The Effect of Stocking Density on Growth Parameters of All-Male Nile Tilapia Fry Nursed in Hapas

Wirat Jiwyam* and Ratchaneegorn Mapanao

ABSTRACT

Sex-reversed all-male Nile tilapia (*Oreochromis niloticus*) fry (mean weight 0.15 g) were stocked at six densities (12, 25, 50, 100, 200 and 400 fish·m^{-2}) in hapas (2x3x1.2 m) placed in a 400 m^2 earthen pond. Fish were fed with mixed-feed containing 32.9% crude protein and 9.5% crude fat. After six weeks, mean weights were 29.32±0.17, 19.05±0.07, 14.80±0.57, 10.20±0.14, 5.80±0.57 and 4.65±0.35 g, respectively. Specific growth rates were 12.44±0.79, 11.43±0.69, 10.80±0.85, 9.87±0.95, 8.41±1.18 and 7.83±1.24% ·day^{-1}, respectively. The negative relationship between stocking density and specific growth rate was expressed as SGR = 15.887-1.354lnD (r^2 = 0.9870, p = 0.00). Low feed conversion ratios were achieved at low stocking densities (12 to 50 fish·m^{-2}) and increased at the high stocking densities of 200 and 400 fish·m^{-2}. The highest condition factor was found at the lowest stocking density (12 fish·m^{-2}) and lowest condition factor was found with the high stocking densities of 200 and 400 fish·m^{-2}. The highest coefficient of weight variance was also achieved at 200 and 400 fish·m^{-2}, while less size variation was found with stocking between 12 and 100 fish·m^{-2}. The stocking density of 100 fish·m^{-2} was apparently an optimum density for nursing all-male Nile tilapia fry in hapas. This density also resulted in the highest standing crop of Nile tilapia fingerlings in hapas at 1.01 kg·m^{-2}.

Keywords: Size variation, Advanced nursing, Nylon net enclosure, Sex-reversed tilapia

INTRODUCTION

Stocking density affects both fish survival and growth (Jobling, 1994). Increasing stocking density usually causes stress (Leatherland and Cho, 1985), which leads to enhanced energy requirements along with reduced growth, feed utilization and net yield (Grant, 1997; Hengsawat *et al*., 1997), while understocking fails to maximize space utilization (Rahman *et al*., 2006). The relationship between stocking density and tilapia yield is generally positive (Watanabe *et al*., 1990; Siddiqui *et al*., 1997), while increasing stocking density negatively affects individual tilapia growth (Sin and Chiu, 1983; Yi *et al*., 1996; Ridha, 2006). Huang and Chiu (1997) found that size variation in Florida red tilapia and tilapia hybrids (*Oreochromis niloticus* (females) x *O. mossambicus* (males)) increased at higher stocking density. However, the relationship between fish survival and stocking density is not consistent (El-Sadyed, 2002). Varied and sometimes controversial results have been reported concerning the relationships of stocking density with larval growth and survival (El-Sayed, 2006). For example, tests conducted using six experimental aquaria stocked with fry (initial body weight 1.35 g) of hybrid tilapia, *O. niloticus* (male) x *O. mossambicus* (female) at densities of 0.1, 0.2, 0.4, 0.8, 1.6 and 3.2 fry·l^{-1} indicated that size, size variation, percentage survival and production were significantly

Program of Fisheries Science, Faculty of Applied Science and Engineering, Nong Khai Campus, Khon Kaen University, Nong Khai Province, Thailand
* Corresponding author, e-mail address: wirjiw@kku.ac.th
Received 20 February 2018 / Accepted 4 July 2018

affected by stocking density, while condition factor was not (Huang and Chiu, 1997). Rana (1981) suggested that 8 fry·l^{-1} was the optimum stocking density for *O. mossambicus*, based on a study where growth rates of Nile tilapia fry were negatively correlated with stocking density, ranging from 2 to 20 fry·l^{-1}. The author suggested that 5 to 10 fry·l^{-1} be adopted as the optimum stocking density. El-Sayed (2002) found that growth of Nile tilapia fry decreased with increasing stocking density from 3 to 20 fry; however, no significant difference was found between 3 and 5 fry·l^{-1}. Therefore, 5 fry·l^{-1} was suggested as the optimum for hatchery-reared Nile tilapia fry. On the contrary, Gall and Baker (1999) reported that body size of tilapia fry was not affected by stocking densities ranging from 1 to 200 fry·l^{-1} in a system with uniform water flow. In addition, Macintosh and De Silva (1984) determined that the relationship between stocking density and survival for both *O. mossambicus* and *O. niloticus* female x *O. aureus* male fry was not consistent. These results suggest that relationships of stocking density with tilapia growth and survival depend on a number of biological and physical factors including fish life stage, size, sex, social hierarchy, tolerance to environmental changes and the configuration and hydrodynamics of the culture system (Huang and Chiu, 1997; El-Sayed, 2002), and that more work is required along these lines (El-Sayed, 2006). Optimum stocking density in Nile tilapia nursing depends on each culture practice and, thus, each technique or system should be evaluated individually.

The high degree of control that can be achieved using finely-meshed nylon net cages or 'hapas' has made them popular for both breeding and nursing tilapia seed-stock at several levels of intensity (Guerrero and Garcia, 1983; Hughes and Behrends, 1983; Muir and Little, 1991; Little *et al*., 1993; Barman and Little, 2011). Hapa nursing of small fry to larger, more predator-resistant fingerlings has been the focus for intensification of aquaculture in North East Thailand and Lao PDR (Haitook *et al*., 1999; Little *et al*., 1991). In aquaculture, size control and fish production are important to meet market demand. Fish supply and market demand determine the price of tilapia. Farmers should, therefore, carefully define their target consumers and determine the appropriate stocking density to produce the size of fish preferred by each (El-Sayed, 2006).

Size variation is a major problem during both grow-out and nursing periods of Nile tilapia cultivation. In practice, farming densities are based on experience, with codes of practice and handbooks used as guidelines. Continuous grading in nursing units to separate larger fry is recommended for tilapia (El-Sayed, 2006); however, this technique is labor intensive and increases handling stress, which leads to fish mortality. Hence, the optimum stocking density of fry to maximize growth performance while minimizing size variation during hapa nursing is of interest. However, information regarding optimum stocking densities and biological conditions for Nile tilapia production in hapas is still limited.

Here, the effects of stocking density on growth, size variation, survival and production of tilapia fry in hapas were assessed.

MATERIALS AND METHODS

Experimental setup

Experiments were conducted in a fish pond (surface area 400 m^2, mean depth 1.2 m) using 2x3x1.2 m hapas. The submersed volume of each hapa was approximately 6 m^3. There were six treatments using different densities, with three replicates for each treatment. In May 2012, sex-reversed Nile tilapia (*Oreochromis niloticus*) fry (Chitralada strain) with mean weight of 0.15 g were stocked at six different densities (12, 25, 50, 100, 200 and 400 fish·m^{-2}) and reared for six weeks. Fish were fed twice a day (09:00 am and 04:00 pm) in equal amounts with a 32.89% crude protein mixed-feed (Table 1). Twenty percent (by number) of the fish in each cage were randomly sampled at bi-weekly intervals for growth monitoring by weight measurement. The calculated total biomass of fish in each cage was used to readjust the food quantity downwards from 20% body weight per day for the 1st and 2nd weeks of rearing to 15% for the 3rd and 4th weeks and to 10% for the 5th and 6th weeks.

Experimental diets

The ingredients and nutrient contents of experimental diets are presented in Table 1. Moisture, crude protein, crude fat, crude fiber and ash content of the mixed-feed were determined by standard AOAC methods (AOAC, 1990). All the feed ingredients were mixed thoroughly in a Hobart mixer, then boiling water was added, mixed for another 5 min and the mash was extruded by a meat grinder with 3-mm diameter holes.

Water quality monitoring

Water quality in each hapa was measured both in early morning (06:00 am) and afternoon (04:00 pm) at weekly intervals to determine temperature (ºC), dissolved oxygen (DO) ($mg \cdot l^{-1}$) and pH. All water quality parameters were determined *in situ*. Temperature and dissolved oxygen were determined by a water quality analyzer (YSI 58, YSI Corp., Yellow Springs, Ohio, USA) and pH by a pH-meter (IQ Scientific Instruments).

Calculations and statistical analyses

Specific growth rate (SGR) ($\% \cdot day^{-1}$) was calculated as $(\ln W_2 - \ln W_1)/t \times 100$, where W_1 refers to the initial live body weight (g), W_2 is the final live body weight (g) and t is the nursing time in days. Daily weight gain (DWG) ($g \cdot fish^{-1} \cdot day^{-1}$) was calculated as $(W_f - W_i)/t$, where W_f is the final live weight, W_i is the initial live weight and t is the nursing time in days. Feed conversion ratio (FCR) was calculated as dry feed supplied (kg)/live weight gain (kg). Survival rates (%) were estimated as number of fish harvested×100/number of fish stocked. Net fish yield ($kg \cdot m^{-2}$) was calculated by deducting the initial biomass at stocking from the biomass at harvesting. Condition factor (K) was calculated as $(W \times 100)/TL^3$, where W is weight (g) and TL is total length (cm). Coefficient of variation (CV) (%) was calculated as $(SD/\bar{x}) \times 100$.

The data were presented as mean ±SD of three replicates. Data were assessed using one-way analysis of variance (ANOVA). Significant results were further tested using the Tukey's test. Least squares regression was performed to evaluate the relationships between stocking density and each of the variables, and judged by the coefficient of determination (R^2). All statistical analyses were performed with SPSS (SPSS Inc., Chicago, Illinois, USA). Differences were considered significant when $p < 0.05$.

Table 1. Ingredients (% wet weight) and proximate composition (% dry weight) of the mixed-feed used to feed Nile tilapia fry in hapas during a six-week period.

Ingredients	**Ratio**
Fish meal (%)	57
Rice bran (%)	33
Broken rice (%)	10
Proximate compositions	
Moisture (%)	10.45
Crude protein (%)	32.89
Crude fat (%)	9.51
Crude fiber (%)	8.48
Ash (%)	16.50

RESULTS

Fish growth

Fish growth data are presented in Table 2. Survival of the fish was significantly different only between the 400 fish·m^{-2} and the rest ($p < 0.05$). The lowest survival occurred at 400 fish·m^{-2}. Survival rates achieved at 12 to 200 fish·m^{-2} ranged from 98.50±0.71 to 99.50±0.14%. After six weeks, mean final weights (FW) from lowest to highest densities were 29.32±0.17, 19.05±0.07, 14.80±0.57, 10.20±0.14, 5.80±0.57 and 4.65±0.35 g. The mean final weight of the fish was significantly affected by stocking density ($p < 0.05$) but no significant difference was found between 200 and 400 fish·m^{-2}. The negative regression between stocking density (D) and final mean weight (FW) was expressed as $FW = 112.3D^{-0.537}$ ($r^2 = 0.9890$, $p = 0.00$; Figure 1). Mean final length (FL) was significantly different among all stocking densities. Final total length decreased from 11.59 to 6.44 cm as stocking density increased from 12 to 400 fish·m^{-2}. The strongly negative regression between stocking density and final length was expressed as $y = 17.923x^{-0.173}$ ($r^2 = 0.992$, $p = 0.00$). Daily weight gain (DWG) was significantly different among all stocking densities ($p < 0.05$). The highest daily weight gain was shown by the lowest density (12 fish·m^{-2}) while the lowest gain was recorded for the highest density (400 fish·m^{-2}). The negative correlation between stocking density (D) and daily weight gain (DWG) was expressed as $DWG = 2.7675D^{-0.549}$ (r^2 =09888, $p = 0.00$, Figure 2). Specific growth rate (SGR) was also significantly different among all stocking densities ($p < 0.05$). The highest specific growth rate of 12.44% ·day^{-1} was obtained from the lowest density (12 fish·m^{-2}) while the lowest, 7.83% ·day^{-1}, was recorded for the highest density (400 fish·m^{-2}). The strongly negative correlation between stocking density (D) and specific growth rate (SGR) was expressed as $SGR = 15.887 - 1.354 \ln D$ ($r^2 = 0.987$, $p = 0.00$, Figure 3). Net yields were 0.34±0.00, 0.46±0.01, 0.69±0.03, 0.92±0.01, 0.96±0.11 and 1.40±0.15 kg·m^{-2}, respectively. Highest net yield was recorded for the highest stocking density (400 fish·m^{-2}) while net yields between the lower densities (12-25 fish·m^{-2}),

Table 2. Growth performance (mean± standard deviation) of Nile tilapia fingerlings at six stocking densities (12, 25, 50, 100, 200 and 400 fry·m^{-2}) raised in hapas for six weeks.

Growth parameters	Stocking density (fish·m^{-2})						P-Value
	12	25	50	100	200	400	
SUR (%)	99.30±0.99^{a}	99.35±0.92^{a}	98.50±0.71^{a}	99.30±0.00^{a}	99.50±0.14^{a}	94.30±0.14^{b}	0.01
FW (g)	29.32±0.17^{a}	19.05±0.07^{b}	14.80±0.57^{c}	10.20±0.14^{d}	5.80±0.57^{e}	4.65±0.35^{e}	0.00
FL(cm)	11.59±1.19^{a}	10.21±1.01^{b}	9.33±1.08^{c}	8.22±1.16^{d}	6.95±1.21^{e}	6.44±1.22^{f}	0.00
DWG (g·day^{-1})	0.69±0.21^{a}	0.45±0.13^{b}	0.35±0.12^{c}	0.24±0.10^{d}	0.14±0.08^{e}	0.11±0.07^{f}	0.00
SGR (%·day^{-1})	12.44±0.79^{a}	11.43±0.69^{b}	10.80±0.85^{c}	9.87±0.95^{d}	8.41±1.18^{e}	7.83±1.24^{f}	0.00
GY (kg·m^{-2})	0.35±0.00^{e}	0.48±0.01^{de}	0.73±0.03^{cd}	1.01±0.01^{bc}	1.12±0.11^{b}	1.76±0.15^{a}	0.00
NY (kg·m^{-2})	0.34±0.00^{d}	0.46±0.01^{cd}	0.69±0.03^{bc}	0.92±0.01^{b}	0.96±0.11^{b}	1.40±0.15^{a}	0.00
FCR	1.44±0.08^{c}	1.42±0.01^{bc}	1.47±0.02^{bc}	1.59±0.00^{b}	1.84±0.01^{a}	1.92±0.06^{a}	0.00
K	1.83±0.15^{a}	1.74±0.14^{b}	1.76±0.14^{b}	1.77±0.23^{b}	1.61±0.21^{c}	1.60±0.25^{c}	0.00
CV of weight (%)	30.94±0.60^{b}	29.58±0.57^{b}	34.61±3.70^{b}	40.81±5.80^{b}	58.13±7.54^{a}	63.03±0.11^{a}	0.01
CV of length (%)	10.30±0.85^{c}	9.92±1.12^{c}	11.57±1.65^{bc}	14.06±2.42^{abc}	17.27±1.801^{ab}	18.91±0.59^{a}	0.00

Means in the same row with the same superscripts did not differ significantly (ANOVA, $p < 0.05$).
SUR = survival, FW = final weight, FL = Final total length, DWG= daily weight gain, SGR = specific growth rate, GY = gross yield, NY = net yield, FCR = feed conversion ratio, K = condition factor, CV = coefficient of variance

between medium densities (25 to 50), and among densities of 50 to 200 fish·m^{-2} showed no significant differences. The positive relationship between stocking density (D) and net yield (NY) was expressed as NY = 0.2892lnD$^{-0.4351}$ (r^2 = 0.9597, p = 0.01, Figure 4). Stocking density significantly affected gross yield (GY). Maximum gross yield of 1.76±0.15 kg·m^{-2} was achieved at the highest stocking density of 400 fish·m^{-2} while the lowest was recorded at 12 fish·m^{-2}, which was not significantly different from 25 fish·m^{-2}. Gross yields achieved from stocking densities 100 and 200 fish·m^{-2} were not different. Maximum net yield (NY) of 1.40± 0.15 kg·m^{-2} was achieved at the highest stocking density of 400 fish·m^{-2} while net yields from 50, 100 and 200 fish·m^{-2} were not significantly different.

Lowest feed conversion ratio (FCR) was obtained from the lower stocking densities of 12 to 50 fish·m^{-2} (1.42±0.01 to 1.47±0.02) while the feed conversion ratio for 100 fish·m^{-2} (1.59±0.00) was higher than those of the lower densities but lower than those of the higher densities (200 to 400 fish·m^{-2}). The highest FCR was obtained from the stocking densities of 200 to 400 fish·m^{-2}. Condition factor (K) was significantly different among stocking densities ($p < 0.05$). Lowest condition factor (K) occurred at 200 to 400 fish·m^{-2} while the highest K was obtained from 12 fish·m^{-2}. However, no significant difference of condition factor was recorded among stocking densities of 25 to 100 fish·m^{-2}.

Size variation differed significantly among stocking densities ($p < 0.05$). Highest size variation occurred at densities of 200 to 400 fish·m^{-2}; however, no significant difference in size variation was recorded among the densities of 12 to 100 fish·m^{-2}. Coefficient of variance (CV) for weight of the fish at stocking densities from 12 to 100 fish·m^{-2} ranged from 30.94±0.60 to 40.81±5.80, while higher variation was obtained from stocking densities of 200 and 400 fish·m^{-2}, 58.13±7.54 and 63.03±0.11%, respectively. Correlation between stocking density (D) and coefficient of variance (CV) for weight was expressed as CV= 25.777+0.2058D-0.0003D^2 (r^2 = 0.9780, p = 0.01, Figure 5).

Water quality

There was no significant difference among water quality parameters and stocking densities (Table 3). Average values of water quality parameters in the hapas during the six-week nursing period for pH, dissolved oxygen and temperature in the morning (and afternoon) were 7.13 (7.78), 2.70 (4.67) mg·l^{-1} and 29.89 (33.57) ˚C, respectively.

Table 3. Water quality parameters in hapas placed in a fish pond, used for nursing Nile tilapia fry at different stocking densities (12, 25, 50, 100, 200 and 400 fry·m^{-2}) for a six-week period.

Water quality parameters	Time of day	Stocking density (fish·m^{-2})					
		12	25	50	100	200	400
pH	Morning	6.56-7.77	6.72-7.65	6.59-7.77	6.71-7.65	6.71-7.68	6.66-7.56
	Afternoon	7.46-8.44	7.30-8.70	7.44-8.08	7.32-7.79	7.41-7.86	7.40-8.03
DO (mg·l^{-1})	Morning	1.1-4.1	1.6-3.9	1.7-3.8	1.6-3.8	1.7-3.7	1.6-3.8
	Afternoon	3.4-4.8	3.8-5.3	4.1-5.5	4.2-5.2	4.3-5.1	4.0-5.1
Temperature (°C)	Morning	28.5-31.4	28.8-31.4	28.7-31.3	28.7-31.3	28.7-31.3	28.6-31.3
	Afternoon	36.2-32.0	35.9-32.0	36.1-32.0	36.3-32.1	36.3-31.8	36.1-31.9

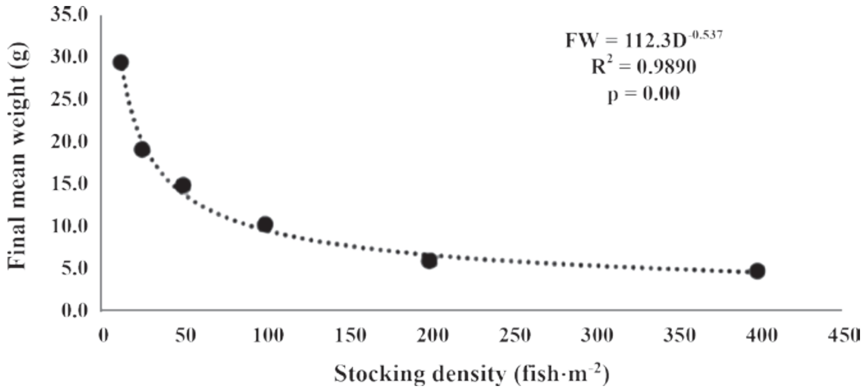

Figure 1. Relationship between stocking density and final mean weight (FW) of Nile tilapia fingerlings reared in hapas at six stocking densities (12, 25, 50, 100, 200 and 400 fry·m^{-2}) for a six-week period.

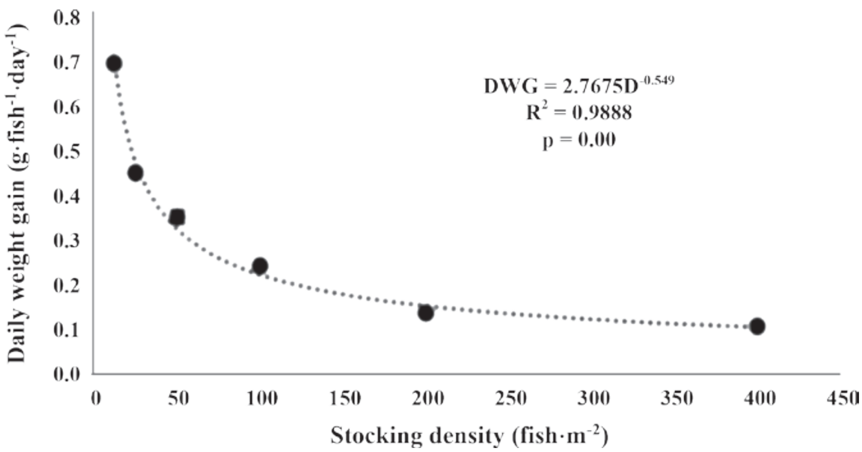

Figure 2. Relationship between stocking density and daily weight gain (DWG) of Nile tilapia fingerlings after nursing in hapas at six stocking densities (D) (12, 25, 50, 100, 200 and 400 fry·m^{-2}) for six weeks.

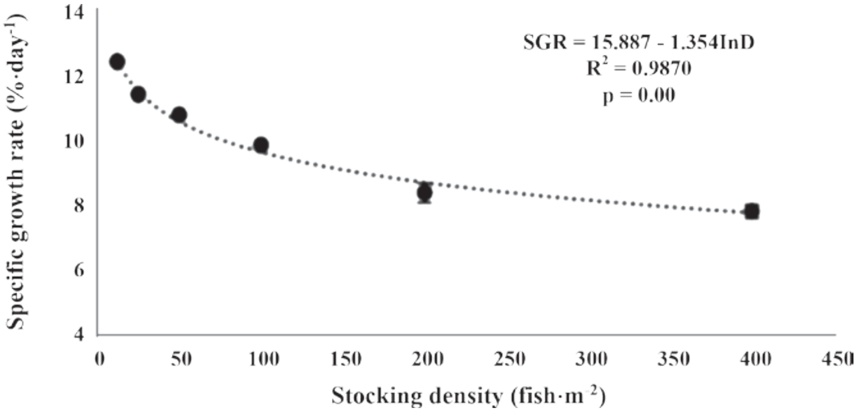

Figure 3. Relationship between stocking density and specific growth rate (SGR) of Nile tilapia fingerlings reared in hapas at six stocking densities (D) (12, 25, 50, 100, 200 and 400 fry·m^{-2}) for six weeks.

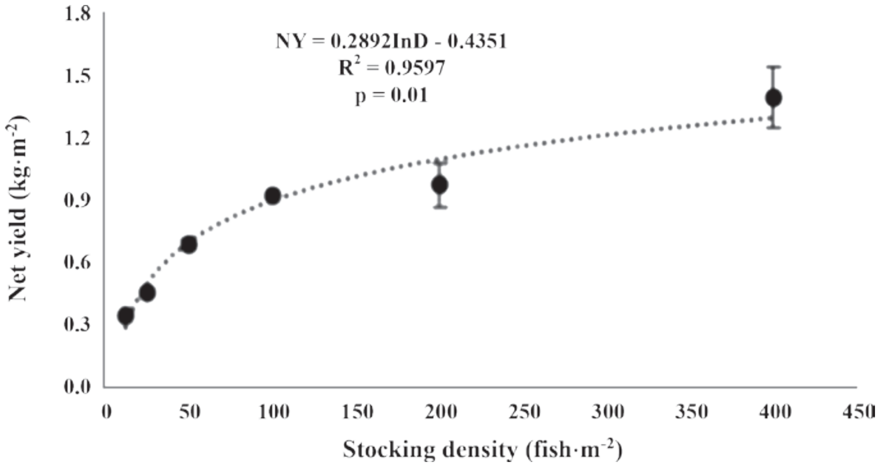

Figure 4. Relationship between stocking density and net yield (NY) of Nile tilapia fingerlings reared in hapas at six stocking densities (D) (12, 25, 50, 100, 200 and 400 fry·m^{-2}) for six weeks.

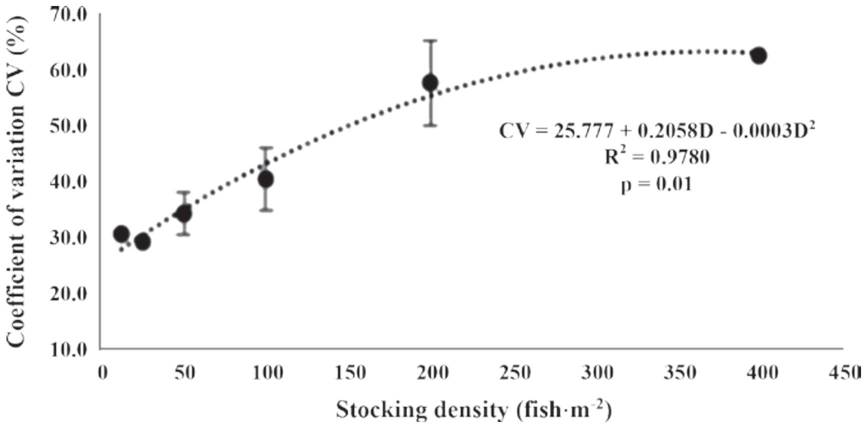

Figure 5. Relationship between stocking density and coefficient of variance (CV) in weight of Nile tilapia fingerlings reared in hapas at six stocking densities (D) (12, 25, 50, 100, 200 and 400 ffry·m^{-2}) for six weeks.

DISCUSSION

All water quality parameters were within the desirable range for Nile tilapia, according to El-Sayed (2006), who reported that tilapia are known to withstand very low levels of DO. Most tilapias can tolerate DO levels as low as 0.1-0.5 mg^{-1} for varying periods of time. Survival rates at all stocking densities were high (> 90%). In a similar study, nursing of mono-sex Nile tilapia fry with initial weight of 0.08 g in a hapa set up in a fertilized pond at stocking density of 150 fish·m^{-2}, survival rate after 2 months was 86%, specific growth rate and final weight were 7.6%·day^{-1} and 0.7 g, respectively (Little *et al*., 2003). In the present study, specific growth rates and final weights at stocking densities of 100 and 200 fish·m^{-2} were 9.87±0.95 and 8.41±1.18%·day^{-1} and 10.20±0.14 and 5.80±0.57 g, respectively. The differences from our results could be partly caused by different study objectives. However, the higher final weight recorded in our study may be due to the larger size at stocking, while the higher specific growth rate we recorded may be due to higher protein feed used and higher feeding rate. Factors affecting Nile tilapia fry growth have been reported by several authors (El-Sayed, 2002, 2006).

Growth performance, size variation, survival, feed conversion ratio, condition factor and production were all significantly affected by stocking density. Size variation reported by Huang and Chiu (1997) was attributed in part to the social interaction of fish. In crowded conditions, fish that are bigger and maintain a dominant position grow faster. Therefore, high stocking rates may result in high size variation. Growth performance and production reported by El-Sayed (2002) concurred with previous studies, except for size (Gall and Baker, 1999), survival (Macintosh and De Silva, 1984; El-Sayed, 2002) and condition factor (Huang and Chiu, 1997), which were inconsistent or controversial. No data were available regarding the relationship between stocking density and feed conversion ratio in Nile tilapia fry nursing.

As mentioned earlier, several authors such as Huang and Chiu (1997) and El-Sayed (2002) suggested that the relationships of stocking density with growth and survival were dependent on various biological and physical factors including fish life stage, size, sex, social hierarchy and tolerance to environmental changes. In addition, configuration and hydrodynamics of the culture system may affect the results. Under crowded conditions, larger fish dominate the population while subordinate individuals grow at much slower rates (El-Sayed, 2006). Several authors have suggested that high stocking density causes excessive cannibalism, leading to high mortality of Nile tilapia (Dambo and Rana, 1992; El-Sayed, 2002), *O. mossambicus* and tilapia hybrids (Macintosh and De Silva, 1984).

Natural death can be determined by the presence of dead fish floating in the cage (Haylor, 1991). Here, no dead fish were observed floating in the hapas during the experiment. The lowest survival at the highest stocking density (400 fish·m^{-2}) may have resulted from high predation pressure as the dominant fish became larger than the subdominant group. Increasing the size gap may increase predation pressure at high stocking densities, resulting in low survival rates at stocking density of 400 fish·m^{-2}. The notion that gape is an important constraint on prey use is widespread in fish biology and frequently cited as an explanation for correlations between prey and predator body size (Felley, 1984; Shirota, 1978). In Nile tilapia, maximum prey size was determined as a function of cannibal gape (Smith, 1989). The oral gape of a predator largely determines maximum prey size; a predator can consume a fish with body depth smaller or equal to its maximum oral gape (Fessehaye *et al*.,2004).

Final weight and length, which were inversely correlated with increased stocking density in this study were consistent with several previous studies. Macintosh and De Silva (1984) reported that increasing stocking density of *O. mossambicus* fry usually leads to social stress and causes a chronic stress response which impairs fish growth, possibly due to the mobilization of dietary energy by the physiological alterations provoked by the stress response (Dambo and Rana, 1992; Kebus *et al*., 1992). This may lead to a higher feed conversion ratio at 200 and 400 fish·m^{-2}, as recorded in this study. Also, if high predation pressure at the high density led to lower survival, this could, in turn, reduce fish biomass by the end of nursing period and lead to the higher feed conversion ratio.

Optimal of Nile tilapia fry in each nursing system was reported by various authors (Dambo and Rana, 1992; El-Sayed, 2002; Gall and Bakar, 1999). In this study, the final weights of Nile tilapia fry stocked at all densities were significantly different, except for 200 and 400 fish·m^{-2}. However, weight sharply decreased by 1.76 fold as stocking density increased beyond 100 fish·m^{-2}. In addition, no significant difference was found in condition factor among stocking densities of 25, 50 and 100 fish·m^{-2}, or between 200 and 400 fish·m^{-2}. Water quality and feed supply were determined as not being limiting factors for this study, hence crowding stress might have affected growth performance of the fish when the standing crop reached 1.01 kg·m^{-2}. Our results indicated that ideal stocking density in fry nursing of Nile tilapia was 100 fish·m^{-2}. Growth of stunted populations of Nile tilapia at high stocking densities may recover after restocking at optimum density (Derun and Yakupitiyage, 1998); however, a high degree of stunting may not be reversible (Abdel-Tawwab *et al*., 2006; Wang *et al*., 2000).

CONCLUSION

In conclusion, for a six-week nursing period with no fish size grading, a stocking density of 100 fish·m^{-2} was determined as the optimum density for monosex Nile tilapia fingerling production in hapas. The stocking strategy, coupled with feed and feeding regime, could increase individual size while reducing size variation. However, the economic advantage of such a stocking strategy for fry nursing when compared to manual size grading during the nursing period needs to be further studied prior to its adoption.

ACKNOWLEDGEMENTS

This work was supported financially by Khon Kaen University, Nong Khai Campus.

LITERATURE CITED

Abdel-Tawwab, M., Y.A.E. Khattab, M.H. Ahmad and A.M.E. Shalaby. 2006. Compensatory growth, feed utilization, whole-body composition, and hematological changes in starved juvenile Nile tilapia, *Oreochromis niloticus* (L.). **Journal of Applied Aquaculture** 18: 17-36.

AOAC. (1990). **Official Methods of Analysis,** 15th edn. Washington, DC.

Barman, B.K. and D.C. Little. 2011. Use of hapa to produce Nile tilapia (*Oreochromis niloticus* L.) seed in household food fish ponds: A participatory trial with small-scale farming households in Northwest Bangladesh. **Aquaculture** 317: 214-222.

Dambo, W.B. and K.J. Rana. 1992. Effects of stocking density on growth and survival of Nile tilapia *Oreochromis niloticus* (L.) fry in the hatchery. **Aquaculture and Fisheries Management** 23: 71-80.

Derun, Y. and A. Yakupitiyage. 1998. Compensatory growth of Nile tilapia (*Oreochromis niloticus*). **The Fifth** Asian Fisheries Forum-Fisheries and Food Security beyond the Year 2000. Asian Fisheries Society, Chiang Mai, Thailand. p. 333.

El-Sayed A. 2002. Effects of stocking density and feeding levels on growth and feed conversion efficiency of Nile tilapia (*Oreochromis niloticus*) fry. **Aquaculture Research** 33: 621-626.

El-Sayed, A.-F.M. 2006. **Tilapia Culture.** CABI Publishing, Cambridge, USA.

Felley, J.D. 1984. Multivariate identification of morphological environmental relationships within the Cyprinidae (Pisces). **Copeia** 1984: 442-455.

Fessehaye, Y., M. Rezk, H. Bovenhuis and H. Komen. 2004. Size dependent cannibalism in juvenile Nile tilapia (*Oreochromis niloticus*). In: **6th International Symposium on Tilapia in Aquaculture (ISTA) – New Dimensions on Farmed Tilapia** (ed. R. Bolivar, G. Mair and K. Fitzsimmons), pp. 230–240. Manila, Philippines.

Gall, G.A.E. and Y. Bakar. 1999. Stocking density and tank size in the design of breed improvement programs for body size of tilapia. **Aquaculture** 173: 197-205.

Grant, J.W.A. 1997. Territoriality. In: **Behavioral Ecology of Teleost Fishes** (ed. J.G.J. Godin), pp. 81-103. Oxford Univ. Press, Oxford.

Guerrero, R.D. and A.M. Garcia. 1983. Study on the fry production of *Sarotherodon niloticus* in a lake-based hatchery. In: **Proceedings of International Symposium on Tilapia in Aquaculture** (ed. L. Fishelson and Z. Yaron), pp. 388-393. Tel Aviv University, Telviv, Israel.

Haitook, T., S. Kosy and D.C. Little. 1999. New approaches on fish seed supply. **Appropriate Technology** 25(4): 26-27.

Haylor, G.S. 1991. Controlled hatchery production of *Clarias gariepinus* (Burchell 1822): growth and survival of fry at high stocking density. **Aquaculture and Fisheries Management** 22: 405-422.

Hengsawat, K, F.J. Ward and P. Jaruratjamorn. 1997. The effect of stocking density on yield, growth and mortality of African catfish (*Clarias gariepinus* Burchell 1822) cultured in cages. **Aquaculture** 152: 67-76.

Huang, W.B. and T.S. Chiu. 1997. Effects of stocking density on survival, growth, size variation, and production of *Tilapia* fry. **Aquaculture Research** 28: 165-173.

Hughes, D.G. and L.L. Behrends. 1983. Mass production of *Tilapia nilotica* seed in suspended net enclosures. In: **Proceedings of International Symposium on Tilapia in Aquaculture** (ed. L. Fishelson and Z. Yaron), pp. 394-401. Tel Aviv University, Telviv, Israel.

Jobling, M. 1994. **Fish Bioenergetics.** Chapman and Hall, London.

Kebus, M.J., M.T. Collins, M.S. Brownfield, C.H. Amundson, T.B. Kayes and J.A. Malison. 1992. Effects of rearing density on stress response and growth of rainbow trout. **Journal of Aquatic Animal Health** 4: 1-6.

Leatherland, J.F. and C.Y. Cho. 1985. Effect of rearing density on thyroid and interregnal gland activity and plasma hepatic metabolite levels in rainbow trout, *Salmo gairdneri*, Richardson. **Journal of Fish Biology** 27: 583-592.

Little, D.C., N.L. Innes-Taylor, D. Turongruang and S. Komolmart. 1991. Large seed for small-scale aquaculture. **Aquabyte** 4(2): 2-3.

Little, D.C., R.C. Bhujel and T.A. Pham. 2003. Advanced nursing of mixed-sex and mono-sex tilapia (*Oreochromis niloticus*) fry, and its impact on subsequent growth in fertilized ponds. **Aquaculture** 221: 265-276.

Little, D.C., D.J. Macintosh and P. Edwards. 1993. Improving spawning synchrony in the Nile tilapia (*Oreochromis niloticus*). **Aquaculture Research** 24:319-325.

Macintosh, D.J. and S.S. De Silva. 1984. The influence of stocking density and food ration on fry survival and growth in *Oreochromis mossambicus* and *O. niloticus* female x *O. aureus* male hybrids reared in a closed circulated system. **Aquaculture** 41: 345-358.

Muir, G.C. and D.C. Little. 1991. Population control in farmed tilapias. **NAGA, the ICLARM Quarterly** 4(2): 8-13.

Rahman, M.M., Islam, S.M., Halder, G.C. and M. Tanaka. 2006. Cage culture of sutchi catfish, *Pangasius sutchi* (Fowler 1937): effects of stocking density on growth, survival, yield and farm profitability. **Aquaculture Research** 37: 33-39.

Rana, K.J. 1981. **Effects of rearing conditions, age and size on performance of normal hormone-treated *Sarotherodon mossambicus* fry, with observations on fry abnormalities.** MSc thesis, University of Stirling, UK.

Ridha, M.T. 2006. Comparative study of growth performance of three strains of Nile tilapia, *Oreochromis niloticus*, L. at two stocking densities. **Aquaculture Research** 37: 172-179.

Siddiqui, A.Q., A.H. Al-Harbi and Y.S. Hafedh. 1997. Effects of stocking density on patterns of reproduction and growth of hybrid tilapia in concrete tanks in Saudi Arabia. **Asian Fisheries Science** 10: 41-49.

Sin, A.W. and M.T. Chiu. 1983. The intensive monoculture of the tilapia hybrid, *Sarotherodon nilotica* (males) x *S. mossambica* (females) in Hong Kong. In **Proceedings of the International Symposium on Tilapia in Aquaculture** (ed. L. Fishelson Z. Yaron), pp. 506-516. Tel Aviv University, Tel Aviv, Israel.

Shirota, A. 1978. Studies on the mouth size of fish larvae. II. Specific characteristics of the upper jaw length. **Bulletin of the Japanese Society for the Science of Fish** 44: 1171-1177.

Smith, C. 1989. An investigation into the problem of conspecific predation among the fry of the Nile tilapia, *Oreochromis niloticus* (Linnaeus, 1775) in an intensive culture system. MSc thesis, Plymouth Polytechnic.

Wang, Y., Y. Cui, Y. Yang and F. Cai. 2000. Compensatory growth in hybrid tilapia, *Oreochromis mossambicus*×*O. niloticus*, reared in seawater. **Aquaculture** 189: 101-108.

Watanabe, W.O., J.H. Clark, J.B. Dunhkam, R.I. Wicklund and B.L. Olla. 1990. Culture of Florida red tilapia in marine cages: the effects of stocking density and dietary protein on growth. **Aquaculture** 90: 123-134.

Yi, Y., C.K. Lin and J.S. Diana. 1996. Influence of Nile tilapia (*Oreochromis niloticus*) stocking density in cages on their growth and yield in cages and in ponds containing the cages. **Aquaculture** 146: 205-215.