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Research article

Weight estimation model for red tilapia (*Oreochromis niloticus* Linn.) from images

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Abstract

Importance of the work: The conventional method of weighing the fish is by hand, which is labor-intensive and can cause stress or injury to the fish.

Objectives: To investigate a length-weight model of red tilapia and develop a computer program to estimate the weight from the length.

Materials & Methods: Red tilapia were raised in three cages suspended in a pond. In total, 270 fish (weight 50–810 g) of the first crop were sampled every 2 wk and total length and weight were measured. A program was developed and validated using fish weights from the next crop.

Results: The length-weight relationship was determined as $y = 0.0196\ x^{2.9868}$. The correlation coefficient was 0.9902, indicating a good correlation between the length and weight of the fish. The coefficient of determination was 0.9802, indicating a showing high-quality linear regression prediction. The growth coefficient, (b value of 2.9868) was not significantly ($p > 0.05$) different from the standard value of 3.0, indicating isometric growth, while the condition factor was in the range 0.81–1.98. These values were greater than 1, suggesting that the fish were in good condition. The program was developed and validated on 170 fish from the second crop. Accuracy in evaluating the body weight of the fish was 93.01 ± 3.11% compared to the conventional method.

Main finding: The developed program showed acceptable weight accuracy and involved no requirement to catch the fish, thereby reducing fish stress and their possible injury, with time and labor reductions.

Introduction

Red tilapia farming in Thailand has recently gained popularity because the red color of the fish is similar to expensive sea species and both domestic and international markets have shown increased demand for live fish and fish meat (Pongthana et al., 2010). During rearing, the weight and length of red tilapia are measured continuously to determine the growth rate and to optimize feeding (Volvich and Appelbaum, 2001). The conventional growth rate measurement method

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is performed on the farm using a random number of caught fish that are then measured for length and weight; however, this method is labor intensive, causes stress and may injure the fish (Pickering and Christie, 1981; Maule et al., 1989). Fish stress can also lead to significantly lower feed intake, reducing the growth rate (Leal et al., 2011; Gao et al., 2022). Therefore, some fish farmers avoid manual measurement methods and apply growth prediction models based on initial stocking density, size and mortality rate. However, as these methods are based on assumptions without measuring the fish and are therefore prone to large errors (Beddow et al., 1996). Nowadays, image processing techniques for measuring fish length or weight and are widely applied. For example, Balaban et al. (2010) used image analysis to predict the weight of different Alaskan salmon species for sorting after harvest, while Torisawa et al. (2011) used an underwater digital stereo-video camera system in conjunction with a simple image processing technique for length estimation of individual Pacific bluefin tuna swimming freely in a net cage. Costa et al. (2013) developed online tools using image analysis and outline morphometry combined with multivariate techniques to sort farmed sea bass into size, sex and presence of abnormalities, while Gerami et al. (2016) applied machine vision to evaluate the visual features of *Oncorhynchus mykiss* and to estimate fish weight. Viazzi et al. (2015) developed an automatic mass estimation process for jade perch swimming freely in a tank of a recirculation-based aquaculture system using computer vision. Furthermore, Miranda and Romero (2017) developed a prototype to measure the length of rainbow trout within a water flow system using an image processing technique.

In Thailand, Taparhudee and Is-haak (2013) developed a program to assess the length of aquatic animals from images. The program calculated the average coefficient of variation, minimum length and maximum length of the fish. However, there is no published paper regarding a program to evaluate the weight of fish.

The study of allometry is essential to understand the basic growth pattern of a species. The allometric length-weight relationship (LWR) can be used to indicate species status in an environment and characterize patterns of growth. Allometric relations take the general form of the power law $Y = aX^b$ or its logarithmic form $log\ Y = b\ log\ X + log\ a$, where X and Y are measured quantities, a is the normalization constant and b is the scaling exponent. When scaling is isometric, fish weight (equal to the volume if constant density is assumed) will vary with the length cubed ($b = 3$), while the standard length will show a linear correlation with total length ($b = 1$) according to Froese (2006) and Kharat et al. (2008). If the LWR of red tilapia is known and the total length of the fish can be measured, then these readings can be used to estimate weight. The advantages of using red tilapia include ease of observation as the body color is red, contrasting with the surrounding water, while during feeding time they swim near the water surface. Zion (2012) reviewed the development of many sophisticated image processing techniques for counting, size measurement and mass estimation, gender identification and quality assessment, and species and stock identification to monitor welfare. However, no research has been conducted on red tilapia using modern techniques.

The current study developed a simple program using digital image processing techniques to measure the length and estimate the weight of red tilapia as a guideline technology for future applications in aquaculture.

Materials and Methods

This study was divided into two parts: 1) the relationship between total length and body weight of red tilapia; and 2) the development of a program for weight estimation based on the correlation with length and its comparison with the results from the conventional method.

Relationship between total length and body weight of red tilapia

This study was conducted in a 0.8 ha earthen pond at the Kamphaeng Saen Fisheries Station at Kasetsart University (Kamphaeng Saen campus), Kamphaeng Saen district, Nakhon Pathom province, Thailand. Red tilapia (mono sex *Oreochromis niloticus* Linn.) were raised in three 5 m ×5 m ×1.5 m (width × length × depth) cages suspended in a pond, with a stocking density of 100 fish/cage (4 fish/m^2). The initial fish weight was around 50 g. A 5 horsepower paddlewheel aerator was installed in the pond and operated overnight from 2000 hours to 0630 hours to maintain dissolved oxygen (DO) levels at more than 4 mg/L. The fish were fed 30% crude protein floating pellets by hand until satiation three times a day at 0700 hours, 1200 hours and 1700 hours. During the experiment, water quality as DO, and the temperature, transparency, pH, total ammonia nitrogen (TAN) and nitrite-nitrogen (NO_2-N) levesl of the water were monitored and controlled to maintain optimal conditions for fish growth. Water temperature, DO and pH were measured using a YSI Professional Plus unit (Yellow Springs, OH, USA).

TAN and NO_2-N were measured following the guidelines of the American Public Health Association et al. (2005). Water transparency was measured using a Secchi disk. A minimum level of DO in water of 4 mg/L is required for culture (Kolding et al., 2008; Tran-Duy et al., 2012) with the water temperature in the range 26–32°C (Azaza et al., 2008) and transparency in the range 30–40 cm (Santhosh and Singh, 2007). The pH should be around 7–8 (El-Sherif and El-Feky, 2009) with the TAN concentration below 0.5 mg/L for long-term exposure (Hargreaves and Tucker, 2004), while NO_2-N should not exceed 0.25 mg/L in soft water (Lawson, 1995). The water in the culture pond was exchanged whenever water quality problems identified, and especially when the TAN was greater than 0.5 mg/L or the DO fell below 3 mg/L.

Fish samples were randomly collected nine times every 2 wk (at weeks 0, 2, 4, 6, 8, 10, 12, 14 and 16) from three cages during a 4 mth culture period. The fish weight at the commencement of stocking was around 50 g., while at harvesting they weighed around 800 g. Ten fish were sampled from each cage (a total of 30 fish per week) and the total number of fish sampled during the experiment was 270 (Table 1). Each fish was measured using a ruler for total length (from tip of snout to end of caudal fin) in centimeters with a precision of 0.1 cm. The weight was measured to an accuracy of 0.01 g, using a digital balance (conventional method). The data were compiled into an Excel program (Microsoft Corp.; Redlands, WA, USA) to calculate the length-weight relationship (LWR) using the equation $W = aL^b$ (Pauly, 1984) and then logarithmically transformed into log W = log a + b log L, where W is the weight of the fish in grams and L is the length (L = total length) of the fish measured in centimeters, a is the intercept of the regression curve, b is the correlation coefficient, R is the correlation coefficient and R^2 is the coefficient of determination. The a, b and R values were calculated from the linear regression model of the fish length and weight measurements. The R^2 value was used as an indicator of linear regression quality (Scherrer, 1984). Values of the exponent b provide information on fish growth; when b = 3, the weight increase is isometric, while any other value of b indicates the weight increase is allometric (positive allometric if b > 3, negative allometric if b < 3). To check whether the average b value was significantly different from 3.0, the Student's t test was conducted at the 0.05 significance level, using the equation ts = (b-3)/sb (Zar, 1984), where ts = Student's t test, b = slope and sb = standard error of the slope. The condition factor (K) was computed by applying the formula: $K = 100W/L^3$ (Pauly, 1983), where W is the fish weight in grams and L is the total length in centimeters.

Table 1 Frequency of data collection

Week	Number of fish/cage	Number of fish	Total number of fish
0	10	30	30
2	10	30	60
4	10	30	90
6	10	30	120
8	10	30	150
10	10	30	180
12	10	30	210
14	10	30	240
16	10	30	270

Development of program for weight estimation correlation with length and comparison of results with conventional method

Equipment

The measuring device was a digital camera Olympus EM 10 Mark II (Olympus Corporation; Tokyo, Japan). Pictures were taken with a focal length of 14 mm, exposure of 1/40 sec, ISO 1600 and a resolution of 4,608 × 2,592 pixels using a computer (Windows 10 Pro, AMD FX-9800P RADEON R7 processor, 12 GHz COMPUTE CORE 4G + 8G, 8GB RAM, System type 64-bit operating system and Microsoft Visual Basic 6.0).

Program development

The equation from the first experiment was used. Before using the program, a floating object such as straw or an empty drinking water bottle with known length was placed in an experimental cage near the fish and used as the calibrator. Photographs were taken 15–30 min before the morning feeding time (0700 hours). This time was chosen to reduce the effect of sun glare. Then, the images were loaded into the computer program and adjusted using zoom-in or zoom-out to obtain a suitable size for measurement. A calibration was first performed by drawing a straight line on the calibrator and adding the exact length in the scale textbox before pressing the calibration button. This procedure calibrated the pixels into centimeters, as 1 pixel = the exact length of the object (cm)/ total pixels. The length of each fish was measured by drawing a straight line from the top of the mouth to the tip of the caudal fin (total length measurement). The distance or length formula was derived using the Pythagorean theorem, where the distance between two points (x1, y1) and (x2, y2) is calculated by using the coordinates of these ordered pairs and using $\sqrt{(x2 - x1)^2 + (y2 - y1)^2}$ to calculate the distance. When each line was completed, the program calculated the total length and weight of all the measured fish and the number of fish that had been measured. After pressing the statistical analysis button, the program displayed the average weight, SD, coefficient of variation (CV), minimum weight and maximum weight. The program automatically generated the data and stored it in Excel (Fig. 1).

Validation

The developed program application was examined using 170 sampled fish (10 fish per week) from one cage of the second culture crop. Fish management was similar to the first culture crop. Total lengths of the fish were measured until the end of the experiment and data were collected weekly. The conventional method for fish weighing used a scoop net and a digital balance, while the developed program applied photos taken with a digital camera 60 min before the first feeding (0800 hours). Five photos were taken. In each photo, 10 fish showing their whole body were measured for total body length to assess weight estimation. Weight measurements of the two methods are shown in Figs. 2A–B for the developed program and Figs. 2C–D for the conventional method. The results from both methods were compared. Before statistical analysis, all data were tested for homogeneity using the Levene's test of variance. In case of unequal variances, Welch test was applied. If the data were found to be homogeneous, statistical differences were analyzed using an independent sample t test at a significance level of 0.05. All statistical analysis was performed using SPSS 24.

Ethic statements

This study was approved by the Ethics Committee of Kasetsart University, Bangkok, Thailand (Approval no. ACKU 61–FIS–056).

Results

Relationship between total length and body weight of red tilapia

For the 270 red tilapia samples, the total length was in the range 13.40–35.00 cm, while weight was in the range 50–810 g. Processing these data in the Excel program using a power function gave the following relationship $y = 0.0196\ x^{2.9868}$, with R = 0.9902 and $R^2 = 0.9802$, where y is the fish weight (measured in grams) and x is the total length (in centimeters), as shown in Fig. 3. The b value was 2.9868 and was not significantly different from the standard value of 3.0. The results indicated there was a significant correlation between fish total length and total weight, with values for R and R^2 of 0.9902 and 0.9802, respectively.

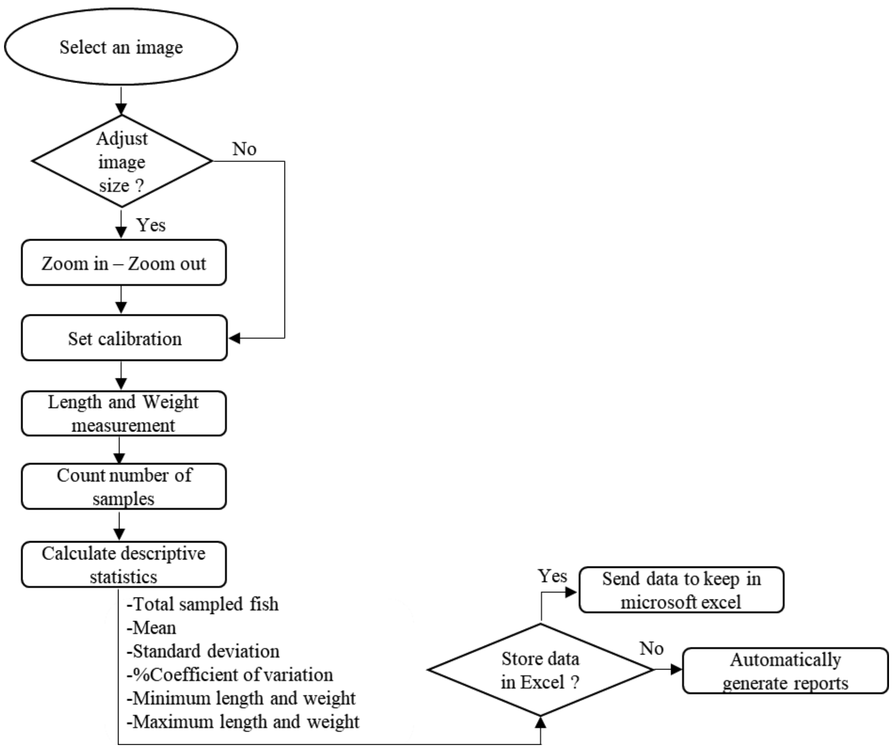

Fig. 1 Flow chart showing basic steps in red tilapia weight estimation program

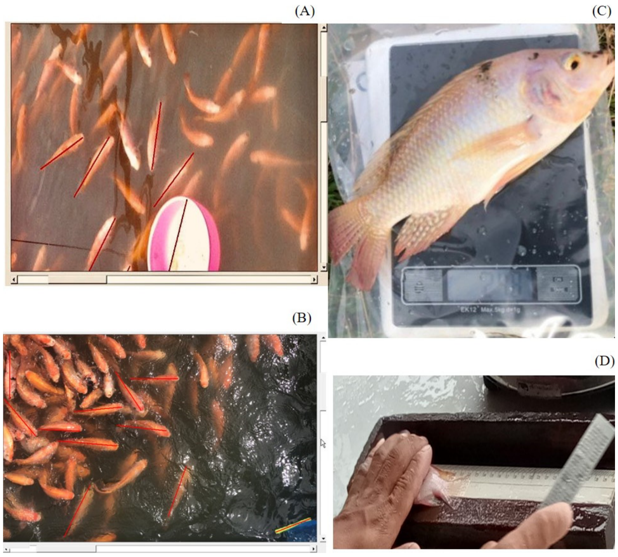

Fig. 2 Comparison of the developed program: (A) and (B) with the conventional method; (C) and (D) for weight estimation

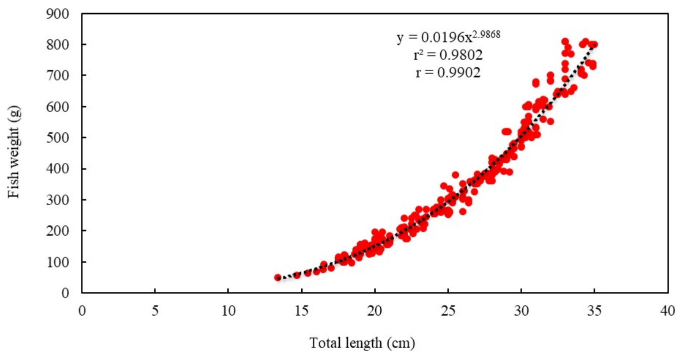

Fig. 3 Relationship between total length and weight of red tilapia, where R = correlation coefficient and R^2 = coefficient of determination

The average condition factor (K) of the fish during the experiment was in the range 1.81–1.98, as shown in Table 2.

Development of program and comparison of results with conventional method

The program results produced the total number, average weight, SD, CV, minimum weight and maximum weight of fish samples, as shown in Fig. 4, with the report shown in Fig. 5.

In total, 170 red tilapia with a weight range of 50.00–850.00 g were examined using the developed program for weight estimation, with an average accuracy of 93.01 ± 3.11% compared to the conventional method. Levels of accuracy for the weight ranges over the culture period of 16 wk were 97.19 ± 2.35, 93.34 ± 2.21, 95.01 ± 2.76, 93.49 ± 4.33, 90.95 ± 4.82, 93.86 ± 2.55, 93.13 ± 2.40, 91.78 ± 2.41, 93.31 ± 1.29, 92.56 ± 1.04, 93.69 ± 3.30, 94.09 ± 3.98, 92.87 ± 5.56, 89.18 ± 5.62, 91.48 ± 2.88, 91.62 ± 1.97 and 93.60 ± 3.39%, respectively. The estimated average weights of fish from the program at week 4, weeks 6–9 and weeks 13–16 were significantly different from the average weight determined using the conventional method, while in the other weeks there was no significant difference (Table 3). Furthermore, the average estimated fish weight results obtained from the program were mostly lower than the weights recorded using the conventional method (Fig. 6).

Table 2 Average and standard deviation (SD) of condition factor (K) during the 16-week study period

Week	Average	SD
0	1.84	0.18
2	1.93	0.19
4	1.93	0.21
6	1.85	0.17
8	1.86	0.14
10	1.82	0.13
12	1.81	0.08
14	1.95	0.12
16	1.98	0.19

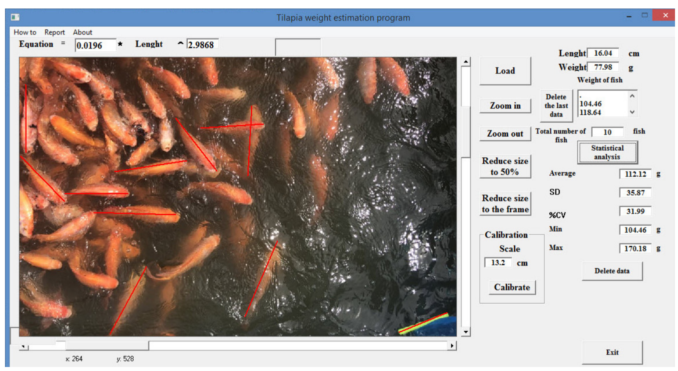

Fig. 4 Screen capture of red tilapia weight estimation program

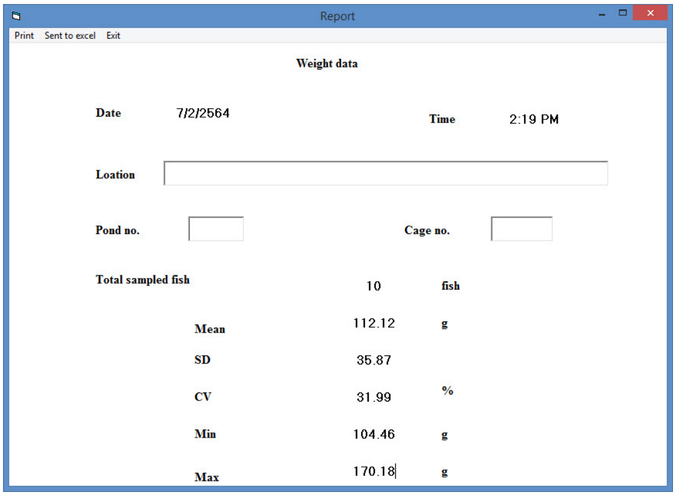

Fig. 5 Screen capture of data report of developed program

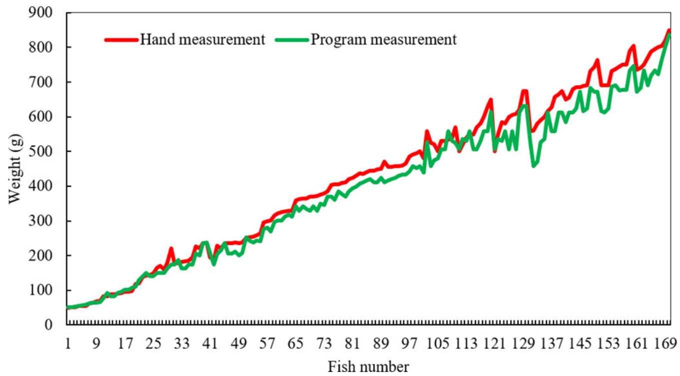

Fig. 6 Comparison of weight estimation between developed program (average from five photographs, with 50 fish images/fish number) and conventional method (caught by hand and measured using a digital balance; n = 170)

Table 3 Accuracy of the developed program compared to conventional measurement

Week	Mean ± SD			Levene's test		t-test for equality of means
	Conventional measurement (g)	Program measurement (g)	Accuracy (%)	F	p-value	p value for 2-tailed test
0	58.40±7.35	58.20±5.56	97.19±2.35	2.26	0.15	0.94
1	93.06±9.93	94.55±10.69	93.34±2.21	0.43	0.52	0.75
2	152.00±27.66	148.89±12.80	95.01±2.76	3.12	0.94	0.32
3	201.91±24.58	193.53±27.56	93.49±4.33	0.01	0.92	0.39
4	224.79±18.60	206.77±14.81	90.95±4.82	1.24	0.28	0.03*
5	281.22±28.01	264.33±23.54	93.86±2.55	1.48	0.24	0.16
6	350.28±19.76	325.95±14.65	93.13±2.40	4.72	0.04	0.00*
7	396.85±17.16	364.21±18.11	91.78±2.41	0.45	0.83	0.01*
8	442.50±12.52	410.72±9.16	93.31±1.29	0.69	0.42	0.00*
9	472.25±18.44	436.73±14.95	92.56±1.04	2.02	0.17	0.00*
10	528.88±25.92	500.12±36.99	93.69±3.30	2.01	0.16	0.06
11	569.00±47.25	540.29±33.71	94.09±3.98	1.21	0.28	0.13
12	599.68±52.37	557.29±50.43	92.87±5.56	0.07	0.80	0.82
13	612.90±42.69	547.05±55.90	89.18±5.62	0.50	0.49	0.01*
14	697.30±37.07	637.65±34.09	91.48±2.88	0.06	0.94	0.01*
15	737.90±40.00	674.39±46.06	91.62±1.97	0.11	0.74	0.00*
16	785.80±36.24	735.96±52.13	93.60±3.39	0.77	0.39	0.02*
			93.01±3.11			

*significant ($p < 0.05$) difference between conventional and program measurment in a row

Discussion

The LWR provides important information on the growth patterns of animals and varies depending on environmental conditions (Ighwela et al., 2011; Jisr et al., 2018). Here, the LWR was $y = 0.0196x^{2.9868}$ with an R value of 0.9902, indicating a good correlation between the length and weight of the fish and implying that the fish sampled were growing proportionately (Lawson et al., 2013). The high R^2 value of 0.9802 implied good quality of the prediction (Jisr et al., 2018).

The value of b in this study was 2.9868 and not significantly different from the standard value of 3.0, indicating that the fish followed an isometric growth curve, with b close to the standard value of 3.0. This was in accordance with the 'cube law' rule that when an object increases in size, its volume will increase from the original volume at an exponent of 3.0 (Ricker, 1973; Pauly, 1983). The value of b may be different for fish from different localities, different sexes, or for larval, immature and mature fish and depends on season and food availability (Yilmaz et al., 2012; Ali et al., 2016). However, the value of b here was within the range 2.5–3.5 recorded for many fish species by Froese (2006). The value of b in the current study was also consistent with Anani and Nunoo (2016), who reported values in the range 2.9–3.1, with Asmamaw et al. (2019) reporting values for males (3.210), females (2.868) and both sexes combined (3.170), while Silva et al. (2015) reported 3.0604 for cage-farmed fish species.

The condition factor (K) of fish is affected by many variables such as stress, sex, season, availability of feeds, maturity stage and water quality (Khallaf et al., 2003; Karrar et al., 2016). The K values of the fish in the current study were in the range 1.81–1.98. A value higher than 1.0 indicated that the environmental conditions were suitable for *O. niloticus* Linn. growth (Anani and Nunoo, 2016; Karrar et al., 2016; Asmamaw et al., 2019), when the fish were fed until satiation with high quality feed and the pond water was controlled at optimum conditions for fish growth.

The current results indicated the mean (± SD) accuracy of weight estimation was 93.01 ± 3.11% that concurred with other researchers who applied similar techniques with other types of aquatic animals. For example, Costa et al. (2006) used image processing techniques, with an underwater camera mounted on a bar and fixed on a goniometer, to estimate the length of tuna fish raised in cages and reported a 5% error. Yamana and Hamano (2006) applied a photographic processing technique to measure the size of Japanese sea cucumber for laboratory conditions and reported less than 7% error. Misimi et al. (2008) used a photogrammetric area measurement technique to determine the size of salmon and reported less than 6% error and Viazzi et al. (2015) studied jade perch weight estimation and recorded a mean relative error of approximately 6%. However, based on the results from the current study, the weight estimation for larger fish was less accurate than for smaller ones because the fish weight was estimated using the relationship between length and weight. Therefore, if the length estimate were not accurate, a larger object would have greater error than a smaller one.

Red tilapia have a red-colored body. When fed with floating feed pellets, the whole body of many fish can be seen near the water surface for easy selection of many samples. The errors in this study from the results of fish weight obtained using the program were lower than the using a digital balance. Errors occurred mainly from the occasional inability to measure the total length of the fish samples due to water turbidity that made the water cloudy or murky, with reduced transparency due to the presence of suspended clay particles, dispersion of plankton organisms, particulate organic matters and also pigments caused by the decomposition of organic matter (Bhatnagar and Devi, 2013). Suitable water transparency for fish culture should be in the range 15–40 cm (Boyd, 1982; Wahab et al., 1995; Santhosh and Singh, 2007). The transparency recorded in this study was in the range 10–60 cm. High turbidity reduced the amount of light that penetrated water and this affected the image quality. Factors such as the different depths of sampled fish from the water surface, angle view from the camera lens to the fish and the distance between the fish and the calibrator may also affect measurement accuracy. Sanchez-Torres et al. (2018) mentioned other factors such as lighting inequality, poor contrast and extraneous data 'noise' as obstacles in the implementation of computer vision technologies for studies in a sea cage.

The impact of sun glare was reduced in this study because the images were taken 15–30 min before morning feeding at 0700 hours. At this time, the fish were hungry and easily seen swimming near the water surface in the cage as the water temperature and dissolved oxygen began increasing. The other time option for taking photographs was 15 min before the late afternoon feeding before sunset, when there was high-water temperature and DO content (Coche et al., 1996).

The advantages of the developed program included acceptable weight accuracy and no requirement to catch the fish, thereby reducing fish stress and possible injury, with time and labor reductions associated with this simple and convenient technique. The program could be easily modified to adjust the length-weight equation to match individual farming conditions and to generate reports, with data stored using the Excel program. As mentioned earlier, many applications of sophisticated fish measurement techniques were reviewed by Zion (2012) and underwater cameras have been used (Martinez-de Dios et al., 2003; Costa et al., 2006; Torisawa et al., 2011; Sanchez-Torres et al., 2018). However, these methods are not suitable for fish cultured in earthen ponds or cages because suspended solids from plankton, humic stains and clay cause turbidity resulting in poor water visibility. The optimal transparency for fish growth measurement is in the range 15–40 cm (Boyd, 1982; Santhosh and Singh, 2007).

One disadvantage and limitation of the program is that it suitable only for fish with a dominant body color. The red tilapia fish should be raised in cages with a walkway above the water surface for easy photography. The image must show the total length of the fish in a straight position, with a floating object of known size (such as a ruler, straw or empty drinking water bottle) for calibration.

This technique requires further development to reduce errors and in automation for image segmentation and classification using machine or deep learning algorithms.

The LWR and condition factor in this study indicated good correlations between length and weight for isometric growth. The developed program produced 93.01 ± 3.11% accuracy for weight estimation that mainly depended on image quality.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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