http://www.egejfas.org
Ege Journal of Fisheries and Aquatic Sciences, 39(2), 125-134 (2022)

Su Ürünleri Dergisi (2022)
DOI: 10.12714/egejfas.39.2.06

RESEARCH ARTICLE ARAŞTIRMA MAKALESİ

Weight and color evaluation of whole and filleted carp by image analysis

Görüntü analizi ile bütün ve fleto sazanların ağırlık ve renk değerlendirmesi

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Received date: 20.01.2022 *Accepted date: 14.04.2022*

How to cite this paper:
Gümüş, B., Gümüş, E., & Balaban, M. O. (2022). Weight and color evaluation of whole and filleted carp by image analysis. *Ege Journal of Fisheries and Aquatic Sciences,* 39(2), 125-134. DOI: 10.12714/egejfas.39.2.06

Abstract: Weight estimation of whole fish and fillets, and skin color of whole fish and fillet meat colors of the male and female scaled and mirror carp (*Cyprinus carpio*) were evaluated by image analysis. After measuring the weight of 10 scaled and 10 mirror carp and their fillets, pictures of both sides of whole fish, and meat side of fillets were taken in a light box. The relationship between weight (W) and view area (V) was calculated by linear (W = A + BV), and power ($W = A\ V^B$) equations. According to the power equation B values, scaled and mirror carps showed positive allometric growth in culture conditions. Statistically, there was no significant difference between the parameters of whole fish left and right sides, as well as whole fish gender. The same was true for right and left fillets, and female and male fish fillets. For both left and right sides scaled and mirror carp had no difference between average L*, a* and b* values (P>0.05). Also, there was no difference between average L*, a* and b*values of male and female of scaled and mirror carp fillets (P>0.05). Image analysis can be used to determine the size, weight, view area and skin and meat color of two carp species and their fillets.

Keywords: Common carp, mirror carp, image analysis, size, color, gender

Öz: Bütün balık ve filetoların ağırlık tahmini, bütün balığın deri rengi ile erkek ve dişi pullu ve aynalı sazanların (*Cyprinus carpio*) fileto et renkleri görüntü analizi ile değerlendirilmiştir. 10 adet pullu ve 10 adet aynalı sazan balığı ve filetolarının ağırlıkları ölçüldükten sonra ışık kutusunda bütün balık için her iki yüzün ve filetoların et yüzünün resimleri çekilmiştir. Ağırlık (W) ve yüzey alanı (V) arasındaki ilişki lineer (W = A + BV) ve güç ($W = A\ V^B$) denklemleriyle hesaplanmıştır. Güç denklemi B değerlerine göre, pullu ve aynalı sazanlar kültür koşullarında pozitif allometrik büyüme göstermiştir. İstatistiksel olarak, bütün balığın sol ve sağ taraf parametreleri ile bütün balık cinsiyeti arasında anlamlı bir fark bulunmamıştır. Aynı durum sağ ve sol filetolar ile dişi ve erkek balık filetoları için de tespit edilmiştir. Bütün pullu ve aynalı sazan için hem sol hem de sağ taraf için ortalama L*, a* ve b* değerleri arasında fark bulunmamıştır (P>0.05). Ayrıca pullu ve aynalı sazan filetolarının erkek ve dişi ortalama L*, a* ve b* değerleri arasında fark tespit edilmemiştir (P>0.05). Görüntü analizi, iki sazan türünün ve bunların filetolarının boyutunu, ağırlığını, görüş alanını ve deri ve et rengini belirlemek için kullanılabilir.

Anahtar kelimeler: Sazan, aynalı sazan, görüntü analizi, boyut, renk, cinsiyet

INTRODUCTION

Aquaculture production reached 82.1 million tons in 2018, up by 3.2 percent from 2017 (FAO, 2020a). Cyprinids are the most cultivated fish group worldwide and their production is increasing. Common carp (*Cyprinus carpio*) is a major cultured fish species especially in Asia and European freshwater aquaculture, due to its fast growth, strong adaptability, good flesh qualities, high nutritional value, good taste, high meat content and cheap price (Ljubojevic et al., 2017; Yang et al., 2020). The global production of common carp peaked at over 4.18 million tons in 2018 (FAO, 2020b).

Carps are used as a whole, gutted, scaled, or fillets (Bauer and Schlott, 2009). Flesh quality is affected by many biological or nonbiological parameters (Lie, 2001). Fillets have been the focus of processing studies (Gela et al., 2003; Kocour et al., 2007). The relationship of morphology and fillet yield has been studied (Cibert et al., 1999). The economic importance of marketing carp as fillet has grown.

Morphological parameters such as the length-weight relationship (LWR) are important to understand growth patterns in fish, and the condition factor is used as an important feature in estimating average weights of whole fish of given length groups (Froese, 2006). LWR is considered as an important biological parameter to generate information about the growth and condition of fish living in both natural and culture conditions (Samsun et al., 2017; Awas et al., 2020). The relationship between the length and weight of the fish is given by the equation $W = AL^B$, with B = 3 as an isometric weight gain. If B is different from 3, the weight gain is negative or positive allometric (B> 3; B <3) (Froese et al., 2014; Khristenko and Otovska, 2017).

Accurate measurement of length, area and weight manually is not easy and may result in measurement errors. With computerized image analysis, length and surface area measurement can be done accurately and easily, leading to rapid weight estimation (Gümüş and Balaban, 2010; Balaban et al., 2010a).

The carp fillet meat color is one of the important parameters in determining its acceptability for consumers (Johnston et al., 2006; Song et al., 2020). Despite its affordability and high nutritional value, carp fillet might be ignored if it has an unattractive look. A more acceptable appearance might improve the market adoption of carp fillets.

The color, size, shape and visual texture of fish can be obtained by computerized image analysis (Gümüş et al., 2011). There are many such studies on color quantification (Balaban et al., 2014; Ünal-Şengör et al., 2019; Gümüş, 2021). However, no studies have been found to determine the size and color quality of carp fillets by the computerized image analysis method.

In many studies, one side of the fish is used in image analysis. Evaluating differences on right and left sides may confirm or deny this practice. Erikson and Misimi (2008) reported that there was no statistical difference between the right and left side colors of Atlantic Salmon. Also, in some fish, the appearance of male and female fish is different. In this study, using image analysis, it was aimed to determine the length-weight, and area-weight relationships of two species of the whole carp (scaled and mirror carp) and right and left fillets from them. In addition, the skin color of whole fish, and meat color of fillets were quantified. The effect of gender on these attributes was evaluated.

MATERIAL AND METHODS

Fish samples and weighing

Scaled carp and mirror carp (*C. carpio*) were obtained from the Fisheries Research, Production and Training Institute, Kepez, Antalya, Turkey in May 2021. The fish were harvested after starving for one day. A total of 20 fish, including 10 scaled and 10 mirror carp, were immediately transferred to Akdeniz University Fisheries Faculty in ice in Styrofoam boxes. Before imaging, the weight of each fish was measured and recorded on an electronic balance (max. 4100 g, 0.1 g precision, Precisa Instruments Ltd./Switzerland). The weights of the fish varied between 246-769 g.

Image acquisition

After weighing each fish, images were taken in a light box described by Gümüş et al. (2021). A Nikon D610 DSLR camera (Nikon Corp., Tokyo, Japan) with a 24-300 mm zoom Nikon lens with a circular polarizing filter was used. Camera settings are given in Table 1. Only polarized images were taken to assure correct colors, and the spoon reflecting the upper LED panel indicated that the polarization was used, since the reflection was black. Size and color references were present in each picture, as described by Gümüş et al. (2021). The dual-image method was used to take the images (Alçiçek and Balaban, 2012). Images of each fish were taken from both the left and right sides. In addition, each fish was classified as male and female.

The fish were then filleted manually without prior bleeding. The skin and all visible pin bones were removed. The fillets were weighed, and images of the meat side of the fillets were taken. Corel PhotoPaint (Corel Corp., Ottawa, Ontario, Canada) was used to clear the bottom-lighted images to isolate the color reference (Figure 1 for whole fish, Figure 2 for fillets).

Image analysis

LensEye-NET (ECS, Gainesville, FL) was used to analyze images. Since the true color of the reference color was known, the whole image was color-corrected to make the color of the reference color match its true color. Then, the size reference of known surface area (9 cm^2) was used to convert pixel-based areas to cm^2 and pixel-based lengths to cm (Figure 3).

$$Fish\ view\ area\ (cm^2) = \frac{\#\ pixels\ of\ fish}{\#\ pixels\ of\ size\ ref}\ x\ 9 \qquad \text{(Eqn. 1)}$$

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

Camera settings	Front-lighting	Back-lighting
Exposure mode	manual	manual
Shutter speed	1/2.5 sec	1/20 sec
Aperture	f/9	f/9
Exposure compensation	0 EV	0 EV
ISO sensitivity	200	200
White balance	Preset 1	Preset 1
Image small size (pixels)	3008*2008	3008*2008

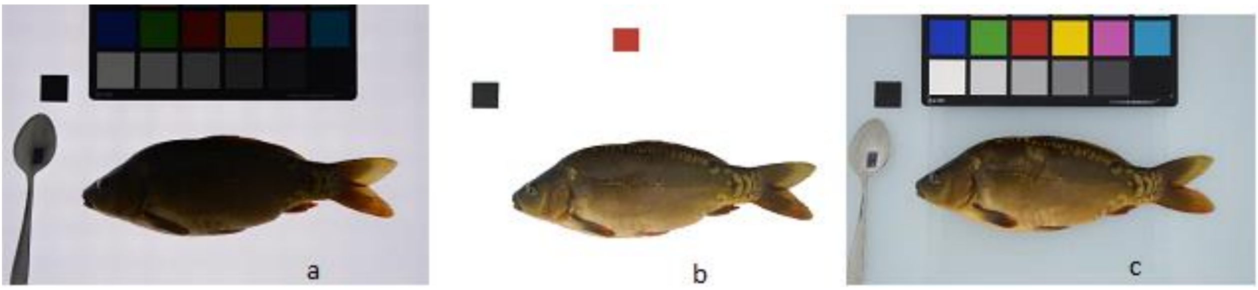

Figure 1. Example of the dual-image method applied to whole scaled and mirror carps. a) backlighted image. b) backlighted image cleaned. c) front lighted image

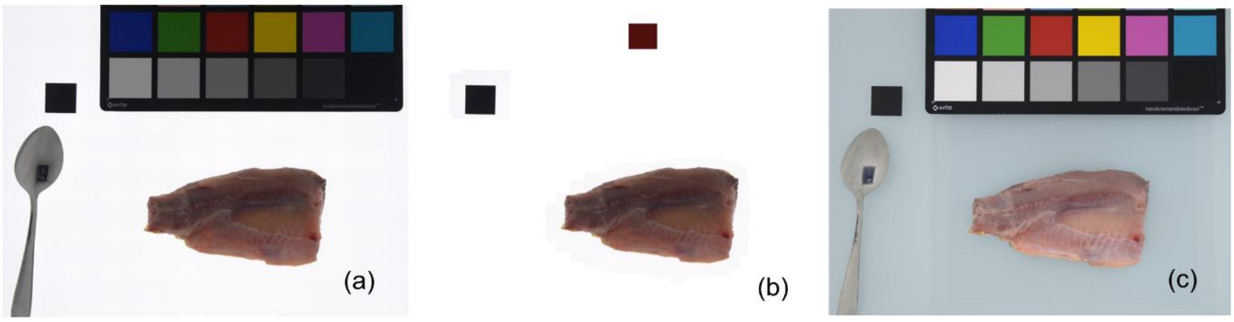

Figure 2. Example of the dual-image method applied to scaled and mirror carp fillets. a) backlighted image. b) backlighted image cleaned. c) front lighted image

Weight-View area relationship

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

Linear: $W = A + B V$ (Eqn. 2)

Power: $W = A V^B$ (Eqn. 3)

In the equations above, W=weight (g), V=view area (cm^2), A, B are coefficients obtained by regression.

Weight-Length relationship

The length of each fish was obtained by fitting the best rectangle (rectangle of minimum surface area that encloses the fish), and the length of the rectangle was taken as the length of the fish.

The following equations between the weight and the length were tried for the length – weight relationship (LWR) (Balaban et al., 2010a):

Linear: $W = A + B L$ (Eqn. 4)

Power: $W = AL^B$ (Eqn. 5)

In the equations above, W=weight (g), L=length (cm), A, B are coefficients obtained by regression.

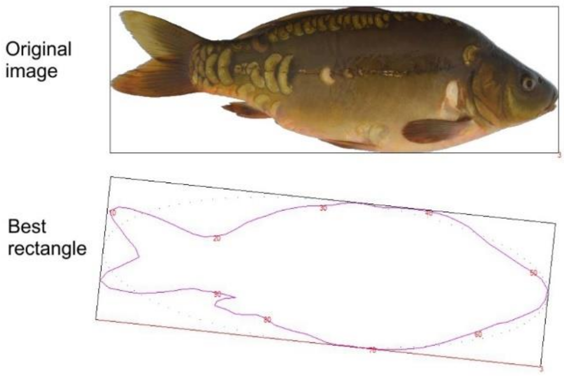

Figure 3. Example of an original fish image, and the best rectangle fitted to it to obtain fish length

Color analysis

The LensEye-NET program obtained the L*, a*, and b* values of each pixel of the fish image. Averages and standard deviations for each object were calculated.

The surface visual texture of each fish was quantified as Texture Change Index (TCI) using the texture primitives method (Balaban, 2008). LensEye-NET program was used for this.

The delta E values of the skin color of whole fish and meat colors between the right and left fillets were calculated based on the equation below:

$$Delta\ E = \sqrt{(L_R{}^* - L_L{}^*)^2 + (a_R{}^* - a_L{}^*)^2 + (b_R{}^* - b_L{}^*)^2} \quad \text{(Eqn.6)}$$

where L*, a* and b* are the CIE color components, the subscripts R and L represent right and left fish/fillets, respectively.

Statistical analysis

The statistical procedures were performed using SPSS v.23 (IBM-SPSS, Armonk, NY, USA). For analysis of variance (ANOVA), differences between the means were subjected to one-way analysis, and Duncan's multiple range test was used to compare the means (*$P < .05$*). The R^2 values for each fit were also calculated. Results were given as mean ± standard deviation (SD).

RESULTS AND DISCUSSION

Using both length and view area of catfish (Gümüş et al., 2021), and commercial Mullidae species (Gümüş, 2021) for weight estimation have been reported. Measuring length may be problematic if the fish can bend easily. Area measurement does not have this disadvantage, and may be more reliable in predicting weight.

Weight - Area relationship of whole fish

The upper part of Table 2 summarizes the calculated parameters of the linear and power fits to the view area vs weight of scaled carp. All R^2 values are higher than 0.94. For female fish, the linear and power fit parameters (A and B) for the left and right sides are not different at 95% confidence. This is also true for the male fish. Therefore, it is not necessary to separate the fish by gender when analyzing VWR or to separate the left and right sides. All scaled carp can be lumped together for VWR analysis, and the side does not matter.

Balaban et al. (2010a) developed the equations to predict the weight of 4 Alaskan salmon species, and Balaban et al. (2010b) did the same for Alaskan pollock. Gümüş and Balaban (2010) developed the equations to predict the weight of whole rainbow trout from different farms using the view area of the fish. Konovalov et al. (2018) estimated the weight of Asian Seabass from its images. When view area ($length^2$) is correlated to weight (and therefore to volume, $length^3$) the exponent term of the power equation to correlate view area to weight is expected to be in the vicinity of 1.5. Again, differences in the shape, thickness and morphology of the fish will result in different fitted parameters for different equations.

Table 2. Weight vs right and left side view area relationships for female and male whole scaled and mirror carps

Scaled carp	Area-Weight	Female		Male	
		Linear W = A+BV	Power W = AV^B	Linear W=A+BV	Power W = AV^B
Left	A	-192.19±237.1	0.308± 9.181	-132.24± 162.61	0.401±1.415
	B	3.444± 1.208	1.393± 0.420	3.058± 0.893	1.337±0.511
	R^2	0.94	0.955	0.991	0.984
Right	A	-207.98± 209.6	0.264±7.065	-129.43± 144.52	0.417± 10.542
	B	3.511± 1.064	1.422±0.371	3.018±0.787	1.328±0.454
	R^2	0.955	0.966	0.993	0.988
Mirror carp	**Area-Weight**	**Female**		**Male**	
		Linear W = A+BV	**Power W = AV^B**	**Linear W=A+BV**	**Power W = AV^B**
Left	A	232.629±763.842	23.188± 726.098	-327.687±217.55	0.0253±26.433
	B	1.596±3.222	0.598±1.218	3.858±0.953	1.836±0.607
	R^2	0.694	0.691	0.969	0.946
Right	A	242.203±726.608	25.139±568.351	-333.807±215.78	0.024±26.593
	B	1.552±3.057	0.583±1.160	3.879±0.944	1.848±0.608
	R^2	0.705	0.701	0.970	0.947

W = weight, g, V = view area, cm^2. A and B are parameters.

The lower part of Table 2 presents the same VWR analysis results for the mirror carp. In this case, some R^2 values are much lower (0.691 – 0.970). This is because the shape of the mirror carp is slightly different than that of the scaled carp which has a more uniform shape. Also, the fins and tail may affect the results (Balaban et al., 2010b). Regardless, the left and right fit parameters (A and B) of the female fish are within the 95% confidence interval of each other, therefore there is no need to separate the fish as right or left. However, there is a distinguishable, but not statistically significant difference between the parameters of the female and male fish. For example, the B value for the power fit of the left sides of female and male fish are 0.598±1.218 and 1.836±0.607, respectively. The difference in values is easily noticeable, but the 95% confidence intervals make them not statistically different.

Weight - Length relationship (WLR) of whole fish

The upper part of Table 3 shows the results of linear and power fits to the length-weight relationship for whole scaled carp, with right and left sides, and female and male fish separated. The R^2 values range from 0.776 to 0.983. The calculated parameters A and B, both for the linear and power fits, are statistically not different for the left or right sides, or for the female and male fish. The 95% confidence intervals are large enough so that the ranges overlap. Therefore, for scaled carp, the LWR can be applied to the combination of female and male fish, either on the left or the right sideThe lowerwer part of Table 3 shows results of linear and power fits to the LWR for whole mirror carp, with right and left sides, and female and male fish separated. The R^2 values range from 0.404 to 0.910. Again, the R^2 values are lower than that of scaled carp. The calculated parameters A and B for mirror carp are not statistically different between the right and left sides, and between the male and female fish. Therefore, the LWR can be calculated for mirror carp by lumping the male and female fish together and using either the right or the left side.

Measuring the length to estimate the weight of fish has been practiced widely. Ak et al. (2009) developed the length-weight relationship of 16 species from Eastern Black Sea. Bengil (2019) developed the same relationship for fish from the Mediterranean Sea. Ergüden et al. (2009) developed the length-weight relationship for trawl-caught fish in Iskenderun Bay.

Table 3. Weight vs right and left side length relationships for male and female whole scaled and mirror carps

Scaled carp	Weight-Length	Female		Male	
		Linear W = A+BL	Power W = AL^B	Linear W=A+BL	Power W = AL^B
Left	A	-828.03±1030	0.0207± 1210	-689±450	0.0535±75.6
	B	44.9±33.4	2.93±2.07	37.4± 15.2	2.64±1.28
	R^2	0.776	0.794	0.983	0.975
Right	A	-842± 918	0.0308±452	-658± 478	0,068±101
	B	43.1± 29.9	2.82±1.79	36.3±16.1	2.57±1.36
	R^2	0.800	0.827	0.979	0.971
Mirror carp	**Area-Length**	**Female**		**Male**	
		Linear W = A+BL	**Power W = AL^B**	**Linear W=A+BL**	**Power W = AL^B**
Left	A	124.06±1800	41.5±1770	1240±838	1180±5180
	B	15±55.5	0.773±2.81	56.1±26.4	3.76±2.48
	R^2	0.404	0.411	0.897	0.816
Right	A	161±1570	50.8±5060	1180±762	0.00165±2460
	B	13.8±47.9	0.713±2.45	54.3±23.9	3.66±2.26
	R^2	0.433	0.440	0.908	0.835

W = weight, g, V = view area, cm^2. A and B are parameters.

Fernandes et al. (2020) used machine vision to extract body measurements to predict the weight of Nile tilapia. Gökçe et al. (2010) developed the length-weight relationship of marine fish from Yumurtalık coast. Kalaycı et al. (2007) used trawl-caught 10 fish species, and Samsun et al. (2017) 11 fish species from Middle Black Sea to predict weight from length. Miranda and Romero (2017) developed a device to measure the length of rainbow trout using image processing, and Shafry et al. (2012) from digital images. Özvarol (2014) presented the length-weight relationship of 14 species of fish from the Gulf of Antalya. Sangun et al. (2007) used 39 fish species from Northeastern Mediterranean to develop length-weight relationships. Since the shape, thickness and morphology of the fish are different, it is expected that the parameters for the length-weight relationship will be different.

Weight - Area relationship of fillets

VWR depends on how the fillet was cut: thin, or thick. In the upper part of Table 6, the linear and power fits to the view area – weight relationship for left and right fillets, and for those from female and male scaled carp are presented. The R^2 values ranged from 0.850 to 0.990. The calculated parameters A and B are not statistically different between the right and left sides, and between the male and female fish ($p<0.05$). Therefore, male and female fish can be grouped together, and left and right fillet specification is not needed.

Table 4. Weight vs right and left side view area relationships for male and female scaled and mirror carp fillets

Scaled carp	Area-Weight	Female		Male	
		Linear W = A+BV	Power W = AV^B	Linear W=A+BV	Power W = AV^B
Left	A	-38.7±81.6	0.112± 36.6	-4.57±60	0.838±26.1
	B	1.23±0.7	1.44±0.758	0.912± 0.569	1.01±0.704
	R^2	0.855	0.874	0.960	0.950
Right	A	-42.9± 86.7	0.105±46.1	-27.3± 41.9	0.245±5.88
	B	1.27± 0.74	1.45±0.805	1.12±0.386	1.27±0.379
	R^2	0.850	0.862	0.987	0.990
Mirror carp	**Area-Weight**	**Female**		**Male**	
		Linear W = A+BV	**Power W = AV^B**	**Linear W=A+BV**	**Power W = AV^B**
Left	A	-25.7±322	0.511±1.88 10^5	-47.7±18.1	0.0951±2.25
	B	1.13±2.33	1.12±2.47	1.31±0.144	1.47±0.169
	R^2	0.683	0.657	0.994	0.993
Right	A	10.3±479	2.18±3.74 10^7	-50.3±24.5	0.113±1.97
	B	0.917±3.6	0.840±3.57	1.32±0.185	1.43±0.14
	R^2	0.376	0.339	0.990	0.995

W = weight, g, V = view area, cm^2. A and B are parameters.

In the lower part of Table 4, the linear and power fits to the view area – weight relationship for left and right fillets, and for those from female and male mirror carp are presented. The R^2 values ranged from 0.339 to 0.995. The calculated parameters A and B are not statistically different between the right and left sides, and between the male and female fish. Therefore, male and female fish can be grouped together, and left and right fillet specification is not needed.

Color

Table 5 displays the average and standard deviation color parameters of whole scaled and mirror carp. The right and left sides, and gender are separated. It can be seen that for the left and right sides of female scaled carp, there are no significant differences between the average L*, a* and b* values. This means that for color evaluation purposes the right and left sides of whole female scaled carp can be used interchangeably. The same is also true for the L*, a* and b* parameters of male scaled carp, left and right sides. Therefore, the side does not make a difference in the color evaluation of male scaled carp. When comparing the color parameters of the right and left sides of female and male mirror carp, there is no significant difference.

Comparing the female and male scaled carp, there is no significant difference between the color parameters for both the left and right sides. The same is true for the mirror carp. However, there are differences between the scaled carp and mirror carp color parameters.

There is not much literature on the comparison of the color from the right and left sides of fish. Balaban et al. (2014) monitored the average skin color of gurnard (*Chelidonichtys kumu*) and snapper (*Pagrus auratus*) for 12 days at 0^oC. There was no statistical difference between the L*, a* or b* values over the storage period. This is despite the fading of the red color in both fish, meaning that the change in color was the same on both sides of the fish.

Another means of determining if the color difference is perceptible by human eye is to examine the Delta E value (Eqn 6). It is generally accepted that a Delta E value below 1 is visually not detectable by humans: Delta E = 1 is "just noticeable difference" for the human eye (Abeyta, 2011). Based on this definition, the delta E value between the right and left side of whole fish varied between 1.46 and 2.78. This implies that the color difference between right and left side skin color of whole fish may be detectable by human eye. The reason for this apparent difference in color between the sides is unknown.

Table 5. Average skin colors of whole scaled and mirror carps, right and left sides and gender

Carp	Gender	Color	Left	Right
Scaled	Female	L*	42.148±1.751[a]	41.467±1.917[ab]
		a*	3.497±1.220	3.483±1.210
		b*	22.067±2.873	22.147±2.654
	Male	L*	39.603±3.740[abc]	39.358±3.741[abc]
		a*	3.260±1.268	3.730±0.222
		b*	20.283±3.123	21.005±2.716
Mirror	Female	L*	37.508±4.306[bc]	36.383±3.998[c]
		a*	1.895±0.746	2.900±1.341
		b*	23.363±3.307	22.228±3.157
	Male	L*	37.473±2.324[bc]	36.828±1.388[c]
		a*	2.768±1.087	3.318±2.400
		b*	23.082±1.586	23.552±2.887

Means with different letters are significantly different (p< .05)

The visual texture of skin surface

One immediately noticeable difference in the appearance between the scaled carp and mirror carp is visual texture of skin. Visual texture is the concept of how “rough, uneven, variable” the surface looks. One method to quantify the visual texture is the “Texture Change Index (TCI)” based on texture primitives (Balaban, 2008). The rougher the appearance of the surface the higher the TCI value. In Table 6, The TCI values of scaled carp are much higher (3.2 times) than those of the mirror carp. Evaluating the standard deviations of the TCI values, there is no statistically significant difference between the left and right sides of a given fish, and between the female and male fish. However, the difference in the fish species is significant. Literature on the skin-side or meat side of fish regarding visual texture, including TCI analysis, is scarce. Since “objective” image analysis-based visual texture measurement must be correlated with human sensory panel results, and since there is not much standardization on how to conduct visual texture by sensory panels, this area needs more research and standardization (Balaban and Alçiçek, 2016). Then, many computerized methods, including TCI, can be used to reliably quantify the visual texture of fish in particular, and foods in general.

Table 6. Skin TCI values of whole scaled and mirror carps, right and left sides and gender

Carp	Gender	Left TCI value	Right TCI value
Scaled	Female	16.38±0.78[a]	15.94±1.13[a]
	Male	16.88±1.46[a]	16.23±1.87[a]
Mirror	Female	5.15±1.22[b]	4.41±1.46[b]
	Male	4.68±0.91[b]	4.55±0.72[b]

Means with different letters are significantly different (p< .05)

One method to visualize the TCI method is to depict the texture primitives as equivalent circles (Figure 4). In mirror carp, the visual texture is relatively smooth, so the texture primitives are large and less numerous. In scaled carp, however, there are many small texture primitives, indicating that the appearance of the surface is rougher.

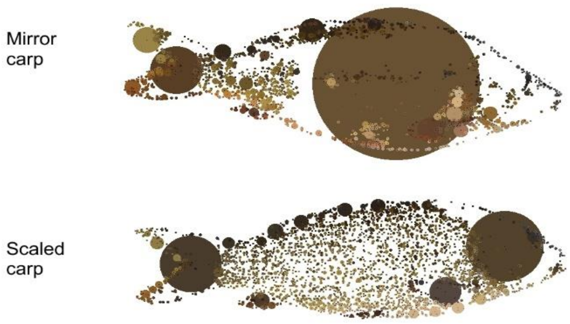

Figure 4. Example of texture circles for mirror scaled and mirror carps. Each circle represents a texture primitive. The more primitives, the higher the visual texture, and the TCI value (Balaban, 2008).

Fillets

Table 7 presents the average color parameters of the meat side of fillets of female and male fish, as well as the right and left side colors. It can be seen that based on the standard deviations, there is no significant difference between the L*, a* and b* values of the left and right fillets from the same fish. Also, there is no significant difference between the female and male fillets of the same species. Finally, there is no significant difference between the scaled carp fillet colors and the mirror carp colors.

Table 7. Average meat colors of scaled and mirror carp fillets, right and left sides and gender

Carp	Gender	Color	Left	Right
Scaled	Female	L*	65.765±2.818	66.032±2.288
		a*	10.381±1.493	9.700±1.250
		b*	11.760±2.043	10.774±2.260
	Male	L*	65.025±3.527	65.115±4.177
		a*	10.095±2.248	9.962±1.896
		b*	9.850±2.244	9.562±1.961
Mirror	Female	L*	65.510±1.271	65.477±2.036
		a*	10.765±0.567	10.600±1.298
		b*	12.222±1.975	12.260±1.884
	Male	L*	64.853±1.960	65.508±1.982
		a*	11.220±1.729	10.750±1.578
		b*	12.81±3.052	12.478±2.813

Finally, the Delta E values represent color differences between the right and left sides of the fillet from the same fish hover between 1.02 and 1.67. This suggests that these color differences are barely detectable by the human eye.

CONCLUSION

The results of this study confirm the use of one side of the carp species used for image analysis, be it for length, view area, or skin color evaluation. In addition, there was no statistically significant difference between male and female results, in evaluating weight using length or view area. Therefore, for these species of carp, males and females can be grouped together for this type of analysis. In many studies, the B value in the power equation in determining weight from view area is close to 1.5. In whole mirror carp, this value ranged between 0.583±1.160 to 1.848±0.608. The 95% confidence intervals of these values include 1.5, and the wide variability may be due to the low number of samples. For scaled carp, the B value of the power equation ranged from 1.33±0.5 to 1.42±0.37. Again, these confidence intervals include the value of 1.5. Using the same reasoning, the B value of the power fit to weight vs length relationship is expected to be 3. For whole scaled carp, the B value ranged from 2.57±1.36 to 2.93±2.07. For mirror carp, this range was 0.713±2.45 to 3.76±2.48. Considering their 95% confidence interval, these ranges include the number 3. As before, the mirror carp had more variability.

For carp fillets, the prediction of weight using view area by power equation resulted in B values for scaled carp in the range 1.01±0.704 to 1.45±0.805, and for mirror carp in the range 0.840±3.57 to 1.47±0.169. Considering their confidence intervals, these ranges include the theoretical value of 1.5. Again, the wide variability of mirror carp values is observed. In some fish, the appearance of male and female fish is different. In this study, using image analysis, for the length-weight, and area-weight relationships of two species of whole carp and the fillets from them, there was no significant difference between female and male fish. This also applied to the skin color of whole fish, and the meat color of fillets: there was no significant color difference between right and left sides, and between female and male fish. There was a very significant difference between the visual texture of whole scaled carp skin and whole mirror carp skin.

Image analysis can easily and rapidly estimate the weight of whole fish from its length or view area. It can also quantify the color parameters of the skin and fillet meat, and the visual texture of skin.

ACKNOWLEDGEMENTS

We thank Mr. Serkan ERKAN, Director of Republic of Turkey Ministry of Agriculture and Forestry, Mediterranean Fisheries Research Production and Training Institute, Kepez, Antalya, Turkey, for supplying fish samples.

AUTHORSHIP CONTRIBUTIONS

Bahar Gümüş: Conceptualization, formal analysis, data analysis, investigation, project administration, resources, writing-original draft. Erkan Gümüş: Conceptualization, formal analysis, data analysis, investigation, project administration, software, writing-original draft, writing-review & editing, visualization. Murat O. Balaban: Conceptualization, data curation, formal analysis, methodology, resources, software, supervision, visualization, writing-original draft, writing-review & editing.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest or competing interests.

ETHICS APPROVAL

No specific ethical approval was necessary for this study

DATA AVAILABILITY

For questions regarding datasets, the corresponding author should be contacted.

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