

# Image-based quantification of size, color, and image texture in meagre (*Argyrosomus regius* (Asso, 1801)) reared in different culture systems

## Farklı kültür koşullarında yetiştirilen granyöz'ün (*Argyrosomus regius* (Asso, 1801)) boyutu, deri rengi ve görsel dokusunun görüntü tabanlı nicel analizi

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**Abstract:** Meagre is an important fish both regarding fisheries and aquaculture. Visual attributes of whole meagre are important for the purchase intention of consumers. Whole meagre grown in cages and earthen ponds were evaluated by image analysis for visual attributes (length, view area, color of right and left sides, image texture). The fish were weighed, and images of both sides were taken. Weight W vs length L data were fitted a power equation  $W = A L^B$ . The B values for cage and earthen pond fish were 2.95 and 2.93, respectively. The R<sup>2</sup> values for power fit to weight vs view area were 0.976 for cage fish, and 0.983 for earthen pond fish, respectively. The 1<sup>st</sup> null hypothesis was that the colors of cage and earthen pond-reared fish were not different. The 2<sup>nd</sup> null hypothesis was that for both type fish the colors of the right and left colors were not different. Specifically, the cage fish were lighter than the earthen pond-reared fish. The L\*, a\* and b\* values of cage fish were statistically different than those of earthen pond fish (p<0.05). The a\* values of both sides of cage and earthen pond fish, and b\* values of both sides of cage fish were statistically different (p<0.05). Delta E values between the right and left skin colors for cage and earthen pond fish were 1.89, and 1.78, respectively, suggesting noticeable difference upon close examination. Also, there were 13 out of 53 Delta E values greater than 3 for cage fish, and 10 out of 66 for earthen pond fish. Texture change index and color change index of cage and earthen pond fish were statistically different (p<0.05). This suggests considering both sides of the fish should be considered in evaluating color and image texture.

**Keywords:** Meagre, morphometric data, color, image texture, image analysis

**Öz:** Granyöz hem balıkçılık hem de su ürünleri yetiştiriciliği açısından önemli bir balıktır. Granyöz balığının görsel özellikleri, tüketicilerin satın alma niyeti için önemlidir. Kafeslerde ve toprak havuzlarda yetiştirilen bütün granyöz balıkları, görsel özellikler (uzunluk, görüş alanı, sağ ve sol tarafların rengi, görüntü dokusu) açısından görüntü analizi ile değerlendirilmiştir. Balıklar tartıldıktan sonra her iki tarafının görüntüleri alınmıştır. Ağırlık (W) ve uzunluk (L) verileri,  $W = A L^B$  güç denkleminde yararlanılarak değerlendirilmiştir. Kafes ve toprak havuz balıkları için B değerleri sırasıyla 2,95 ve 2,93'tür. Ağırlık ve görüş alanı arasındaki güç uyumunun R<sup>2</sup> değerleri kafes balıkları için 0,976, toprak havuz balıkları için ise 0,983'tür. Çalışmada ortaya konan iki hipotezden birincisi, kafes ve toprak havuzda yetiştirilen balıkların renklerinin farklı olmadığıdır. İkinci ise, her iki balık türü için de sağ ve sol tarafların renklerinin farklı olmadığıdır. Özellikle, kafes balıkları toprak havuzlarda yetiştirilen balıklardan daha hafiftir. Kafes balıklarının L\*, a\* ve b\* değerleri toprak havuz balıklarının değerlerinden istatistiksel olarak farklıdır (p<0.05). Kafes ve toprak havuz balıklarının her iki tarafının a\* değerleri ve kafes balıklarının her iki tarafının b\* değerleri istatistiksel olarak farklı bulunmuştur (p<0.05). Kafes ve toprak havuz balıkları için sağ ve sol deri renkleri arasındaki Delta E değerleri sırasıyla 1,89 ve 1,78 olup yakından incelendiğinde gözle görülür bir fark olduğunu göstermektedir. Ayrıca, kafes balıkları için 53 Delta E değerinden 13'ü, toprak havuz balıkları için ise 66 Delta E değerinden 10'u 3'ten büyüktür. Kafes ve toprak havuz balıklarının doku değişim indeksi ve renk değişim indeksi istatistiksel olarak farklıdır (p<0.05). Bu, renk ve görüntü dokusunu değerlendirirken balığın her iki tarafının da dikkate alınması gerektiğini göstermektedir.

**Anahtar kelimeler:** Kaya levreği, morfometrik veri, renk, görüntü dokusu, görüntü analizi

## INTRODUCTION

The species *Argyrosomus regius* (Asso, 1801) has different common names such as yellowmouth and meagre, and belongs to the Sciaenidae family. It is distributed in the Mediterranean, the Sea of Marmara, the western coasts of the Black Sea, in subtropical regions extending from Norway to the Congo, in the Red Sea and, to a lesser extent, in the Indian Ocean (Mylonas et al., 2013). While meagre has a broad temperature tolerance in nature (14–26 °C) (Duncan et al., 2013), the best growth is observed between 21 and 27°C in culture conditions (Lazo et al., 2010; Kounna et al., 2021). It

feeds mostly on small fish, crustaceans, mollusks, polychaetes, echinoderms and decapods (Haffray et al., 2012).

Meagre has great potential for aquaculture with its fast growth, high feed conversion rate, ability to live in a wide range of salinity and high-quality meat (Fountoulaki et al., 2017; Saavedra et al., 2018; Young and Shaikhi, 2024; Bavčević et al., 2025). In Mediterranean countries, commercial cultivation of meagre is done in cage and earthen pond culture species, where the fish is generally stocked as juveniles with an initial

size of approximately 1–2 g, and then grown to 400 g for 13–14 months (Lozano et al., 2017; Young et al., 2022), or rapid growth rates up to 2.5 kg in two years (Pastor et al., 2002). In 2021, global aquaculture production of meagre exceeded 43 thousand tons, with highest production in Egypt, Turkey, Spain, and Greece (FAO, 2023). In Turkey, meagre aquaculture amounted to 6,149 tons in 2023 (TÜİK, 2024). There are differences in the appearance and meat quality of both wild and cultured fish and, also between fish grown in different culture conditions (Ribeiro et al., 2013; Saavedra et al., 2017). The most important reasons for these differences are nutrition and different rearing conditions (Sinanoglou et al. 2014). However, fish grown in earthen ponds have been reported to have a taste and color similar to wild fish (Ribeiro et al., 2013; Saavedra et al., 2017).

The visual attributes of whole fish skin are important for the purchase intention of consumers. Image analysis has been used in the determination of various quality characteristics such as color, image texture, weight and volume prediction, shape, morphometric data, and defects of many food products in both scientific and industrial fields, because it is fast, non-contact and repeatable (Misimi et al., 2008; Gümüş et al., 2011; Balaban et al., 2014; Şengör et al., 2018; Yavuzer and Köse, 2022). Each pixel of an image has red, green and blue (RGB) colors that can be converted to other color coordinates such as CIE L a b ( $L^*$ ,  $a^*$ ,  $b^*$ ), hue saturation lightness (HSL) and grayscale. Hue can be calculated by converting the RGB coordinate system to the Hue, Saturation, Lightness (HSL) system. The grayscale value is calculated as:

$$\text{Grayscale} = 0.3 R + 0.59 G + 0.11 B \quad (\text{Eqn 1})$$

Color differences between the right side and the left side of the fish are calculated using the  $\Delta E_{76}$  formula as:

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

where the subscripts L and R refer to left and right sides, respectively.

### Energy, entropy, color change index, texture change index

In addition to color, image texture is important. Since many agricultural materials have surfaces with uneven colors and appearance, image texture is defined as uneven patterns, roughness or smoothness of the surface, and visual non-uniformities (Gümüş et al., 2022b).

Computer methods to calculate image texture use grayscale images, resulting in loss of information if the original image is in color. For this, the image is first transformed from color to grayscale, resulting in every pixel's value falling between 0 and 255. Then, the histogram is taken, counting how many pixels exist for each pixel value from 0 to 255. Dividing the histogram values by the total number of pixels results in the probabilities  $p_k$  of levels  $k$  (0-255) occurring in the image. Based on these probabilities, the energy of a grayscale image can be calculated as (Arzate-Vazquez et al., 2012):

$$E = \sum_{k=0}^{255} (p_k)^2 \quad (\text{Eqn 3})$$

Entropy of a grayscale image can be calculated as (Larkin, 2016):

$$H = - \sum_{k=0}^{255} p_k \log_2 (p_k) \quad (\text{Eqn 4})$$

Image texture can also be calculated for color images. The light intensity difference  $\Delta I$  between two pixels is determined:

$$\Delta I = \sqrt{(R_i - R_j)^2 + (G_i - G_j)^2 + (B_i - B_j)^2} \quad (\text{Eqn 5})$$

Here, subscripts  $i$  and  $j$  represent two pixels, RGB are colors red, green and blue. By keeping the pixel  $i$  fixed, if  $\Delta I$  among its neighboring pixels  $j$  is less than a certain threshold, then pixel  $j$  is added to a continuous area (primitive). If  $\Delta I$  is greater than the threshold, a new primitive is started. In the case of color primitives, the anchor pixel  $i$  is kept fixed for the primitive, and depending on the  $\Delta I$  value of pixel  $j$ , this pixel is included in the primitive. When no other pixels can be added, then the anchor pixel is changed to an available, neighboring pixel, and the process is repeated until all pixels are processed. The  $\Delta I$  threshold is important: a small value will result in many small primitives; a large value will result in a lower number of larger primitives. Currently, there is no standard method to determine the "best" threshold value. Therefore, the values most used in the literature were taken (Gümüş et al., 2022b).

The more color primitives there are, the higher the value of the cumulative "color change index". Also, the bigger the area of an object the more color primitives, everything else being equal. Therefore, a "color change index (CCI)" is proposed (Balaban, 2008):

$$\text{CCI} = \frac{(\text{Sum of } \Delta I \text{ for neighboring pixels})(\text{Number of neighbors})}{(\text{Sum distances between equivalent circles})(\text{Object area})} \quad (\text{Eqn 6})$$

The neighbors are defined on an 8-connectivity basis. In the case of "texture primitives" (TCI), the pixel  $i$  is not fixed: if the  $\Delta I$  between pixels  $i$  and  $j$  is less than a threshold, then the pixel  $j$  is included in the primitive, and the anchor becomes pixel  $j$ . The TCI equation is the same. TCI is a measure of how visually textured the image is (Gümüş et al., 2022b).

The 1<sup>st</sup> null hypothesis was that the colors of cage and earthen pond-reared fish were not different. The 2<sup>nd</sup> null hypothesis was that for both type fish the colors of the right and left colors were not different.

The objectives of this study were: 1) To measure the weight and visual properties (morphometric data, view area, color, image texture) for whole meagre using image analysis, 2) To compare visual properties of meagre raised in two culture conditions, 3) For each fish, to compare the visual properties of the right and left-sides.

## MATERIALS AND METHODS

### Source of fish

Meagre grown in two different aquaculture environments

were used: the earthen ponds of Olivka Agricultural Production Industry and Trade Inc., a private enterprise operating in Alçova, Ekinanbarı Mah. Milas/Muğla, Turkey (37°16'07"N; 27°38'09"E), and the cages of Yılmaz Aquaculture Fish Production Tur. Trade and Industry Trade Ltd. Co. operating in Yalı Mah. 0248 Street No 17 Güzelbahçe/İzmir, Turkey (38°44'921" N; 26°49'200" E). In one case, fish were placed in cages weighing 60-80 g and were fed fresh wet feed for 18 months. Bait fish such as bogue, sardine, mackerel, picarel, and sand smelt were used as fresh wet feed, and the fish were hand-fed once a day. Fish that reached an average weight of 800-1000 g were harvested in February.03.2025. Meagre raised in earthen ponds were brought to the rearing facility on 03.04.2023 with an average weight of 4.9 g and were cultured for 24 months until they reached a weight of 800-1000 g. Feed produced by Gümüşdoğa Aquatic Products Production Inc. (Milas/Muğla) containing 45% crude protein, 20% fat, 9% crude ash, 1.8% crude cellulose, 2.3% calcium, 1.5% phosphorus and 0.3% sodium, was hand-fed three times a day. The harvest date was January.12.2025. According to information obtained from cage and earthen pond fish producers, the water temperature, salinity, and dissolved oxygen levels were 14-25 °C, 32-40 ppt and 5-9 mg/l, respectively. These are similar to the data reported by Başaran et al. (2006) and Bodur (2018). Other details of culture conditions, such as stocking density, water quality and flow etc. were not provided.

53 freshly harvested fish from the cage farm and 66 from the earthen pond farm were selected at random. The fish were transported in Styrofoam boxes with ice, brought to the Faculty of Fisheries and kept at +4 °C until processing. Time between arrival and processing was less than 3 hrs.

### Weighing

The weight of each fish was recorded using an electronic scale (max. 30 kg, 0.01 g precision, HZQ model, Densi, Istanbul, Turkey). The fish were weighed in a tared plastic container.

### Light box

A light box (Figure 1) with dimensions of 60 cm wide, 60 cm deep, and 90 cm high, designed originally by Luzuriaga et al. (1997) and later modified (Gümüş et al., 2022a) was used. D65 lighting was provided by the top and bottom LED panels. The inner surface of the upper light box was covered with a polarizing sheet (Rosco, Stamford, CT, USA).

### Method of taking pictures

A 24-300 mm zoom Nikkor lens and a 72 mm diameter polarizing filter were connected to a Nikon D610 digital camera (Nikon Corp., Tokyo, Japan). A color reference (Color Checker Classic, X-Rite Inc., Grand Rapids, MI) was used in each picture, as well as a 3 cm x 3 cm black square as a size reference. Polarized light was used to eliminate specular reflections.

The sample fish was placed in the light box. The

"two-image" method (Alçiçek and Balaban, 2012) was used: the top light was turned off, the bottom light was turned on, and a picture was taken (Figure 2a). This picture provided the silhouette of the fish. Then the bottom light was turned off, the top light was turned on, and the second picture was taken (Figure 2c). Camera settings for these are shown in Table 1.



Figure 1. Light box used in taking pictures

Table 1. Settings of the Nikon D610 camera to take back-lit and front-lit pictures

Camera setting	Front-lit	Back-lit
Exposure mode	Manual	Manual
Shutter speed	1/2.5 sec	1/10 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

Analysis was performed on the 2<sup>nd</sup> picture, using the 1<sup>st</sup> picture's silhouette to segment the image. Both the right side and the left side of the fish were pictured. Figure 2 shows an example of the images taken. LensEye-NET software (ECS, Gainesville, FL, USA) was used for taking pictures and subsequent morphometric and color analyses.

### Length – weight correlation

The length of the fish, in pixels, was obtained from the picture. The length was converted to cm using the size reference (the size reference is 3 cm x 3 cm):

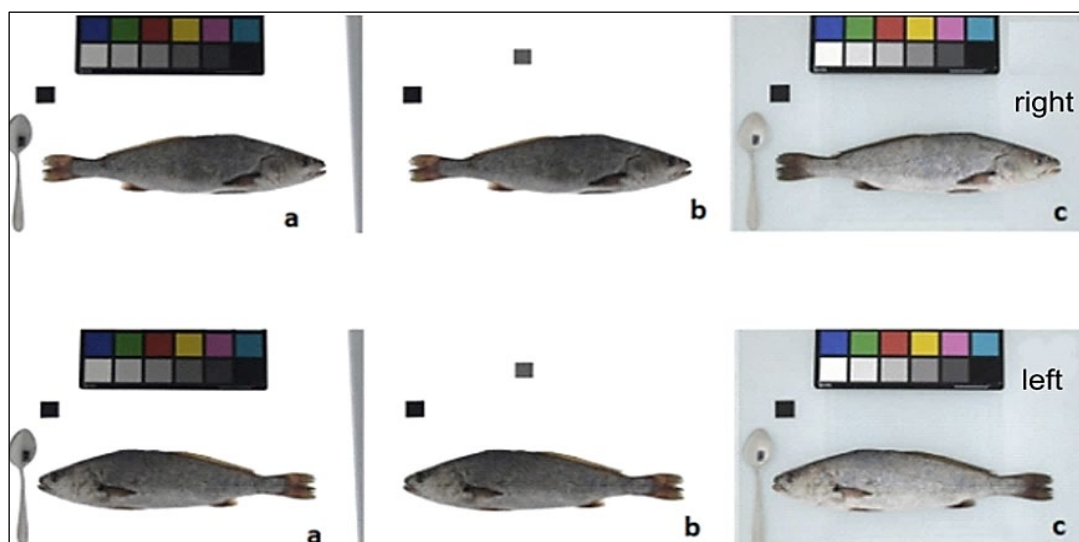
$$\text{Area (cm}^2\text{)} = \text{Number of pixels of the object} / \text{Number of pixels of size reference} \times 9 \quad (\text{Eqn 7})$$

In a square pixel image, the length is converted similarly, by taking the square root of the area as the length reference.

The power equation:

$$W = A L^B \quad (\text{Eqn 8})$$

was used to correlate length to weight (Balaban et al., 2010; Gerami et al., 2013). W is the weight of the fish (g), L is the length (cm), A and B are parameters determined from regression.



**Figure 2.** Right and left side images of fish. a) Bottom-lit image; b) Cleaned bottom-lit image; c) Top-lit image.

### View area – weight correlation

View area of the fish was obtained from the picture by counting its pixels. Then, the size reference was used to convert the view area to  $\text{cm}^2$ . The power equation

$$W = A V^B \quad (\text{Eqn 9})$$

was used, where  $W$  is weight (g),  $V$  is the view area ( $\text{cm}^2$ ),  $A$  and  $B$  are parameters calculated from regression (Balaban et al., 2010).

### Measurement of color

First, the color parameters of every pixel of the color reference were obtained from the picture. The differences between these values and those obtained from reading the color of the color reference using Minolta CR-400 Chroma Meter (Minolta, Japan) were obtained. The colors of every pixel of the picture were then corrected based on the above differences. The corrected color parameters of every pixel of the fish ( $L^*$ ,  $a^*$ ,  $b^*$ , Hue) were averaged using the LensEye-NET software.

### Development of histograms

Using values of each fish pixel, the following histograms were developed: grayscale,  $L^*$ ,  $a^*$ ,  $b^*$ , Hue. For each parameter, the minimum and maximum values were found, this range was divided by 10, and the bins were calculated accordingly. Normalized histograms were obtained to eliminate the effects of sample size: each frequency in a bin was divided by the total number of frequencies, then multiplied by 100.

### Calculation of energy, entropy, color change index, texture change index

LensEye was used to calculate the grayscale energy, entropy, and the color change index and texture change index.

### Statistical analysis

Side color comparison was performed using paired t-test.

For color analysis, the data obtained were evaluated with the ANOVA test in the SPSS v.23 program (IBM-SPSS, Armonk, NY, USA). The results are presented as mean and standard deviation ( $\pm$ SD). Kolmogorov-Smirnov normality test was performed for the normal distribution of the data and the differences were evaluated with the one-way ANOVA test. ANCOVA test was used to control the possible effect of weight in the analysis of view area, height and length data between groups. Duncan's multiple comparison test was used to compare the significance levels of the data and the significance level was selected as  $P=0.05$  (Duncan, 1955).

## RESULTS

There are reports in the literature regarding the comparison of cage-reared and pond-reared meagre. Vallecillos et al. (2021; 2023) used image analysis to compare meagre grown in cages and ponds from a genetics and heritability perspective of certain morphological parameters, but not for color or image texture. Their analysis also did not perform predictive weight vs length or weight vs view area. Zupa et al. (2023) mentioned the reproductive dysfunction of meagre reared in tanks; however, those reared in sea cages displayed normal reproduction. There was no comparison of color, image texture and predictive weight calculations. Navarro et al. (2016) used image analysis to obtain morphological parameters of meagre, but not color or image texture data, or predictive weight analysis. Oikonomou et al. (2025) genomically evaluated meagre for body weight, length and growth, again without mention of color, image texture, or weight-view area correlations. In addition, comparison of the right and left sides of meagre for color was not found in the literature. Therefore, detailed comparison of morphometric data, color and image texture in this study present new data and information regarding meagre aquaculture.

### Dimensions

The mean values for right and left length, height and view

area of cage and earthen pond cultured meagre are given in Table 2. Their frequency distributions are shown in Figures 3, 4, and 5.

**Length – weight and view area – weight relation**

Table 3 presents the results of curve fitting to meagre data. The average length of the right and left side of the fish vs weight is also displayed in Figure 6. The experimental view area and weight data, as well as the power fit for both cage and earthen pond reared fish presents in Figure 7.

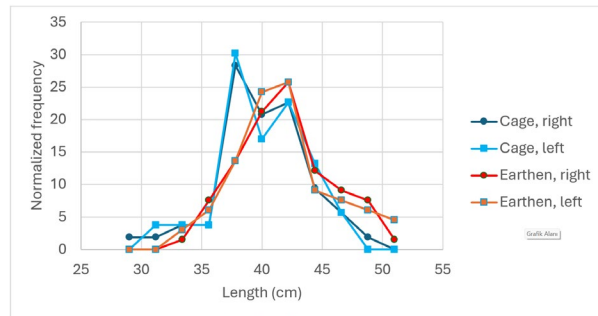
**Table 2.** Mean values of right and left lengths, widths and view areas of cage and earthen pond fish (Mean ±SD, n<sub>cage</sub>=53, n<sub>earthen pond</sub>=66)

		Length (cm)	Width (cm)	View area (cm <sup>2</sup> )
Cage	R	38.94±3.73 <sup>b</sup>	9.48±0.95 <sup>a</sup>	255.28±47.73 <sup>b</sup>
	L	38.87±3.61 <sup>b</sup>	9.50±0.95 <sup>a</sup>	253.96±47.69 <sup>b</sup>
Earthen Pond	R	40.80± 3.82 <sup>a</sup>	9.66±1.53 <sup>a</sup>	277.13± 54.50 <sup>a</sup>
	L	40.68± 3.92 <sup>a</sup>	9.66±1.07 <sup>a</sup>	277.19± 55.00 <sup>a</sup>

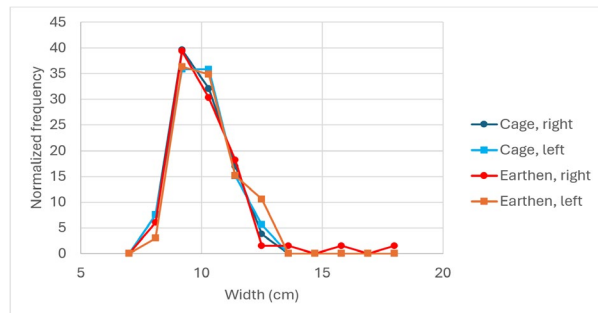
<sup>a,b</sup>Different letters in the same column are statistically significantly different (p<0.05).

**Color**

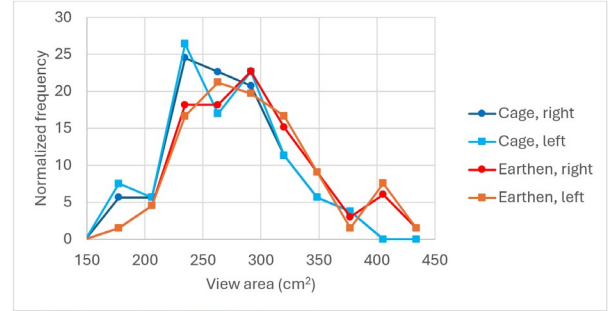
The means and standard deviations of the color parameters L\*, a\* and b\* for the right and left sides of fish reared in cages and earthen ponds are given in Table 4. The distribution of the L\* values, a\* values, and b\* values are given in Figure 8, 9, and 10, respectively. The hues differentiation for the cage and earthen pond fish for the right and left sides is given in Figure 11. In addition, the distribution of the E values represented the differences in the average colors of the two sides of fish is given in Figure 12.



**Figure 3.** Right and left side length distributions of cage and earthen pond fish



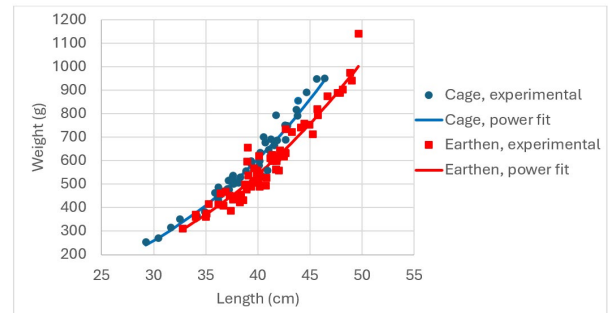
**Figure 4.** Right and left side width distributions of cage and earthen pond fish



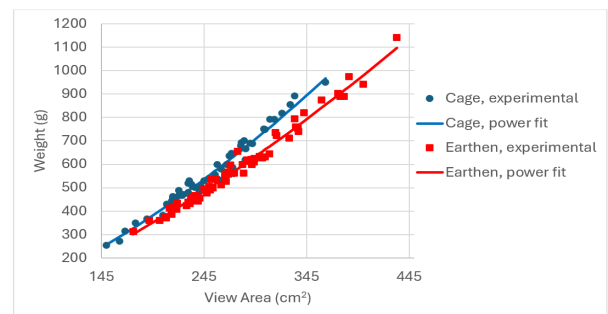
**Figure 5.** Right and left side view area distributions of cage and earthen pond fish

**Table 3.** Correlation of length-weight and view area-weight using power equation for cage and earthen pond fish (n<sub>cage</sub>=53 x 2, n<sub>earthen</sub>=66 x 2)

Power	Length - Weight			View area - Weight		
	A	B	R <sup>2</sup>	A	B	R <sup>2</sup>
Cage	0.011	2.951	0.958	0.144	1.494	0.976
Earthen Pond	0.010	2.930	0.927	0.185	1.431	0.983



**Figure 6.** Experimental and power fit equations to weight vs length data for cage and earthen pond fish



**Figure 7.** Experimental and power fit equations to weight vs view area data for cage and earthen pond fish

**Table 4.** Mean values of right (R) and left (L) side color parameters of cage and earthen pond fish (Mean ±SD, n<sub>cage</sub>=53, n<sub>earthen</sub>=66)

	L*	a*	b*	Hue	Delta E	
Cage	R	35.41± 2.20 <sup>c</sup>	0.845± 0.427 <sup>c</sup>	4.16±0.93 <sup>b</sup>	76.52± 13.92 <sup>a</sup>	1.89±0.99
	L	35.64± 2.63 <sup>c</sup>	0.448± 0.370 <sup>d</sup>	4.13±0.86 <sup>b</sup>	77.57±16.10 <sup>a</sup>	
Earthen Pond	R	40.33± 1.897 <sup>a</sup>	1.572±0.65 <sup>b</sup>	4.982± 0.713 <sup>a</sup>	49,348± 9.82 <sup>c</sup>	1.78±1.02
	L	39.12±1.902 <sup>b</sup>	2.261± 0.85 <sup>a</sup>	4.738± 0.739 <sup>a</sup>	60.79±13.61 <sup>b</sup>	

<sup>a,c</sup>Different letters in the same column are statistically significantly different (p<0.05).

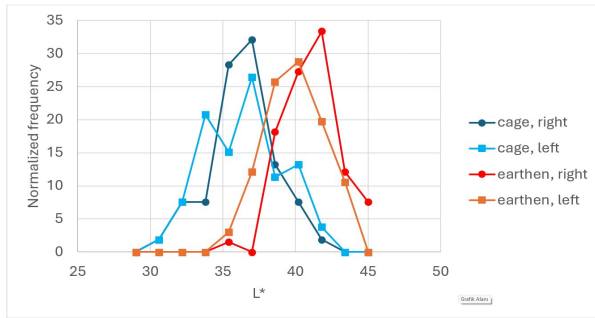


Figure 8. Right and left side L\* histogram of cage and earthen pond fish

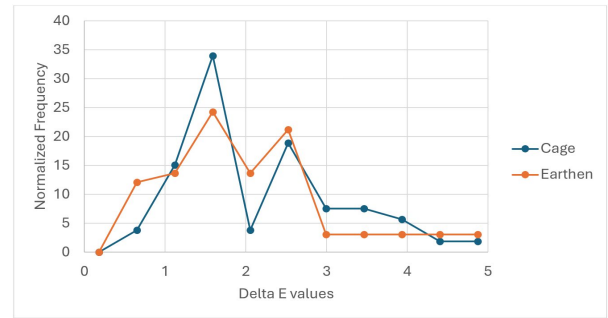


Figure 12. Histogram of Delta E values between right and left sides of cage and earthen pond fish

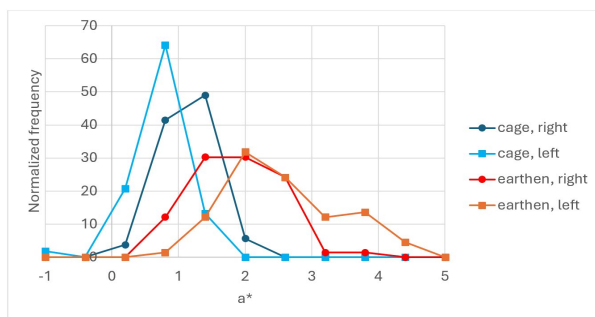


Figure 9. Right and left side a\* histogram of cage and earthen pond fish

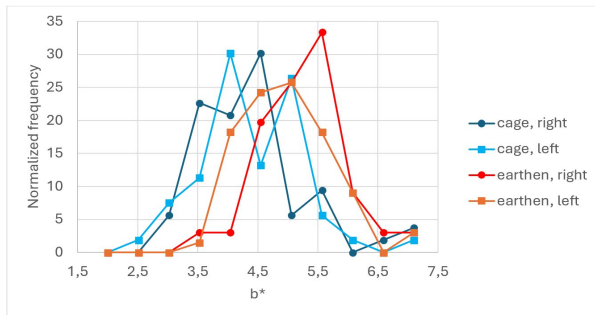


Figure 10. Right and left side b\* histogram of cage and earthen pond fish

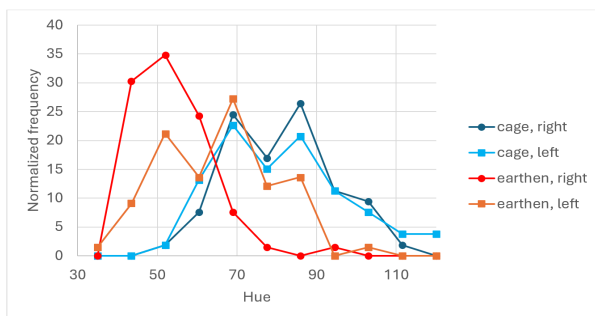


Figure 11. Right and left side hue histogram of cage and earthen pond fish

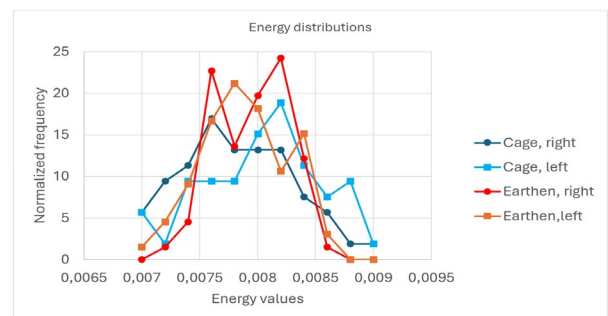


Figure 13. Right and left side distributions of grayscale energy of cage and earthen pond fish

### Image texture

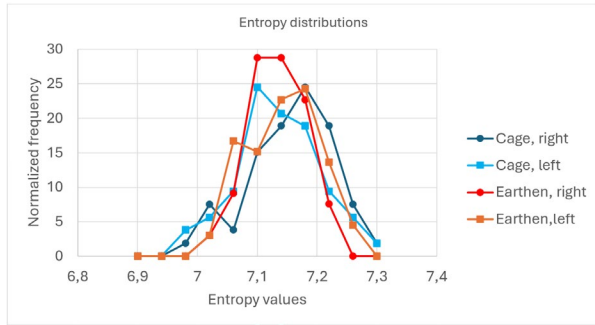
The results of the image texture parameter measurements are presented in Table 5. Right and left side distributions of grayscale energy and entropy of cage and earthen pond fish are shown in Figure 13 and 14. The differences between the TCI and CCI values of the right and left sides of the cage and earthen pond fish are also presented in Figure 15 and 16, and close correlation between TCI and CCI values in Figure 17. Moreover, the correlation of right and left side grayscale energy vs CCI for cage fish is given in Figure 18.

Table 5. Right and left sides texture change index (TCI), color change index (CCI), gray scale energy and entropy values of cage and earthen pond fish (Mean  $\pm$ SD,  $n_{\text{cage}}=53$ ,  $n_{\text{earthen}}=66$ )

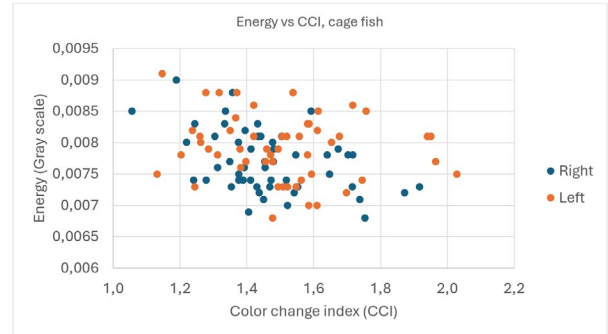
	Texture Change Index (TCI)	Color Change Index (CCI)	Grayscale Energy	Grayscale Entropy
Cage R	4.568 $\pm$ 0.690 <sup>a</sup>	1.465 $\pm$ 0.169 <sup>a</sup>	0.0077 $\pm$ 0.000	7.136 $\pm$ 0.072
Cage L	4.794 $\pm$ 0.764 <sup>a</sup>	1.505 $\pm$ 0.202 <sup>a</sup>	0.0079 $\pm$ 0.001	7.114 $\pm$ 0.073
Earthen R	3.313 $\pm$ 1.062 <sup>c</sup>	1.152 $\pm$ 0.284 <sup>b</sup>	0.0078 $\pm$ 0.000	7.112 $\pm$ 0.048
Earthen L	3.736 $\pm$ 1.140 <sup>b</sup>	1.269 $\pm$ 0.336 <sup>c</sup>	0.0077 $\pm$ 0.000	7.119 $\pm$ 0.060

<sup>a-c</sup>Different letters in the same column are statistically significantly different ( $p < 0.05$ )

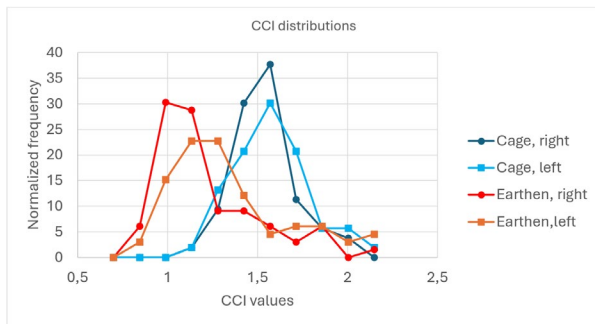
For the cage fish, the correlation between TCI and CCI for the right side is 0.945, for the left side is 0.972. In the case of earthen pond fish, the correlation between TCI and CCI is 0.79 for the right side, and 0.854 for the left side.



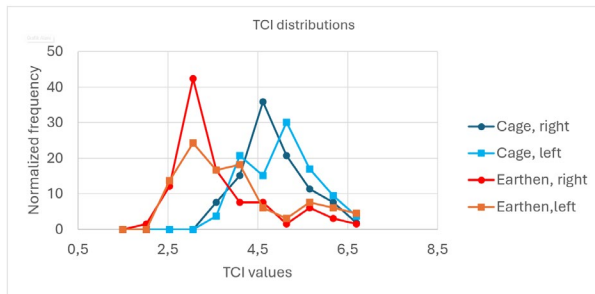
**Figure 14.** Right and left side distributions of grayscale entropy of cage and earthen pond fish



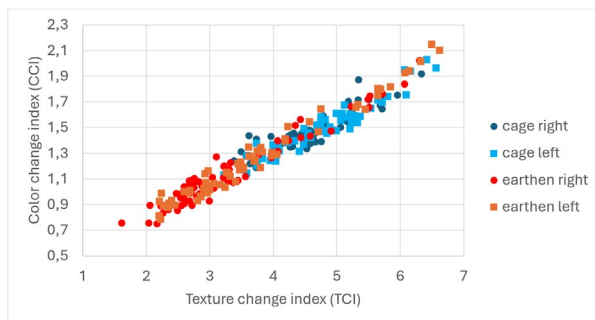
**Figure 18.** Right and left side grayscale energy vs CCI for cage fish



**Figure 15.** Right and left side distributions of color change index (CCI) of cage and earthen pond fish



**Figure 16.** Right and left side distributions of texture change index (TCI) of cage and earthen pond fish



**Figure 17.** Experimental data of right and left side CCI vs TCI of cage and earthen pond fish

## DISCUSSION

### Dimensions of the fish

The mean values for the right and left length of cage-reared fish were not statistically significantly different ( $p > 0.05$ ). Those of the fish reared in earthen pond were also similar (Table 2). This can be explained by the fact that for the same fish the right and left length should be the same. However, the mean lengths of the cage and earthen pond fish were statistically significantly different ( $p < 0.05$ ). This implies that the fish grown in different environments had different sizes. This can be explained by different environmental and rearing conditions in the cage and earthen pond. However, the mean width of fish from different rearing environments were found to be statistically insignificant ( $p > 0.05$ ). One explanation is that the average width is numerically much smaller than the length (about 4 times), and the smaller numbers do not result in statistical differences. The mean view area from the right and left sides of the fish were not statistically significantly different, as expected. However, there was a statistically significant difference between the mean view areas of cage and earthen pond fish ( $p < 0.05$ ).

The frequency distributions of right and left length, width and view area of cage and earthen pond cultured meagre are given in Figures 3, 4, and 5, respectively. The length frequency distributions of fish reared in earthen ponds tend to gather at larger length values compared to those of fish reared in cages. In Figure 4, the differences between right and left side width distribution of the cage and earthen pond fish are smaller, and do not trigger statistical difference. Also in Figure 5, the right and left view area distributions of the meagre raised in cages are clustered towards the lower end of the view area scale.

### Length – weight and view area – weight relation

The length-weight relation (LWR) is used commonly in the evaluation of growth properties of fish (Babori et al., 2010; Bök et al., 2011). The power equation is used to correlate weight to length. In our case, for a given fish the length from the left image and the right image were averaged before using in this analysis. For the cage reared fish, the  $R^2$  value for the LWR correlation is 0.96, and for the earthen pond reared fish  $R^2 = 0.93$  (Table 3). Theoretically, the value of parameter B should be 3, since weight is related with volume, and volume is

dimensionally the cube of length. In this study, the B values were close to 3, but less than 3. This implies a negative allometric growth in both culture environments (Froese, 2006). The experimental and predicted weight vs average length of the right and left side of the fish is displayed in Figure 6, together with the fitted power curves. It can be seen that for this batch of fish, for a given length, the weight of the cage reared fish was higher. This implies that for a given length of fish, the cage reared meagre was thicker, but this was not proven experimentally.

Accurately measuring the length of the fish by image analysis depends on how the fish is presented: if fish is "bent" then accurate length measurement becomes more complicated. In contrast, the view area obtained from image analysis is more robust since it is not affected by bending of the fish. Several studies correlating weight to view area are found in the literature (Gümüş et al., 2022a). Since our data included the view area from the left side and the right side of a given fish, these areas were averaged before using in this analysis. Table 3 shows the results of power curve fitting to the view area-weight data. In this case the theoretical B value should be 1.5, and for both cage and earthen pond reared fish the B value is close to 1.5. The  $R^2$  values are close to 0.98. Figure 7 presents the experimental view area and weight data, as well as the power fit for both cage and earthen pond reared fish. Again, for a given view area, the weight of the fish reared in cages was higher.

### Color

Gümüş et al. (2022a) found statistically significant color differences between fiberglass and concrete tank-reared carp. There may be external causes regarding color difference in different rearing enclosures, such as injury, bruising, wounds, parasites, swimming direction in enclosures, or light levels. If there are biological factors, we are not aware of them in meagre.

According to Table 4, the  $L^*$  values of the cage fish' right and left sides were statistically the same ( $p > 0.05$ ). For the earthen pond fish, not only the  $L^*$  value was significantly higher than that of the cage fish, but the right and left side  $L^*$  values were also different. The difference between the right and the left  $L^*$  cannot be explained. This is visually displayed in Figure 8. In the case of  $a^*$  values, not only the right and the left sides of both type of fish were statistically different, but also the  $a^*$  values between the types of fish were different. Again, the difference between the right and the left side  $a^*$  cannot be explained. Figure 9 presents these data. The average  $b^*$  values behaved similarly to the  $L^*$  values: There was no statistical difference between the  $b^*$  values of the right and left sides of the cage fish. The same was true for the earthen pond fish, but values were significantly different between the types of fish. The distribution of the  $b^*$  values is given in Figure 10. These results bring an important question in the evaluation of the skin color of fish. In the literature, generally only one side of the fish is evaluated for color. The above results suggest

that may be both sides of the fish need to be measured for more accurate color evaluation.

One of the advantages of using Hue as a color parameter is that it represents the color, regardless of its saturation and intensity. Therefore, if the objective is to compare color, hue allows for only one parameter to be used. The average hue values are given in Table 4. It can be seen that the average hue of the cage fish is different than that of the earthen pond fish, but the hues of right and left sides of the cage fish are not different. This is not the case for the earthen pond fish; the hues are different for the right and left sides (Figure 11).

The  $\Delta E$  values were used to quantify the perceptible color difference between the right and left sides of fish. In Table 4, the  $\Delta E$  values represent the differences in the average colors ( $L^*$ ,  $a^*$ ,  $b^*$ ) of the two sides of fish. An  $\Delta E$  value less than 1 is considered to be an imperceptible color difference to the human eye.  $\Delta E$  greater than 3 signifies a noticeable color difference. By these criteria, the average  $\Delta E$  for both cage and earthen pond fish is less than 2, implying noticeable difference upon close examination. However, when the distribution of the  $\Delta E$  values in Figure 12 is examined, it is found that 13 and 10 cage fish and earthen pond fish, respectively, have  $\Delta E$  values at or above 3. This implies that there are easily perceptible color differences between the sides of some fish. Again, this raises the question of measuring the color of both sides of the fish for better accuracy.

### Image texture

The results of the image texture parameter measurements are presented in Table 5. It can be seen that the grayscale energy values are very small, and it is difficult to use this range for good discriminatory resolution. This can be observed in Figure 13. Similar findings were reported by Gümüş et al. (2022b) for the skin color of Red Sea goatfish (*Parupeneus forsskali*). The same can be said for grayscale entropy: there is not enough range to provide good resolution (Figure 14).

The threshold value of the CCI was set to 15 based on previous experience, and that of TCI was set to 5. In Table 5 there was no significant difference between the TCI and CCI values of the right and left sides of the cage fish. However, those of the earthen pond fish were different. They were also different from those of the cage fish. This can be observed in Figure 15 for CCI, and in Figure 16 for TCI distributions. Gümüş et al. (2022b) suggested that for the goatfish the image texture parameter that best represented sensory results was TCI.

In Figure 17, it can be seen that there is a close correlation between TCI and CCI values in this study. This is to be expected since the calculation methods are related. The values of both TCI and CCI also depend on the thresholds selected. There is not much research to develop a method to select the threshold values that best represent sensory results.

Finally, there was an effort to correlate energy and entropy values (grayscale) to TCI and CCI values (color). No

correlation could be found. Figure 18 shows the plot of energy vs CCI for cage fish. If there is a correlation it is very weak: the  $R^2$  for the linear fit is 0.19. Similar plots of energy and entropy vs CCI and TCI for both fish will not be shown, since they look similar. The  $R^2$  values for linear fits to cage fish right side entropy vs CCI, cage fish left side energy vs CCI, cage fish left side entropy vs CCI, earthen fish right side energy vs CCI, earthen fish right side entropy vs CCI, earthen fish left side energy vs CCI, earthen fish left side entropy vs CCI are 0.24, 0.025, 0.039, 0.049, 0.075, 0.0, and 0.018, respectively.

## CONCLUSION

This is the first study comparing bilateral color and texture differences in meagre using image analysis. In addition, comparison of these parameters in cage and pond-reared fish is presented for the first time. This study demonstrates that bilateral image-based evaluation of intact fish can reveal subtle but meaningful color and texture differences.

The length-weight relationship presented in this study is similar to the results given in the literature. The B values of the power fit of the meagre reared in both culture environments were close to 3 and these results are similar to the literature values. Weight estimation using length-weight and view area-weight relationships resulted in high  $R^2$  values. In this study, the average colors of fish grown in two different culture conditions differed significantly. Also, results suggest to consider measuring both sides of fish for more accurate color evaluation in future studies.

Computer image analysis is a powerful method to extract morphometric data, shape and color information from fish images and quantifies many parameters that can later be related to sensory analysis. Therefore, the image analysis method appears to be an effective method in estimating the weight of the meagre and determining the color and sensory data. Future consumer preference studies of the skin color of meagre can provide insight into which type of aquaculture environment should be used more effectively, and if right and

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left side color difference is significant for consumers.

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## AUTHORSHIP CONTRIBUTIONS

Canan Ünlü: Investigation, Resources, Formal analysis; Erkan Gümüş: Conceptualization, Methodology, Validation, Data curation, Visualization, Supervision Writing – original draft; Bahar Gümüş: Resources, Formal analysis, Data curation, Investigation, Writing – original draft; Murat Ömer Balaban: Conceptualization, Data curation, Methodology, Software, Visualization, Writing – review and editing

## CONFLICT OF INTEREST

LensEye software was developed by one author. The rest of 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.

## ETHICS APPROVAL

Ethics approval was not required for this research work.

## DECLARATION OF AI USE

We have not used AI-assisted technologies in creating this article.

## DATA AVAILABILITY

The authors declare that the data supporting the findings of this study will be made available upon request.

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