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RESEARCH PAPER

Image Analysis to Determine Length-Weight and Area-Weight Relationships, and Color Differences in Scaled Carp and Mirror Carp Grown in Fiberglass and Concrete Tanks

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Abstract

Sixty scaled carp *Cyprinus carpio* and sixty mirror carp *Cyprinus carpio carpio* were raised in fiberglass and concrete tanks. Fish pictures were taken by a digital camera in a lightbox. Image analysis was used to determine length-weight and view area-weight relationships. Length-weight data were fitted to a power equation: (Weight W)=A (Length L)^B. R^2 ranged from 0.838 to 0.959. Based on the B values, scaled and mirror carps reared in the fiberglass tank showed a negative allometric growth while this was positive for the fish in the concrete tank. For the view area (V)-weight relationship, linear (W=A+BV), and second order polynomial equations were used in addition to the power equation. The R^2 values for these equations ranged from 0.916 to 0.995. Skin color was measured by image analysis. Both scaled and mirror carp reared in concrete tanks had L*, a* and b* values significantly higher than those reared in fiberglass tanks (P<.05). Also, the fish reared in fiberglass tanks tended to have less weight for the same view area, compared to those reared in concrete tanks.

Introduction

Common carp (*Cyprinus carpio* L.) is one of the main fish species for aquaculture and is probably the oldest and most extensively cultured fish species in the world. The total annual world production of this fish has been estimated to be 4.1 million tons. This was the sixth most extensively cultured and commercially important freshwater fish species and accounted for 5.15% of global aquaculture production in 2017 (FAO, 2019). It is widely distributed in almost all countries of the world (Vilizzi *et al.,* 2015) because it is highly adaptive to both growth environment and food (Soltani *et al.,* 2010; Manjappa *et al.,* 2011; Rahman, 2015). It is very popular in Asia (Weber & Brown, 2011; Kloskowski, 2011), and in some European countries where more than 80% of total fish production comes from common carp (Woynarovich et al., 2010; Anton-Pardo *et al.,* 2014).

Common carp is normally cultured in various aquaculture systems, but the most common is the semi-intensive pond polyculture. However, in cold or semi-cold climates, especially in Europe, the monoculture of common carp is more popular in production environments such as earth-ponds, concrete and fiberglass tanks (Szucs *et al.,* 2007).

In Turkey, common carp is a popular cultured freshwater fish after rainbow trout (*Oncorhynchus mykiss*) (Anonymous, 2020). It is also an important animal protein source for Turkish consumers due to its year-around availability.

Weight determination is very important in fisheries stock assessment or measuring fish biomass in fish farms

(Ueda *et al.,* 2001). A common method for estimating weight is the Length-Weight Relationship (LWR) which estimates weight based on fish length (Gerami *et al.,* 2013, 2016). Measuring length is quick and easy. LWR has important implications for fisheries science and population dynamics where many stock assessment models require the use of length-weight parameters (Bobori *et al.,* 2010; Tsagarakis *et al.,* 2015; Bostancı *et al.,* 2022; Yedier, 2022). LWR equations are also useful to assess the fitness, health status and life history information like reproduction in fish (Froese, 2006). The relationship between length (L) and weight (W) typically takes the allometric form:

$$W = A\,L^{B} \quad \text{(Equation 1)}$$

or in the linear form:

$$\text{Log } W = \text{Log } A + B \text{ Log } L \quad \text{(Equation 2)}$$

where A and B are constants calculated by regression analysis. In this study the 95% confidence intervals of these parameters were also calculated. If fish retains the same shape, it grows isometrically and the length exponent B has the value 3.0 (Wootton, 1992). The B values above 3 indicate positive allometric growth, where fish becomes heavier for its length while B values below 3 indicate that the fish becomes lighter for its length therefore negative allometric growth (Ratnakala *et al.,* 2013).

With the advent of Machine Vision (MV) and image analysis, fish view area can now be easily and accurately determined. This allows View Area-Weight (VAW) relationships to be developed, which are generally more accurate. MV systems have been applied to determine the color, shape, species, visual defects, weight and volume of different foods, and MV has been adopted in the aquatic food industry for quality assurance to provide speed, accuracy, flexibility, repeatability, and quantitative measurement at relatively low cost (Balaban *et al.*, 2005; Balaban & Odabaşı, 2006; White *et al.,* 2006; Hu *et al.,* 2012). Economic competition, a large volume of materials, and increasing human labor costs have also encouraged the use and deployment of MV systems within the aquaculture industry (Hong *et al.*, 2014; Miranda & Romero, 2017; Saberioon *et al.,* 2017).

MV has been used to estimate morphological features of many aquatic animals such as shrimp (Balaban *et al.,* 1994), Alaska salmon (Balaban *et al.,* 2010a), oysters (Damar *et al.,* 2006), Atlantic Salmon (*Salmo salar*) fillet shape and size (Misimi *et al.,* 2007), rainbow trout (Gümüş & Balaban, 2010), jade perch (*Scortum barcoo*) (Viazzi *et al.,* 2015), and Asian seabass (*Lates calcarifer*) mass estimation (Konovalov *et al.,* 2018). Alçiçek and Balaban (2014) reported that the volume estimation R^2 of whole green shelled mussels did not improve when length, width and thickness was used (R^2=0.95) compared to when top and side view areas were used (R^2=0.97). In view of the extra work necessary for the calculation of the length and width, and since their value depends on how the fish is presented to the camera, it is recommended that the view area alone should be used for weight prediction.

MV systems also have the flexibility to measure the visual attributes of foods with non-homogeneous colors and shapes, and methods have been developed to evaluate the degree of non-homogeneity of colors (Balaban, 2008). Color MV system has been applied to various foods such as Atlantic salmon (*Salmo salar*) fillet color (Misimi *et al.,* 2007), shrimp (Luzuriaga *et al.,* 1997), sturgeon (Oliveira & Balaban, 2006), rainbow trout (*Oncorhynchus mykiss*) cutlets (Stien *et al.,* 2006), rainbow trout and mahi mahi (Yağız *et al.,* 2007), skin and fillet of Atlantic salmon (*Salmo salar*) (Erikson & Misimi, 2008; Yağız *et al.,* 2009; 2010), and gilthead sea bream stored in ice (Dowlati *et al.,* 2012), and for live fish (Yedier *at al.,* 2014).

There are reports in the literature regarding the effect of the growth environment on the growth rate and skin color of several species of fish. Ebrahimi (2011) reared juvenile common carp in tanks colored as black, red, white, blue and yellow. Fish reared in black and red tanks resulted in lower final body weight and specific growth rate. This was tied to the highest blood plasma cortisol levels for fish reared in red tanks. It was suggested to rear juvenile carp in bright colored tanks. Enache *et al.* (2012) reared common carp at two light intensity levels, and observed that higher light intensity induced a higher biomass gain and specific growth rate. Marandi *et al.* (2018) observed that background black color had a negative effect on the fish skin color indices. Brightness (L*) and yellowness (b*) values of the fish skin in the white tanks were higher than those of the black tanks. Luchiari & Freire (2009) concluded that red environmental color during growth of Nile tilapia was harmful to its growth, while yellow color seemed to be positive for the fish. McLean *et al.* (2008) evaluated black, green, red, dark, and light blue colored tanks on the short–term growth and feed efficiency of summer flounder and growth, feed efficiency, body composition of Nile tilapia. They concluded that fish in red colored tanks had better percent increase in weight. Sabri *et al.* (2012) showed that Nile tilapia had preference for blue light followed by green light, while red light was unfavorable to the fish. Solomon & Ezigbo (2018) observed that black tank color resulted in the best overall survival rate and growth compared to white, green, blue, and yellow tanks for African catfish. There seems to be an effect of surrounding color, but the results are contradictory, and more research is needed in this area.

The objective of this study was to use MV / image analysis methods to develop length-weight, and view area-weight relationships for two carp species (scaled and mirror carp) reared in fiberglass and concrete tanks. Also, the differences in the skin color (L*, a*, b*) distributions of the fish reared in fiberglass and concrete tanks were measured.

Materials and Methods

Fish

Sixty fish each of common carp (scaled and mirror) was obtained randomly from a concrete tank (Figure 1a) with a water flow system of the Republic of Turkey Ministry of Agriculture and Forestry, Mediterranean Fisheries Research Production and Training Institute, Kepez, Antalya, Turkey, in February 2020. Another group of 60 fish each was supplied from a fiberglass tank (Figure 1b) with recirculating aquaculture system (RAS) of Akdeniz University, Fisheries Faculty, Fisheries Research Laboratory, Antalya, Turkey. The diameter and depth of both tanks were not measured, and the sex of the fish were also not recorded. Experiments were performed immediately after the harvested fish died.

Weighing and Imaging

A scale (Schimatzu, Grawimetrics, 610 g, Tokyo, Japan) with a maximum load of 610 g and an accuracy of 0.001 g was used to weigh each fish. The fish was placed in a tared plastic plate before weighing, and the scale was "zeroed" for every fish. Minimum and maximum weight of fish raged from 72.13-167.59 and 60.49-186.95 g for mirror carp raised in concrete and fiberglass tanks, respectively. For scaled carp the weight ranges were 52.37-150.31 and 75.14-187.5 g.

The fish was then placed in a light box (dimensions 120-cm high, 60-cm wide, and 60-cm deep) under a Nikon D610 digital camera (Nikon Corp., Tokyo, Japan) with a 24-300 mm zoom Nikon lens with a circular polarizing filter. The light box had D65 illumination using LED light panels. The inner surface of the upper light box was covered with a polarizing sheet (Rosco, Stamford, CT, USA). A color reference (Color Checker Classic, X-Rite Inc., Grand Rapids, MI) was placed in every image to correct the image colors during image analysis.

The two-image method (Alçiçek & Balaban, 2012), was used to take pictures. Briefly, the top light of the light box is turned off and the bottom light is turned on, and a picture is taken. This results in the silhouette of the objects. Then the top light is turned on and the bottom light is turned off, and another picture is taken (Figure 2). LensEye-NET software (ECS, Gainesville, FL) was used to segment the images using the silhouette picture. The camera settings are described in Table 1. Also, the color of the whole picture was corrected by using the known color of the reference color. For this, a hand-held Minolta CR-400 Chroma Meter (Minolta Camera Co., Japan) was used to measure the color of the reference color object before experiments. Finally, a 3 cm x 3 cm size reference (thin-mica black square) in the picture allowed pixel distances and areas to be converted to real units of cm and cm^2.

Polarized images were used by adjusting the circular polarizing filter, assuring measurement of real color by eliminating reflection-related shine (specular reflection) and the resulting color deviations. The average L^*, a^* and b^* values representing the color values in the color coordinates of the CIE (International Commission of Illumination) of the view area of each fish were calculated by the software. L* represents lightness (0 is black, 100 is white), a* represents the green-to-red color change, and b* represents the blue-to-yellow color change.

Image Analysis

Corel PhotoPaint (Corel Corp., Ottawa, Ontario, Canada) was used to clear the jpg images from the Nikon camera to isolate the color reference. Then, LensEye-NET software (Engineering and Cyber Solutions, Gainesville, FL, USA) was used to analyze the image. The view area of each fish was calculated by converting the number of its pixels to cm^2. For this, LensEye-NET used the number of pixels of the reference square, together with its known surface area (9 cm^2):

$$View\ Area\ (cm^2) = \frac{Pixels\ of\ fish}{Pixels\ of\ reference\ square}\ x\ 9 \quad \text{(Equation 3)}$$

Figure 1. a) Picture of a concrete tank, b) Picture of a fiberglass tank

Color Analysis

Every pixel in the image of the fish was analyzed with LensEye-NET for its L*, a*, and b* values, and the average was calculated for each fish. In the CIE system of colors, L* defines lightness (0 for black, 100 for white), a* shows green (negative a*) to red (positive a*), and b* shows blue (negative b*) to yellow (positive b*). The color reference's color was then used to calibrate the image to the "correct" color by the software. The histogram of the average L*, a*, and b* distributions for both fish species from each tank was developed using Microsoft Excel's (version 2010, Redmond, WA, USA) histogram function. The other side of the fish was assumed to have the same color.

Regression Analysis

Length-Weight Relationship

Based on ample literature evidence, the power curve $W=A\ L^B$ was used to correlate length to weight (Balaban *et al.,* 2010a). The linearized version is (Wootton, 1992):

Log W=B log L+log A (Equation 4)

Where W=the weight of the fish in kg,
L=the total length of the fish in centimeters,
A=exponent describing the rate of change of weight with length
B=weight at unit length

View area – Weight Relationship

The following equations between the weight and the view area were tried (Balaban *et al.,* 2010a):

Linear: $W=A+B\ V$ (Equation 5)

Power: $W=A\ V^B$ (Equation 6)

Polynomial: $W=C_o+C_1\ V+C_2\ V^2$ (Equation 7)

In the equations above, W=weight (kg), V=view area (cm^2), A, B, and C_i are coefficients.

Table 1. Nikon D610 camera settings for front-lighting and back-lighting images.

Camera settings	Front-lighting	Back-lighting
Exposure mode	manual	manual
Shutter speed	1/2.5sec	¼ sec
Aperture	f/9	f/9
Exposure compensation	0 EV	0 EV
ISO sensitivity	200	200
White balance	Preset 1	Preset 1
Image size (pixels) small	3008*2008	3008*2008

Table 2. Length-weight relationships of scaled and mirror carps, and other fish.

Species		Length range (cm)			L-W relationship			References
	Culture condition	n	min	max	A	B	R^2	
Scaled carp, kg	Fiberglass	60	17.4	28.5	$6.39\ 10^{-6} \pm 2.18$	3.18±0.25	0.918	Current study
	Concrete	60	18.5	29.2	$2.05\ 10^{-5}\pm1.78$	2.91±0.18	0.943	Current study
Mirror carp, kg	Fiberglass	60	19.9	30.4	$9.03\ 10^{-6}\pm3.09$	3.06±0.35	0.838	Current study
	Concrete	60	16.6	29.1	$3.57\ 10^{-5}\pm1.58$	2.76±0.15	0.959	Current study
Cyprinus carpio, g		11	16.0	55.0	0.0145	2.983	0.991	Bobori *et al.* (2010)
		19	21.5	49.0	0.0147	2.997	0.932	
		66	19.9	44.9	0.0137	2.989	0.975	
		307	14.0	36.0	0.00705	3.319	0.943	Karataş *et al.,* 2007
		315	12.8	47.9	0.025	3.01	0.87	Çolakoğlu and Akyurt, (2011)
		51	12.8	84.0	0.0149	3.14	0.986	Tarkan *et al.,* (2006)
		155	22.5	52.4	0.0349	2.822	0.970	Yılmaz *et al.,* (2012)
		328	8.2	61.7	0.039	2.847	0.951	Elp *et al.,* (2008)
Carrasius gibelio, g		205	8.4	30.7	0.0137	3.059	0.989	Bobori *et al.* (2010)
		143	12.9	32.3	0.0214	2.945	0.972	
		49	8.3	33.5	0.0094	3.187	0.994	
Diplodus annularis, g		159	9.5	19.0	0.0179	2.985	0.971	Akyol *et al.* (2007)
Diplodus vulgaris, g		69	9.6	26.5	0.0145	3.034	0.988	
Sparus auratus, g		14	14.5	32.6	0.0122	3.034	0.967	
Epinehelus aeneus, g		125	18.6	56.6	0.0178	2.855	0.942	
Saurida undosquamis, g		80	19.6	33.1	0.0046	3.109	0.951	
Atherina boyeri, g		14	7.6	11.7	0.0015	3.485	0.992	Bök *et al.* (2011)
Arius latiscutatus, g		183	87	347	-	3.166	0.989	Ecoutin *et al.* (2005)
Mullus barbatus, g		111	8	19.6	0.0091	3.10	0.970	Gökçe *et al.* (2007)
Merlangius merlangius, g		904	7.7	22.7	0.0067	3.0248	0.960	Kalaycı *et al.* (2007)
Boops boops, g		122	14.5	28.5	0.0146	2.877	0.91	Moutopoulos and Stergiou (2002)

The numbers following ± are the 95% confidence interval ranges.

Statistical Analysis

Results were presented as mean±standard deviation (SD). All data were subjected to normality to determine the accurate statistical method. Data from each tank were subjected to one-way analysis of variance (ANOVA) using SPSS v.23 (SPSS Inc., Chicago, IL, USA). Differences between the means were tested by Duncan's multiple range tests. Statistically significant differences were reported at P<.05. The R^2 values for each fit and the LWRs values were also calculated.

Results

Length-Weight Relationship

Table 2 summarizes the results of fitting the power equation to the length-weight data for mirror and scaled carp, as well as literature findings for some other fish. Regarding the results of this study, the 95% confidence intervals of the parameters A and B calculated by regression are also given in Table 2. It can be seen that in general the B parameter is close to 3. This is logical, since weight is related to volume, and volume is related to the cube of the length dimension. For scaled carp in fiberglass tank, the B value was 3.18±0.25, in concrete tanks 2.91±0.18; for mirror carp in fiberglass tank 3.06±0.35, and in concrete tank 2.76±0.15. Since B values in fiberglass tank was higher than 3 this is considered positive allometric growth. In concrete tank B values are lower than 3 implying negative allometric growth. When the R^2 values in Table 2 were compared with those of other study results, weight-length relationship values calculated with MW are compatible with those of some other fish.

If length is only one parameter used to predict weight, this restricts the predictive power, compared to models with multiple parameters. Another difficulty of using length is when dealing with "flexible" fish. If the fish is not straight, its length may not be measured correctly. There are image analysis methods such as medial axis determination to measure the "true" length of a curved fish, but this adds to the complexity of the analysis (Williams *et al.,* 2016).

View Area – Weight Relationship

Table 3 summarizes the results of fitting various equations to both species of carp VAW data, as well as those from other fish in the literature. In general, the

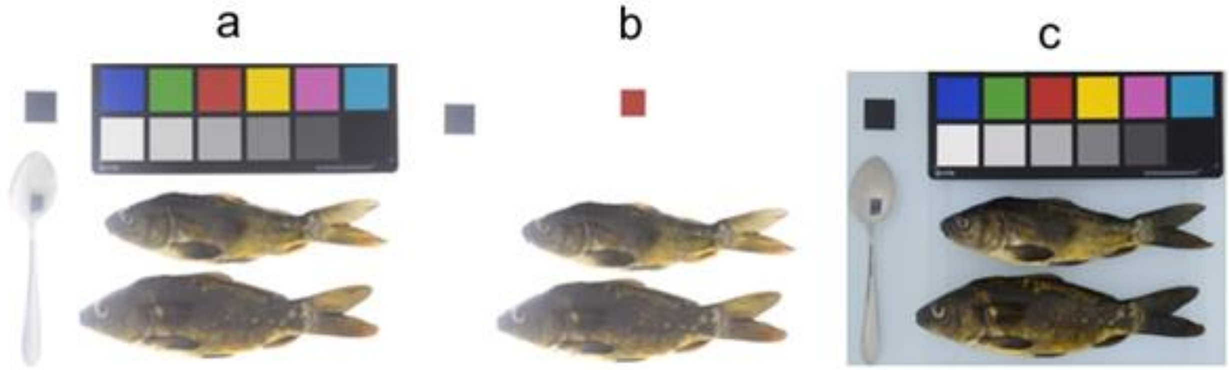

Figure 2. Example of the two-image method. a) backlighted image. b) backlighted image cleaned. c) front lighted image

Table 3. View area – weight relationships of scaled and mirror carp, and other fish.

Fish		Fitted equations									
		Power			Linear			Polynomial			
	Culture condition	A	B	R^2	A	B	R^2	C_0	C_1	C_2	R^2
Scaled carp, kg	Fiberglass	$1.33\ 10^{-4}$	1.5213	0.969	$-6.95\ 10^{-2}$	$2.19\ 10^{-3}$	0.963	$-1.58\ 10^{-2}$	$1.04\ 10^{-3}$	$5.92\ 10^{-6}$	0.969
	Concrete	$1.72\ 10^{-4}$	1.4814	0.986	$-9.58\ 10^{-2}$	$2.56\ 10^{-3}$	0.982	$-4.83\ 10^{-2}$	$1.73\ 10^{-3}$	$3.4\ 10^{-6}$	0.984
Mirror carp, kg	Fiberglass	$1.14\ 10^{-4}$	1.5502	0.938	$-9.07\ 10^{-2}$	$2.37\ 10^{-3}$	0.942	$-3.89\ 10^{-2}$	$1.44\ 10^{-3}$	$4.01\ 10^{-6}$	0.944
	Concrete	$1.91\ 10^{-4}$	1.4590	0.993	$-8.99\ 10^{-2}$	$2.52\ 10^{-3}$	0.987	$-1.31\ 10^{-2}$	$1.14\ 10^{-3}$	$5.74\ 10^{-6}$	0.995
[1]Rainbow trout, g		0.26	1.4200	0.98	-73.55	2.55	0.98	−49.37	2.07	0.002	0.98
[2]Alaskan pollock, whole, g		0.18	1.4700	0.993	-249	3.58	0.987	-94.08	2.16	$2.83\ 10^{-3}$	0.985
[2]Alaskan pollock no fins, g		0.16	1.5100	0.993	-273	3.91	0.978	-69.3	1.92	$4.27\ 10^{-3}$	0.987
[2]Alaskan pollock no fins, no tail, g		0.18	1.5100	0.993	-268	4.24	0.980	-81.19	2.25	$4.62\ 10^{-3}$	0.986
[3]Pink salmon, kg		$1.53\ 10^{-4}$	1.5030	0.948	-0.668	$4.8\ 10^{-3}$	0.945	-0.715	0.005	$-2.17\ 10^{-7}$	0.945
[3]Red salmon, kg		$3.15\ 10^{-4}$	1.3889	0.968	-0.857	$5.24\ 10^{-3}$	0.97	-0.9	$5.4\ 10^{-3}$	$-1.12\ 10^{-7}$	0.97
[3]Silver salmon, kg		$2.67\ 10^{-4}$	1.4179	0.983	-1.111	$5.77\ 10^{-3}$	0.976	-0.1681	$2.81\ 10^{-3}$	$2.22\ 10^{-6}$	0.981
[3]Chum salmon, kg		$2.24\ 10^{-4}$	1.4451	0.976	-1.0546	$5.67\ 10^{-3}$	0.97	-1.07804	$5.74\ 10^{-3}$	$-5.61\ 10^{-8}$	0.97

[1]Gümüş and Balaban (2010), [2]Balaban et al. (2010b), [3]Balaban et al. (2010a).

power equation fits this relationship best. Observing the power equation's B parameter, the value is in general close to 1.5. Again, this is logical since weight is related to volume, and volume dimension is 3/2 power of area dimension. This method has more dimensions (length vs area), and will be more accurate. Also, measuring area using image analysis is quick, accurate, quantitative, and is not affected by curved fish. It is, however affected by the positioning of the fins, of the tail, and of barbels, if any (Balaban *et al.,* 2010b).

Figure 3 shows the experimental view area – weight data. It is apparent that both the mirror carp and scaled carp reared in fiberglass tank tend to have less weight for the same view area compared with the fish reared in concrete tank. It is apparent from Figure 4 that the two different fish reared in concrete tank had the same power curve parameters, and those reared in the fiberglass tank had the same parameters. It is maybe that the conditions of growth are more important than the difference in species for these two carp species.

The fish used in this study came from two different aquaculture facilities. The feeding protocols of these facilities were not investigated and may be different. It is known that different facilities use different amounts of feed as percentages of the estimated fish weight (Stickney, 2005; Mengistu *et al.,* 2020; Dikel *et al.,* 2020). Another potential difference may be the stocking density per unit tank area. This value was also not investigated regarding these two facilities. As the stocking density increases the feed consumption and rate of growth slow down. The amount of available oxygen is also important. We did not measure the oxygen levels in these facilities. The observed difference between weight per unit view area of the fish from different facilities may therefore be the result of feeding regimes, stock densities, light, and water flow rates into the tanks. Measurement of these parameters may explain the observed differences presented in this study.

Color Differences Between Carp Reared at Different Culture Conditions

Figure 5 summarizes the histograms (distribution) of the average L*, a* and b* values of mirror and scaled carps, from two different culture conditions. It is statistically evident that the fish reared in concrete tank had higher L*, a*, and b* values (Table 4). The average L* values of scaled and mirror carps are close to 42, while the average L* values of the fish in fiberglass tank are close to 29. The ranges of standard deviations are

Table 4. The average L*, a* and b* values of scaled and mirror carps of two different culture conditions.

Culture Condition	L*	a*	b*
Concrete, scaled	42.24 ± 3.04^a	1.02 ± 1.26^b	23.61 ± 2.67^b
Concrete, mirror	42.15 ± 3.70^a	2.49 ± 1.59^a	27.22 ± 4.01^a
Fiberglass, scaled	29.06 ± 3.54^b	0.26 ± 1.15^c	12.56 ± 2.71^d
Fiberglass, mirror	29.36 ± 3.92^b	-0.66 ± 0.97^d	13.75 ± 3.27^c

Values with different letter superscripts in a column are statistically different (P<.05)

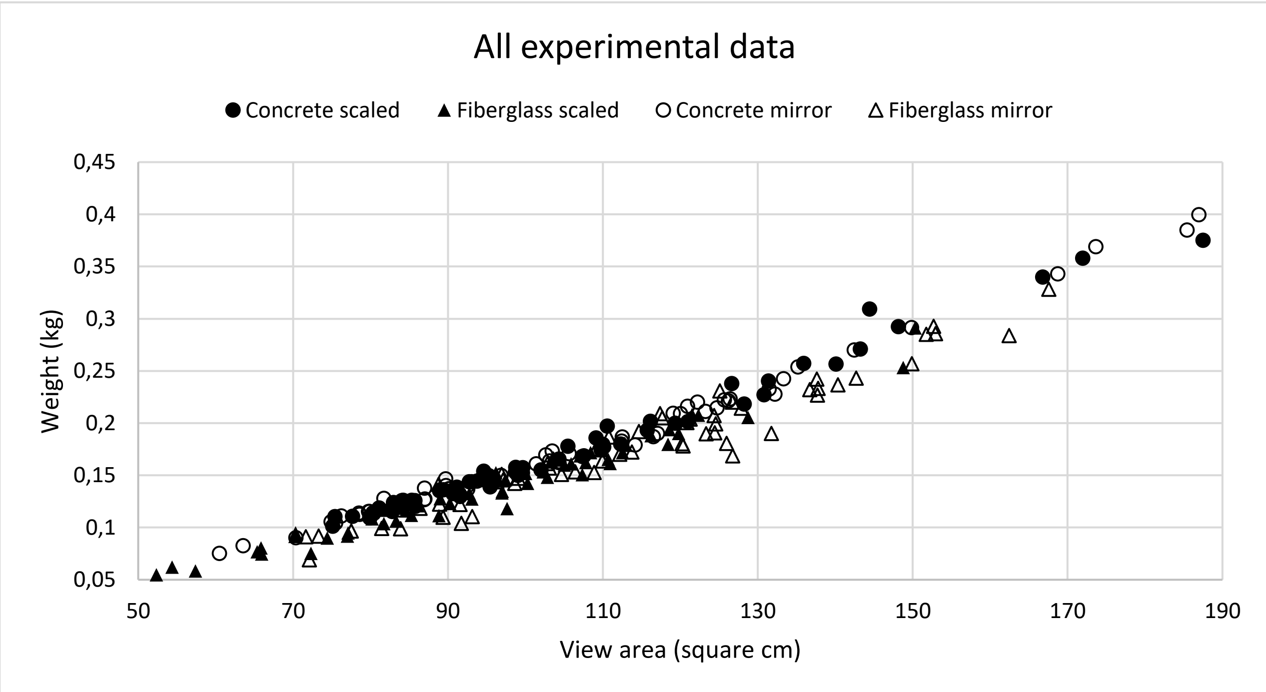

Figure3. Experimental view area – weight data of scaled and mirror carp

not even close to overlap. This is also reflected in the superscripts given in the Table. The average a* values of fish in the concrete tank are about 1 and 2.5, while the average a* values of the carp in the fiberglass tanks are close to zero. Since the fish are mostly yellow, the a* value is of little consequence. The average b* values of the fish in concrete tank are 24 and 27, while the average b* values from fiberglass tank are 13 and 14, about half of those from the concrete tank.

The authors are not aware of consumer sensory / preference studies performed regarding the color of carp. If consumers prefer light-colored fish, then concrete tanks may be better. Therefore, this study should be followed up with a consumer preference study.

Discussion and Conclusion

The LWR relationship developed in this study for carp was similar to those in the literature. The expected value of B is 3, and the B values in our study were close to 3, and the R^2 values were slightly lower than those of the literature for carp. It was also noted that for fish other than carp the B values were still close to 3, confirming the general applicability of this approach.

The prediction of weight using the VAW relationship resulted in higher R^2 values, and was less problem-prone than the LWR method: the accurate measurement of view area is easy using the MV / image analysis methods. The B value of the power curve in this instance was close to 1.5, as expected, and was similar

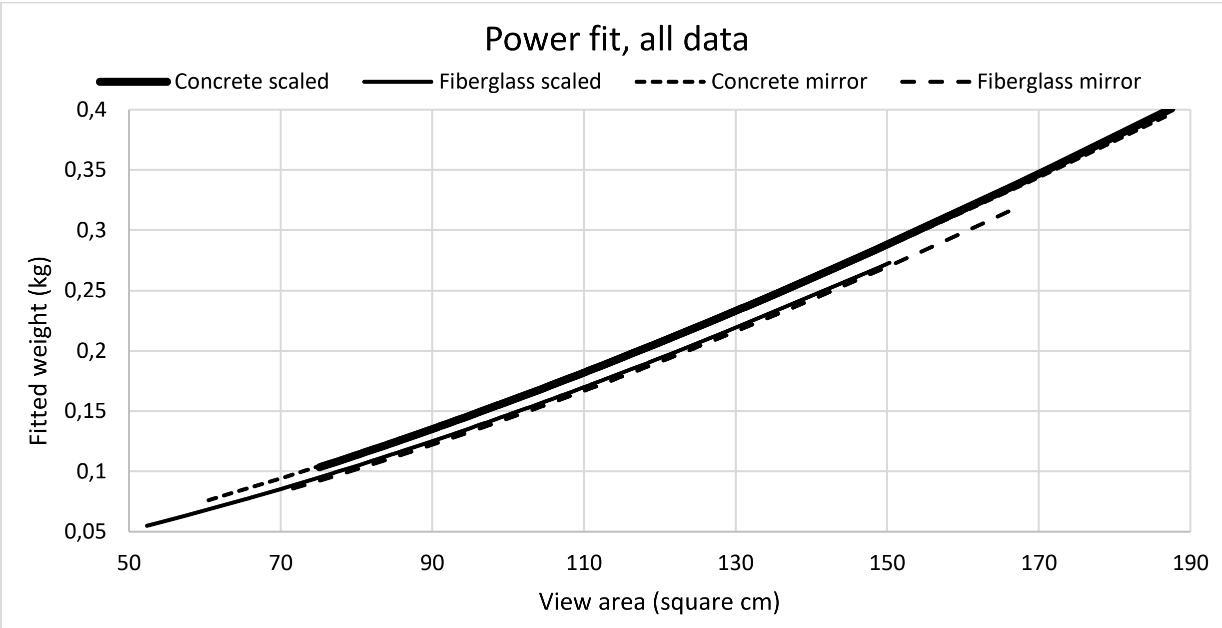

Figure 4. Power curve parameters of scaled and mirror carp.

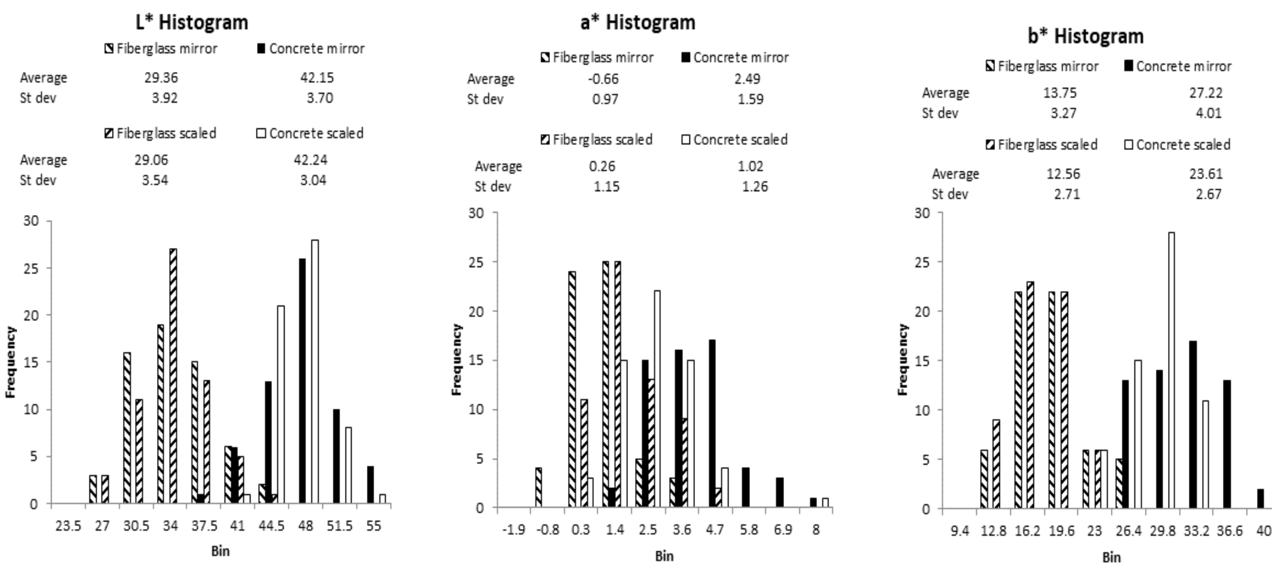

Figure 5. The distribution of the average L*, a* and b* values of scaled and mirror carp of two different culture conditions

to the literature values for other fish. Therefore, the VAW method using MV is an efficient method to estimate the weight of carp.

In this study, the color of fish reared in two different containers (fiberglass and concrete) was significantly different, regardless of the carp species used. Since the age, species, feeding regime, and residence time were the same for both containers, other possible reasons (stocking densities and other culture conditions) for the color difference needs to be investigated further. Also, consumer preference studies regarding the skin color of carp may yield insight into which type of aquaculture environment to use. In addition, possible effects of feeding management, stocking densities, and other culture conditions on the observed color differences should be investigated.

Ethical Statement

Not applicable

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Author Contribution

BG: Conceptualization, Resources, Formal analysis, Data analysis, Software, Writing-original draft. EG: Conceptualization, Methodology, Formal analysis, Data analysis, Writing-original draft, Writing-review & editing, Visualization. MOB: Conceptualization, Software, Methodology, Writing-original draft, Writing-review & editing, Supervision.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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