*Dens	16	0.32	0.5774												
Yr*Sx	3838	12.56	0.0004												
Str*Dens	3838	1.52	0.2174	2441	0.01	0.9087	2441	0.13	0.7223	2441	0.15	0.6988	2441	0.00	0.9905
Str*Sx	3838	7.01	0.0081	2441	5.23	0.0223	2441	1.96	0.1613	2441	6.13	0.0133	2441	8.53	0.0035
Dens*Sx	3838	18.20	<.0001	2441	6.22	0.0127	2441	6.99	0.0082	2441	3.24	0.0719	2441	4.30	0.0382
Residual	3.2338			3.2066			0.7205			0.1788			0.3207		

†Denominator degrees of freedom.

Discussion

General considerations

The experimental fish used in the present strain comparison were spawned in two different locations, about 160 km apart, but not differing in climate. The standard of management and production systems in Abbassa and in the farm producing the Kafr El Sheikh strain are totally comparable not only because of the environment but also due to the adoption of the same aquaculture practices. The fish for the comparison were chosen from spawnings occurring at the same time in both locations, thus eliminating concerns about differences in age between the two strains in 2008 or in 2010. There were smaller (negligible) between-strain differences in weight at stocking in 2008 than in 2010. However, in both years, the Abbassa line significantly outperformed the Kafr El Sheikh strain in harvest weight. This indicates that stocking weight *per se* did not play a role in influencing future between-strain differences in harvest weight. Any differences in stocking weight are likely to be an early expression of the greater potential for growth rate of the Abbassa line. Note also that in 2010, age at stocking was greater than in 2008 (see Table 1), thus providing greater opportunity for the strains to depart in terms of weight at stocking.

We are conscious of the requirements of experimental design in strain comparisons (e.g. see James 1975; Ponzoni, Nguyen & Khaw 2011) and hence of what may be perceived as limitations in the present study. No account was taken of family structure because it was not possible to obtain this information in the commercial line. To compensate for this, in the production of experimental progeny, no less than 30 pairs of individuals per strain were used to generate the experimental fish. Furthermore, we ran the experiment in several replicate ponds, and repeated it for 2 years. These measures should have resulted in the inclusion of representative individuals from both strains in the present comparison.

Fig. 1, schematically describes the design of the present experiment. An important point is that in each pond, both strains were present. There are both arguments in favour and against this approach. One may say that it is good because both strains are in the same environment. By contrast, it may be argued that if there were competition among the fish and between the strains, the

Table 4a Harvest weight (g) least squares means (back transformed to actual units from the square root scale

		Year		Strain		Density		Sex	
Effect	**Level**	**2008**	**2010**	**A**	**K**	**2**	**4**	**F**	**M**
Year	2008	**106.09**		118.81	94.09	123.65	90.06	81.90	133.63
	2010		**127.01**	154.26	102.62	148.84	107.12	104.86	151.54
Strain	A			**135.96**		158.51	115.13	112.15	161.80
	K				**98.41**	114.92	82.99	75.52	124.10
Density	2					**135.96**		107.54	167.44
	4						**98.41**	79.39	119.25
Sex	F							**92.93**	
	M								**142.32**

A, Abbassa selection line; K, Kafr El Sheikh strain; 2 and 4, two and four fish m^{-2} respectively; F and M, female and male respectively.

Bold values are used to highlight main effects at the diagonal.

Table 4b Standard length (cm) least squares means

		Strain		Density		Sex	
Effect	**Level**	**A**	**K**	**2**	**4**	**F**	**M**
Strain	A	**15.90**		16.66	15.14	15.08	16.71
	K		**13.84**	14.59	13.10	12.86	14.83
Density	2			**15.62**		14.62	16.62
	4				**14.12**	13.31	14.92
Sex	F					**13.97**	
	M						**15.77**

Bold values are used to highlight main effects at the diagonal.

Table 4c Body depth (cm) least squares means

		Strain		Density		Sex	
Effect	**Level**	**A**	**K**	**2**	**4**	**F**	**M**
Strain	A	**6.33**		6.72	5.95	5.93	6.74
	K		**5.33**	5.69	4.96	4.87	5.78
Density	2			**6.21**		5.73	6.69
	4				**5.45**	5.07	5.84
Sex	F					**5.40**	
	M						**6.26**

Bold values are used to highlight main effects at the diagonal.

Table 4d Body width (cm) least square means

		Strain		Density		Sex	
Effect	**Level**	**A**	**K**	**2**	**4**	**F**	**M**
Strain	A	**2.91**		3.08	2.75	2.76	3.06
	K		**2.57**	2.72	2.41	2.37	2.76
Density	2			**2.90**		2.71	3.09
	4				**2.58**	2.42	2.73
Sex	F					**2.57**	
	M						**2.91**

Bold values are used to highlight main effects at the diagonal.

Table 4e Head length (cm) least squares means

		Strain		Density		Sex	
Effect	**Level**	**A**	**K**	**2**	**4**	**F**	**M**
Strain	A	**5.03**		5.27	4.79	4.81	5.24
	K		**4.38**	4.62	4.14	4.10	4.67
Density	2			**4.94**		4.67	5.22
	4				**4.47**	4.24	4.69
Sex	F					**4.45**	
	M						**4.96**

Bold values are used to highlight main effects at the diagonal.

Table 5 Tests of fixed effects for fish recovery using the GLIMMIX procedure in SAS Institute (2008)

Effect	**Den DF†**	***F*-value**	***P*-value**
Year (Yr)	16	128.74	<.0001
Strain (Str)	17	5.04	0.0383
Density (Dens)	16	6.23	0.0238
Yr*Str	5960	2.36	0.1242
Yr*Dens	16	5.24	0.0360
Str*Dens	5960	0.17	0.6782

†Denominator degrees of freedom.

Table 6 Fish recovery rate least squares means

		Year		Strain		Density	
Effect	**Level**	**2008**	**2010**	**A**	**K**	**2**	**4**
Year	2008	**0.44**		0.36	0.51	0.35	0.53
	2010		**0.83**	0.82	0.84	0.83	0.83
Strain	A			**0.62**		0.56	0.67
	K				**0.70**	0.66	0.73
Density	2					**0.61**	
	4						**0.70**

A, Abbassa selection line; K, Kafr El Sheikh strain; 2 and 4, two and four fish m^{-2} respectively; F and M, female and male respectively.
Bold values are used to highlight main effects at the diagonal.

comparison could be biased in favour of the most competitive fish, which may not necessarily be the best from a production viewpoint. The coefficient of variation (CV) of harvest weight can be interpreted as indicating the intensity of the competition among the fish in each pond. One would expect greater competition in ponds stocked at higher density (i.e. four fish m^{-2}). This would be reasonable because with greater stocking density, there is less space available per fish in the pond. Several authors have identified increases in CV as an indication of inter-individual competition and dominance hierarchy (McCarthy, Carter & Houlihan 1992; Jobling 1995; Adams, Huntingford, Turnbull, Arnott & Bell 2000). On the other hand, a low CV is suggestive of less competition and of a good social environment within a population (Jobling 1995; Mambrini, Labbé, Randriamanantsoa & Boujard 2006). Table 7 shows the CVs for harvest weight by year, stocking density, strain and pond. The average for the five ponds per year, stocking density and strain is also shown. The CVs are consistent with other reports on this parameter for Nile tilapia (e.g. Ponzoni, Hamzah, Tan & Kamaruzzaman 2005). Within a year by strain sub-class, there were virtually no differences in CV between densities. The Abbassa selection line had a lower CV than the Kafr El Sheikh strain. This may be explained by the fact that the between-sex difference in the latter strain was greater than in the former, thus contributing to a greater CV in harvest weight. CVs were greater in 2010 than in 2008, but overall, there was no indication that any one strain was dominating the other one. This is further backed up by the comparable recovery rate in 2010, when it was a close reflection of survival rate.

Table 7 Coefficient of variation (CV) of harvest weight by year, density, strain and pond

Year	Density	Strain	Pond	CV (%)
2008	2	A	1	27.9
			3	38.6
			6	24.9
			8	28.7
			10	25.8
		Average		29.18
		K	1	34.3
			3	34.4
			6	32.2
			8	39.5
			10	37.7
		Average		35.42
	4	A	2	23.6
			4	32.1
			5	27.9
			7	29.8
			9	30.5
		Average		28.78
		K	2	39.4
			4	38.6
			5	35.9
			7	35.4
			9	35.4
		Average		36.94
2010	2	A	13	34.9
			14	29.9
			16	38.8
			19	37.5
			20	33.9
		Average		35.00
		K	13	39.9
			14	37.8
			16	42.6
			19	49.7
			20	39.2
		Average		41.84
	4	A	11	38.1
			12	39.1
			15	38.7
			17	39.6
			18	41.3
		Average		33.36
		K	11	37.9
			12	39.7
			15	46.8
			17	42.5
			18	45.8
		Average		42.54

A, Abbassa selection line; K, Kafr El Sheikh strain; 2 and 4, two and four fish m^{-2} respectively; F and M, female and male respectively.

Note also that if competition had been an issue in this trial, it would have been greater at the greater density. Statistically, this would have been captured as a significant strain by density interaction. However, this term was not statistically significant for harvest weight or for any of the other body traits recorded (Table 3). At both densities, harvest weight of the Kafr El Sheik strain was 72 per cent of that of the Abbassa line (Table 4a).

Overall, the results indicate that the between-strain differences found in this study were not the result of competition favouring any of the strains, but that they were the consequence of differences in their inherent capacity to grow. Note also that in a study of testing methods for strain comparisons of Nile tilapia, Danting, Eknath and Bentsen (1995) concluded that the ranking of strains on growth rate was consistent with different methods, including communal testing and separate testing of the strains. These authors' results further strengthen the notion that our results were not affected by the decision of growing out the strains in the same ponds.

Body traits

For the sake of clarity, the discussion is focused on harvest weight, a trait of major economic importance. The results for other body traits (length, depth, width and head length) follow the same pattern as harvest weight, and comments similar to those made about harvest weight could be made about each one of them.

The results leave no room for doubt about the superior harvest weight (28 per cent) of the Abbassa selection line over the Kafr El Sheikh commercial strain when the 2008 and 2010 data are jointly considered. This superiority is likely to be biased downwards due to the relatively low fish recovery rate in 2008 due to tag losses among heavier fish. In 2010, when tag losses were low (3.0 per cent), the advantage in favour of the Abbassa selection line was of the order of 33 per cent.

At harvest, males were heavier than females, but the between-sex difference was greater in the commercial than in the Abbassa selection line (39 and 31 per cent respectively). The Abbassa selection line not only grew faster but also the difference between the sexes was smaller. Females in the Abbassa selection line grew almost as fast as males in the commercial line.

Both strains grew faster at the lower density of two fish m^{-2}, and the percentage reduction in harvest weight at the higher density was about the same for both strains (27 per cent). The advantage of the Abbassa selection line over the commercial line was about 28 per cent at both densities (Table 3, non significant strain by density interaction for any of the body traits recorded).

Fish recovery rate

This variable reflects the combined effects of tag losses and fish mortality during the grow-out period. It was calculated from the difference in the number of fish between stocking and harvesting. In 2008, it was lower than in 2010 due to high tag losses (in 2008, 913 fish lost tag, approximately 30 per cent). By contrast, tag losses were low (3.0 per cent) in 2010 so that fish recovery rate in that year was a closer reflection of survival rate. In 2008, recovery rate in the Abbassa line was lower than in the commercial strain. We attribute this to the greater tag losses among larger, more vigorous fish, more prevalent in the Abbassa line. Recovery rate was also lower at the lower density, supporting the notion that tag losses were greater among larger fish. This notion is further supported by the fact that in 2008, in eight of the ten ponds used in the trial, fish that had lost their Floy tag were on average heavier at harvest than fish that had retained their tag.

In 2010, when (PIT) tag losses were low, there were no differences in fish recovery rate between strains or between densities (Table 6). Note that the value (0.83) in 2010 was close to an estimation of survival rate in 2008 (0.78) obtained by adding the tag less fish to those that were recovered with a tag at harvest time.

Conclusions and practical implications

The Abbassa selection line outperformed the Kafr El Sheikh commercial strain in terms of growth rate. This was evident at both the usual stocking density of two fish m^{-2} and at double that density. Furthermore, proportionally, the difference in harvest weight between males and females in the Abbassa selection line was smaller than in the commercial strain. The data collected indicate that both strains had a similar (and good) survival rate (approximately 80 per cent) during the grow-out period. We conclude that the Abbassa selection line is ready for release to the tilapia industry in Egypt, which can greatly benefit from its utilization. The Abbassa selection line is also likely to be useful in other Mediterranean and

West Asian countries with a climate similar to that in Egypt. However, any such use should be preceded by rigorous testing against local stock. At the same time, measures have to be taken to ensure the long-term viability of the Abbassa line, strengthening it by increasing its effective population size and by creating satellite nuclei as an insurance against disasters.

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