Evaluation of Kohaku Koi (*Cyprinus rubrofuscus*) Using Image Analysis

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Abstract

Quality evaluation of koi (*Cyprinus rubrofuscus*) is essential to koi industry. However, the community has a lack of knowledge about the quality evaluation of koi and about features of koi which are valuable. During the koi exhibitions like "*All Japan Nishikigoi Show*", quality evaluation of koi is conducting by authoritative experts. And the information about the evaluation methods used is not known to the community. While koi quality rate is the cornerstone for this ornamental fish.

In this study, photographs of participants in the koi exhibitions were used for analysis to discover features that affect the quality of koi varieties of Kohaku. The HSVA color model was used to define and extract from image red and pale red coverage rates in Kohaku body coloration. Body aspect ratio, body proportion values, red coverage ratio, and pale red coverage ratio were extracted using Python programming language tools and analyzed using the R statistical software.

Results of analysis of extracted data show that significant impact on Kohaku quality have: the body aspect ratio ($p < 0.001$) and the pale red coverage rate ($p < 0.001$).

For the body aspect ratio, there was a -0.236 (± 0.105) decrease of the quality rate for each extra unit of aspect ratio. For each extra percent of pale red coverage rate, the quality rate decreases by -0.037 (± 0.004). According to these results pale red coverage rate is more important feature than body aspect ratio.

In the process of the present research, we encountered such problems as inappropriate koi body posture on the photo and poor image quality. An inappropriate koi body posture is

one in which the koi's body is bent and/or carp has fins in an asymmetrical position. The possible reasons of poor image quality are poor lighting, water reflection, indirect camera position, low photo resolution or fuzzy image. We solved these problems with selecting images with appropriate image quality and koi posturer. Also, a serious problem was that the position of the fins varies from image to image, making it impossible to compare them. This problem was solved by cropping the images.

All these problems make analysis difficult, leading to the need for quality control of materials. The number of materials is limited, which leads to the need for self-collection of materials. In addition, the type of material itself, namely photographs, is a limiting factor, as photographs provide a limited representation of a koi's body structure in three-dimensional space. This leads to limitations of the methods that can be used for analysis. Thus, this prompted us to develop a method of collecting materials that would allow us to gain a more complete information of the koi body and, in turn, evaluate its quality.

The advantages and disadvantages of the materials and methods used in the study were discovered and analyzed. Based on which new ways of collecting data were invented for the further development of this topic. The most promising method for collecting materials, in our opinion, is the use of a neural network to automate the interpolation of the shape of a 3D koi template model and texturing.

The present study and its results are an important foundation for the further research into the quality of koi and for the development of the koi industry in general.

1. Introduction

1.1. Wild Carp

The wild carp is one of a big fish of the family *Cyprinidae* found in freshwater. It has a very long lifespan and exceeds 100-200 years in domestication. Carps are now widely distributed around the world (Ishikawa & Takayama, 1977; Tomoda, 1973). There is a hypothesis that first carps appeared in the Danube River, Europe about 8,000 – 10,000 years ago (Balon, 1995b).

The wild common carp *Cyprinus carpio* got its name from Greek – *kyprinos* or *kyprianos* – the name used by Aristotle (384 – 322 B.C., Greece). This name was probably taken from Cytherea – the other name of Aphrodite, goddess of love (Balon, 1995b). Wild carp has at least four subspecies (Kirpichnikov, 1967):

- The European and Transcaucasian;
- The Middle East;
- The East Asian;
- The South Chinese and Vietnamese.

The true wild form of common carp has powerful, elongated, torpedo-like body with dark to yellow-brown scales. In 1676 an English writer Izaak Walton wrote in his book "The Compleat Angler Or the Contemplative Man's Recreation": "The Carp is the Queen of Rivers, a stately, a good, and a very subtil fish, that was not at first bred, nor hath been long in England, but is now naturalized…" (Balon, 1995b; Walton, 1897).

1.2. Carp Domestication

Wild carps - beautiful, golden creatures, became changed under domestication. Regular geometry of scales changed often to severe irregularities, reductions of the scale or complete nakedness (Balon, 1995b).

In Europe carp domestication process with fishing and sales regulation possibly started in Roman Empire and continued in monastery ponds after Christianity establishment (ANDREŠKA, 1984). Building a fishponds was the great step for creating a brand new and unique aquatic habitat. Active construction of ponds started in the eleventh century and increased during twelfth and thirteenth. Medieval fish culturists introduced new species that was easy to colonize in very type of freshwater habitats. Started from area of Danube River carp farms spread throughout Europe. Carp-centered folklore, the holiday customs appeared with domestic forms of the fish (Hoffman, 1995).

To successfully distinguish wild and domesticated carps in archeological findings the size of the gape of the mouth was used. It was considered that enlargement of the mouth gape in domesticated fishes and other animals can be related to the change in feeding habits (Rudziński, 1961). Supplementary food was added to ponds, human-made food made carps grew better and followed by changes in body proportions, enlargerment of mouth and elongation of intestine (Sibbing, 1988). Decreasing of mobility, strength and swim speed in domesticated carps compared to wild individuals is explained by absence of necessity to overcome river currents and food abundance (Balon, 1995b).

Despite the long story of carp domestication, in Europe carps mostly were used for food, not for decoration of the living area. A breeding of ornamental carp for recreation and pleasure has started in Japan.

1.3. Domestication in Japan

Nishikigoi hereinafter referred to as koi (*Cyprinus rubrofuscus* Lacépède, 1803) is a world-famous ornamental variety of domesticated carp (Daniel et al., 2022; Kottelat & Freyhof, 2007).

Journey of domestication of carps in Japan has started in the beginning of nineteen century in Niigata Prefecture. With time and challenging work of farmers, first color koi varieties started to be cultured for future breeding. It is considered that the birthplace of nishikigoi is Yamakoshi Village, Niigata Prefecture, about 280 km west of Tokyo, close to the Sea of Japan. The first color aberrant was most likely red (*higoi*) (Amano, 1970).

In Yamakoshi village 87% of the 906 families were ornamental carp's producers (Amano, 1970). Since Niigata has been a rice agricultural area, paddy field aquaculture of nishikigoi has developed historically (Ikuta & Yamaguchi, 2005).

Common carps were traditionally reared for food in small terrace ponds. There is a theory, that the high incidents of color aberrant here might be related to melatonin production in the prolonged lifetime spent with lack of sunlight because of huge amount of snow (Balon, 1995b). Boredom during long winters and quest for the beauty made farmers began to select and crossbreed common carps (Kuroki, 1990). To our days descendants of first breeders families keep producing ornamental fishes in Niigata Prefecture after many generations of selective breeding (Balon, 1995b).

Around 1904, the domesticated mirror carp was imported from Germany and included in the breeding. New variety was added to the scaled and colored *hara-aka* (red), by combining scale patterns with the color variations in the *doitsu nishikigoi* (German carp). Long before, in the middle of nineteen century - about 1830, koi farmers produced and presented carps that had red lips *kuchibeni koi* (red mouth koi). And after, in the early 1920s wild common carp with golden scales (shiny yellow brown) were crossed with koi to produce the golden species (*ogon*) (Tamadachi, 1994).

Koi began their journey to world fame after the first exhibition in Tokyo in 1914, where farmers from Yamakoshi village, introduced their best koi in the garden of the Imperial Palace (Fletcher, 1999).

Fantastic color patterns and later, scale formations, to be viewed far from the ground, are selected for a people's pleasure, were combined with as little distortion as possible to the torpedo-shaped body (Balon, 1995b). The main feature of koi is striking coloration patterns (Balon, 1995a). Scale colors and color distribution patterns can vary greatly between koi varieties, and the patterns are almost unique and almost impossible to repeat between two individuals. The average lifespan of koi is 50 years (Lee, 2013). Due to the nature of breeding, the number of varieties of koi is difficult to determine because the sources inform about different number of varieties (Pietsch & Hirsch, 2015; Tetra Press Staff., 1996).

Currently ZNA (Zen Nippon Airinkai; worldwide koi organization) defines 16 basic varieties of koi (Zen Nippon Airinkai, n.d.). The basic varieties of koi can be seen in Table 1. Favorites are the *Kohaku* – the red and white koi, the *showa sanshoku* – a fish with a black body and white and red imposed and *taisho sanshoku* – with red and black splashes on white colored body's scale (Balon, 1995b).

Table 1. Classification of nishikigoi according to color pattern (All Japan Nishikigoi Promotion Association, 2008; Balon, 1995b; Tetra Press Staff., 1996).

Variety	**Color pattern**
Kohaku	White koi with different red patterns superimposed.
Taisho Sanshoku	White koi with red and black splashes.
Showa Sanshoku	A black nishikigoi with white and red imposed.
Bekko	On the basic color of white, yellow, orange or red small black blotches are dispersed.
Utsurimono	A black koi with yellow, red or white blotches.
Asagi	Pale blue nishikigoi with scales edged in white. Red ventrum preferred.
Shusui	Blue with some red and yellow on the head and ventrum and with minor scalation.

Koromo	Variety with silver or blue cast over red and white areas or white with red markings under darker pattern.
Kawarimono	Black body with white fin edges, blue bodied fish with white scale edges and red fin bases, single non-metallic color and any other unusual color variety.
Tancho	Nishikigoi with the red limited to a circular marking on the forehead.
Hikari-mujimono	Single colored metallic nishikigoi.
Hikari-moyomono	Metallic white koi with red, black or yellow superimposed.
Hikari-utsurimono	Metallic black nishikigoi with white, red or yellow blotches.
Goshiki	Five-colors koi, the four of them may be white, red, sumi black, indigo blue and the last color is controversial.
Kinginrin 1	Koi that has an arrangement of golden or silver scales on its back.
Kinginrin 2	Includes Kinginrin except the Gosanke and the Utsurimono families.

As of 2018, there are 536 Nishikigoi farms in Japan (Figure 1). These farms are located in many areas of Japan; 61.7% of the farms are found in Niigata Prefecture, followed by Hiroshima (4.5%), Gifu (3.4%) and Fukuoka (3.2%) Prefectures (MAFF, 2022).

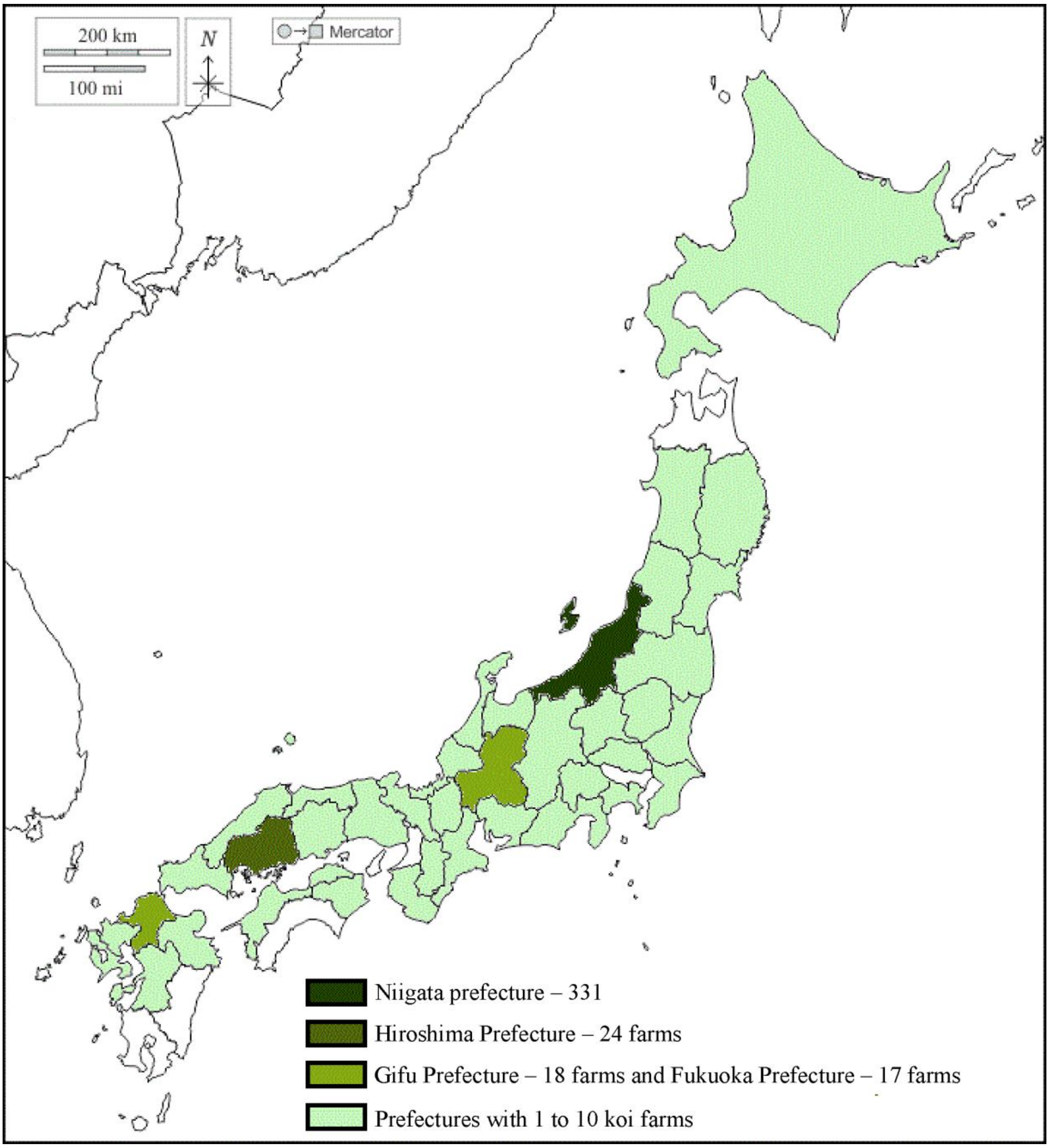

Figure 1. Number of nishikigoi (koi) farms in Japan. The 95th Statistical Yearbook of Ministry of Agriculture, Forestry and Fisheries, Japan, 2022 (MAFF, 2022).

1.4. All Japan Nishikigoi Show

The popularity of the koi eventually spread throughout the world. Now there are koi clubs and associations in Japan and many other countries (Koi Mud Pond, n.d.). Koi exhibitions are held, such as the "All Japan Nishikigoi Show", organized by All Japan Nishikigoi Promotion Association, where koi experts evaluate the carps, choosing the best ones in each performed variety (All Japan Nishikigoi Promotion Association, 2008; de Kock & Gomelsky, 2015).

Winners of that shows become very valuable in price and connoisseurs are willing to pay hundreds of thousands of dollars for such individuals (Pond Informer, 2021). Despite the popularity and distribution of koi around the world, the koi evaluation criteria remain little formalized.

Known criteria contain body conformation, symmetrical and plumper one is preferred, purity of color, its brightness, durability, and pleasing distribution. Highly valued characteristics can increase the value of a koi. Swimming style is also important (Pietsch & Hirsch, 2015). Judges use a 100-point system, where body shape and color are evaluated up to 50% and 20% respectively. Also, color pattern, koi's gracefulness, and dignity award up to 10% each (de Kock & Watt, 2006; Hoshino & Fujita, 2009). However, the exact method of koi scoring is unknown for community.

This lack of knowledge indicates that research of koi evaluation process can help koi breeders with selecting and crossbreeding to produce high quality koi.

Formalization of methods for koi evaluation could provide interesting and useful information for koi enthusiasts and can lead to koi popularization and industry growing accordantly.

1.5. Kohaku Variety of Koi

Between 1818 and 1843 the first white colored carp with red markings - Kohaku was crossbred in Japan (Amano, 1968; Kuroki, 1990). Nowadays Kohaku is one of the most popular varieties of koi in the world (Tamadachi, 1994). Kohaku carps have a white body with red markings all over the body. Now it is one of the bestselling koi on market.

1.6. Image Analysis

With the technology developing, computer science is integrated in almost every aspect of our lives. Applications that analyze images and the amount of data which can be collected from it are growing rapidly. Active work with the images as main data provider have been under development in the last few years. Counting fish number in the pool, fish age definition or fish classification can be made with images analysis (Kartika & Herumurti, 2016; Politikos et al., 2022; Toh et al., 2009). Work with photographs requires a good preparation, starting with images collection and selection, its optimization and data processing (Kartika & Herumurti, 2016). By using image analysis to process photos containing useful data, complex problems can be solved. Kohaku coloration is an important factor influencing fish quality and to use image analysis is the appropriate way to obtain results that could explain which feature how affect the Kohaku quality. To make it real modern programming languages such as Python have been used to extract information and to produce statistical study. It was decided that using this methods and tools we can provide data for this research.

1.7. The Aim of the Research

The present research aims to analysis certain features of the Kohaku koi which can be performed based on photos collected during koi exhibitions and may be useful in evaluating the quality of the Kohaku koi. Features of Kohaku were analyzed to find statistically significant ones and discover how their possible states affect the Kohaku quality.

2. Materials and Methods

2.1. Materials

In the present research photos of koi of Kohaku variety collected over the years of the koi exhibitions were used as data for analysis. The photos were obtained from the archives of the publisher of the koi magazine (Gekkannishikigoi) (Kinsai Publishing Co., LTD.). The archives of photos were collected years of exhibitions by magazine staff over the period 2002-2020. Typical infrastructure of koi exhibitions can be seen in Figure 2 and Figure 3.

Figure 2. The 61st Nagaoka Koi Show at Yamakoshi Branch Office, Nagaoka, Niigata Prefecture, Japan on 26 October 2014.

During the competition, all carps are kept individually or several from the same manufacturer in the similar round blue nylon tanks. This allows to ensure the safety and representativeness of each individual. In addition, identical tanks and their identical blue color ensure identical environmental conditions. This has a positive effect on the quality of judging, because different environments can give different reflections, lighting and affect the perception of the judges. This ensures equal and fair conditions for the competition.

Figure 3. The koi keeping in the blue nylon pool during exhibition.

The photos were taken by professional photographers with professional camera from the same angle, same lighting and same background. The koi shown in the photos were predominantly in a straight body position. In this way, the photographs display the koi in the same way, which allows to analyze of the photographs to extract valuable information about the quality of the koi. An example of such a case can be seen in Figure 4.

Figure 4. The example of photo of Kohaku koi used in the present study.

The present study was conducted without any physical interaction with koi. Only photos of participants of exhibition received from archives were used. Self-collection of data for analysis in the form of photographs presented a problem since it would take more time than the entire period of the study. Therefore, it was decided to analyze the already available archival data and meta-information of individuals in photographs in order to extract useful data.

With each photo, information about the place that Kohaku has occupied in the competition was used as an additional meta-information. Having information about what place the individual took in the competition allows to get a rough understanding of what is the approximate quality of this individual. So, if an individual took first place, it can be assumed that this individual is a high-quality individual. Conversely, if an individual took a low position in the ranking, this suggests that the individual has bad qualities that do not allow it to be considered high-quality koi.

As a rule, koi are evaluated in competition according to a point system. However, the information we used did not include the competition scores of each individual koi. Instead, all koi specimens were grouped into four quality groups. First, second, third and fourth quality groups (Figure 5). Accordingly, the first group is the group that includes the highest quality specimens that are the winners of the exhibition. All other groups contain instances of koi that have disadvantages compared to koi from the first group.

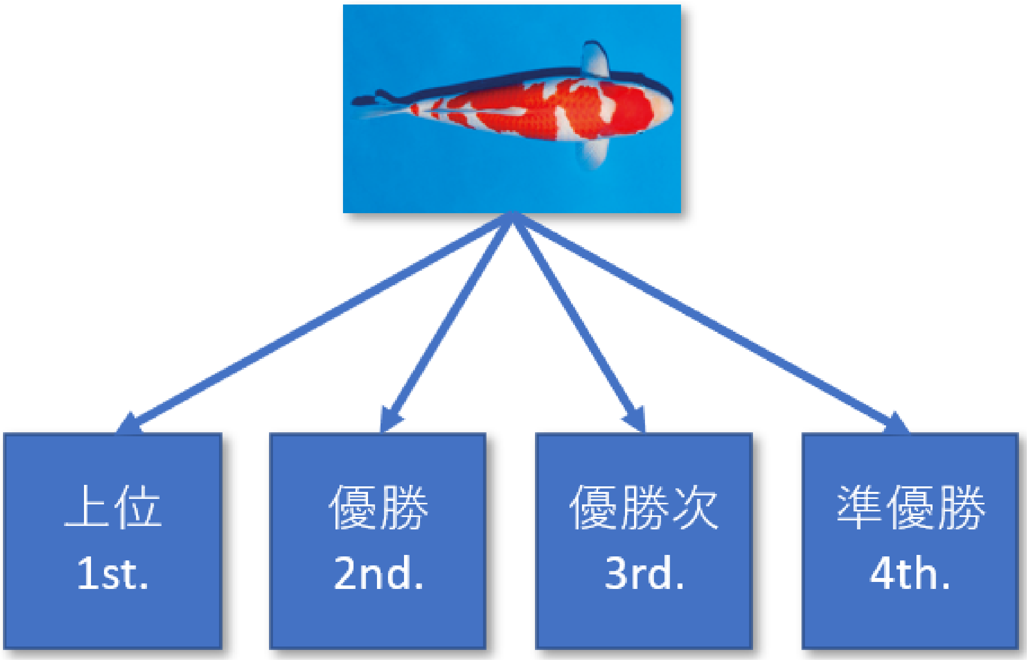

Figure 5. The koi classification principles.

The numbers of photographs used in this study, grouped into four quality groups, are presented in the following table (Table 2).

Table 2. Numbers of photos in each Kohaku quality groups.

Quality Group	**Number of Photos**
The 1st. quality group (上位)	73
The 2nd. quality group (優勝)	55
The 3rd. quality group (優勝次)	140
The 4th. quality group (準優勝)	113

Because the total number of photos is not numerous, the photos were divided into two groups: *winners* and *losers*. The Kohaku that have occupied first place in the competition were included in the *winners* group. The Kohaku that have occupied places other than the first were included in the *losers* group. As a result, in the *winners* group were included 73 photos, and in the *losers* group were included 308 photos (Table 3).

Table 3. Table of the number of photographs in the experimental groups.

Group	**Number of Photos**
Winners	73
Losers	308

All photos have the Portable Network Graphic (PNG) format. The PNG format could represent pixels in RGBA color model which has addition alpha channel to represent transparency (*PNG (Portable Network Graphics) Specification Version 1.0*, 1997). An additional alpha channel allows to remove the background from the image and exclude transparent pixels from color analysis. Thus, this format allows to reduce the noisiness of photographs by preliminary preparation and improve the accuracy of statistical analysis.

2.2. Materials Preparation

2.2.1. Photos Selection

Certain photos of Kohaku in the *losers* group were found to be not suitable for analysis. Two reasons were used for declaring the photo inappropriate: non-straight posture of the body and poor image quality. The reasons for poor image quality are water glare, insufficient lighting, excessive exposure, a very dark shadow on the carp's body, low photo resolution and the wrong camera angle at the time of shooting.

Unfortunately, water flares that occur in the wrong lighting at the time of shooting can blur the image and hide details in the analysis. This creates a big problem and is difficult to fix, for this reason, photos in which the image of Kohaku was spoiled by glare were removed from the sample for analysis. An example of such a photograph is shown in the following Figure 6.

Figure 6. Water reflections spoil the image of koi.

Poor lighting, caused by poor ambient light or underexposure when shooting, sometimes also results in image distortion. Such photographs are not suitable for analysis and data extraction from the image, as the image is of insufficient quality and differs from other images. In addition, excessive darkening leads to a loss of color reproduction, which is critically important in the course of this study. Photos containing such a defect were excluded from the sample. An example of such a defect can be seen in the following Figure 7.

Figure 7. An example of bad quality lighting.

In some cases, for the losers, koi photographers were not patient enough to wait until the koi's body was straightened. Thus, in the collection there were several photographs with a non-straight position of Kohaku's body. Such photographs were also removed from collection for analysis. An example of such a photograph can be seen in the following Figure 8.

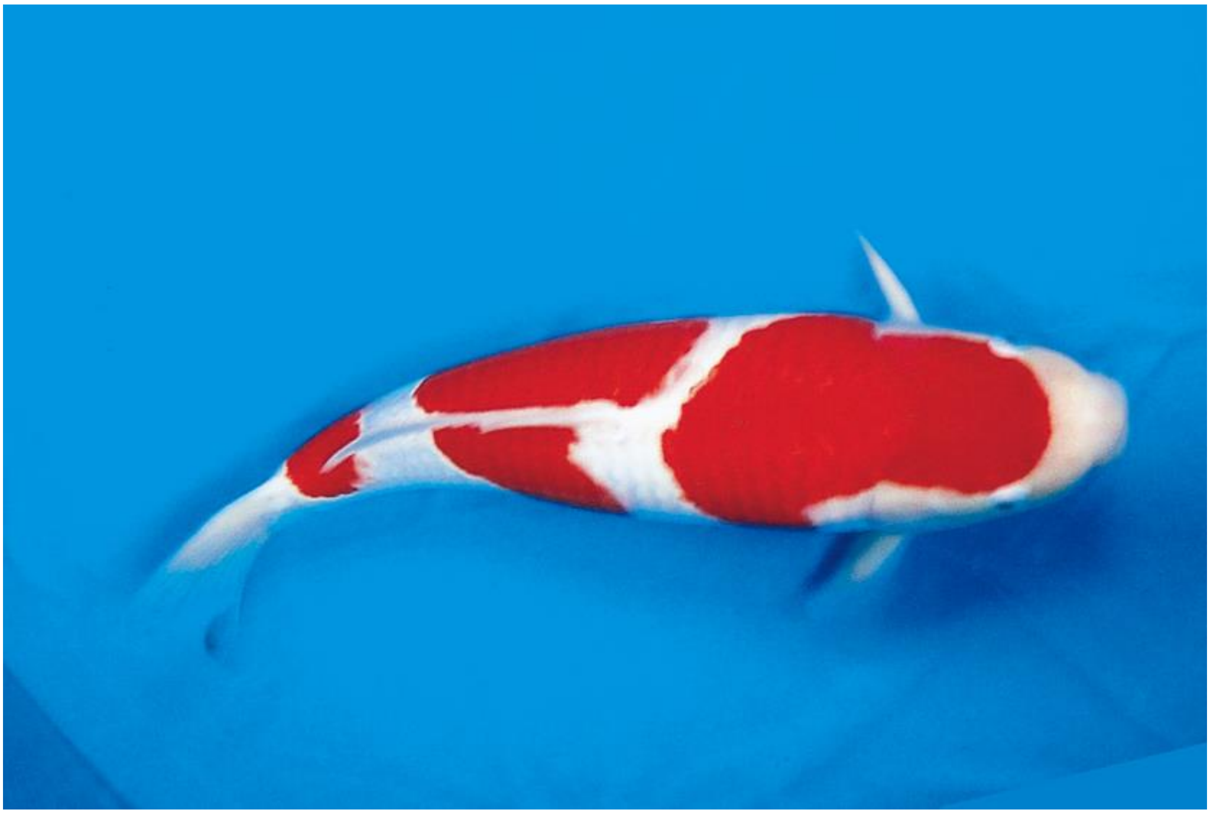

Figure 8. Curved position of the Kohaku koi.

Some Kohaku specimens have been photographed under poor lighting conditions. Thus, a significant shadow formed on their bodies, which negatively affects color reproduction and can ruin the experiment. Thus, those few photos that turned out to be corrupted in this way were removed from the data set. An example of the problem can be seen in the following Figure 9.

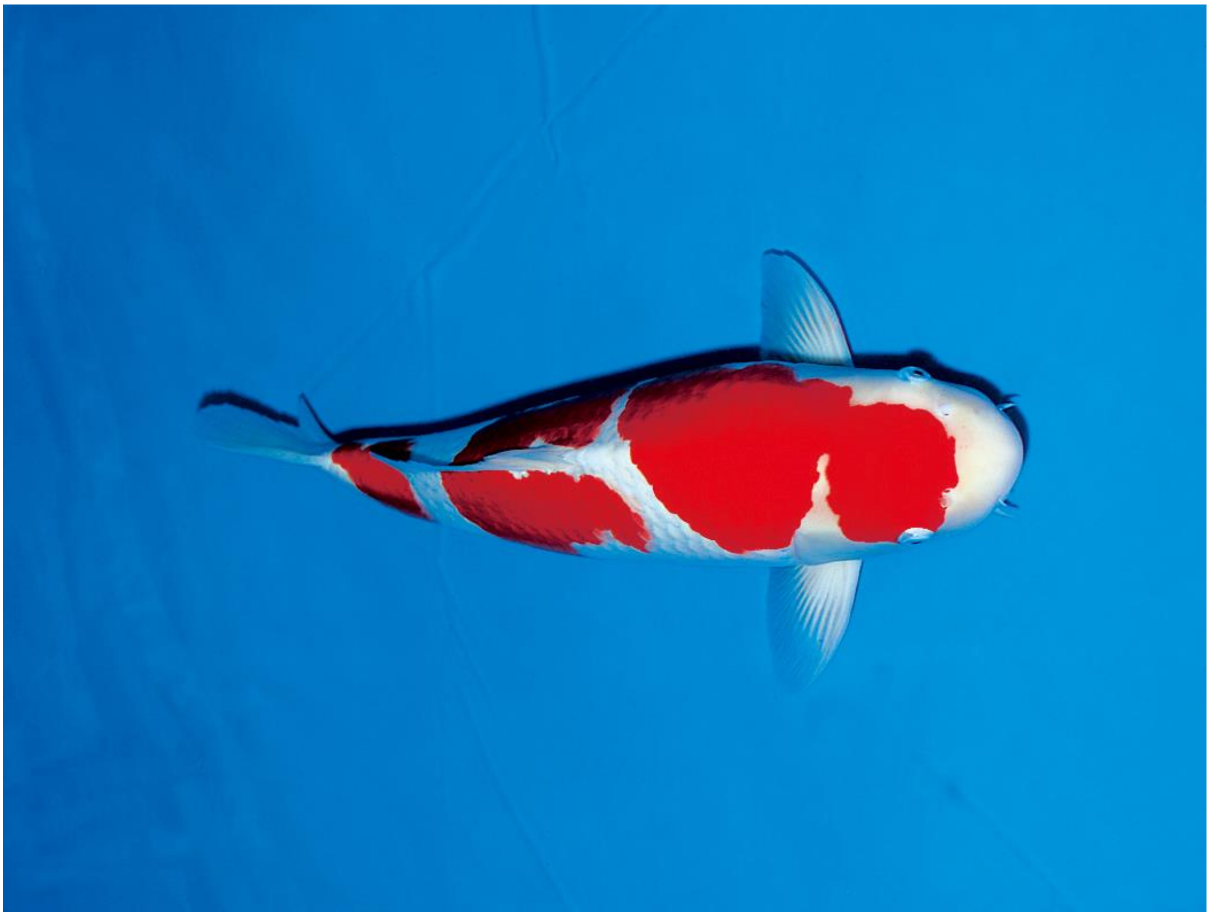

Figure 9. A significant shadow on the Kohaku body.

Some of the photos turned out to be low-resolution or fuzzy photos. This negatively affects the accuracy of the image of Kohaku's real body. Such photographs are unsuitable for analysis and were removed from the sample. An example of such an image can be seen in the following Figure 10.

Figure 10. An example of the fuzzy photo of the Kohaku.

The reasons why such damaged photographs ended up in the collection are unknown. Nevertheless, there were several such photographs and they differed significantly in image clarity from all the others. Therefore, identifying such photographs and removing them from the collection was not a problem.

It was found that some of the images were taken from the wrong angle. Thus, the camera was located not strictly vertically, but at a certain angle towards the direction of the carp's head. Thus, it has been found that such photographs create perspective distortion and therefore distortion in some dimensions of Kohaku's size and color characteristics. This problem turned out to be the most significant of all the negative factors that We encountered. However, much effort has been put into identifying such images visually and removing them from the collection. An example of the most significant indirect camera position at the time of shooting can be seen in the following Figure 11.

Figure 11. An example of significant indirect camera position at the time of shooting of Kohaku koi.

In addition, some other photographic issues have been found, such as photographs of the Kohaku with cutted off body parts and photographs that are distorted by noise. Such photographs have also been removed from the collection. An example of two such problems can be seen in the following Figure 12 and Figure 13.

Figure 12. Cropping parts of Kohaku's body along the borders of the photo.

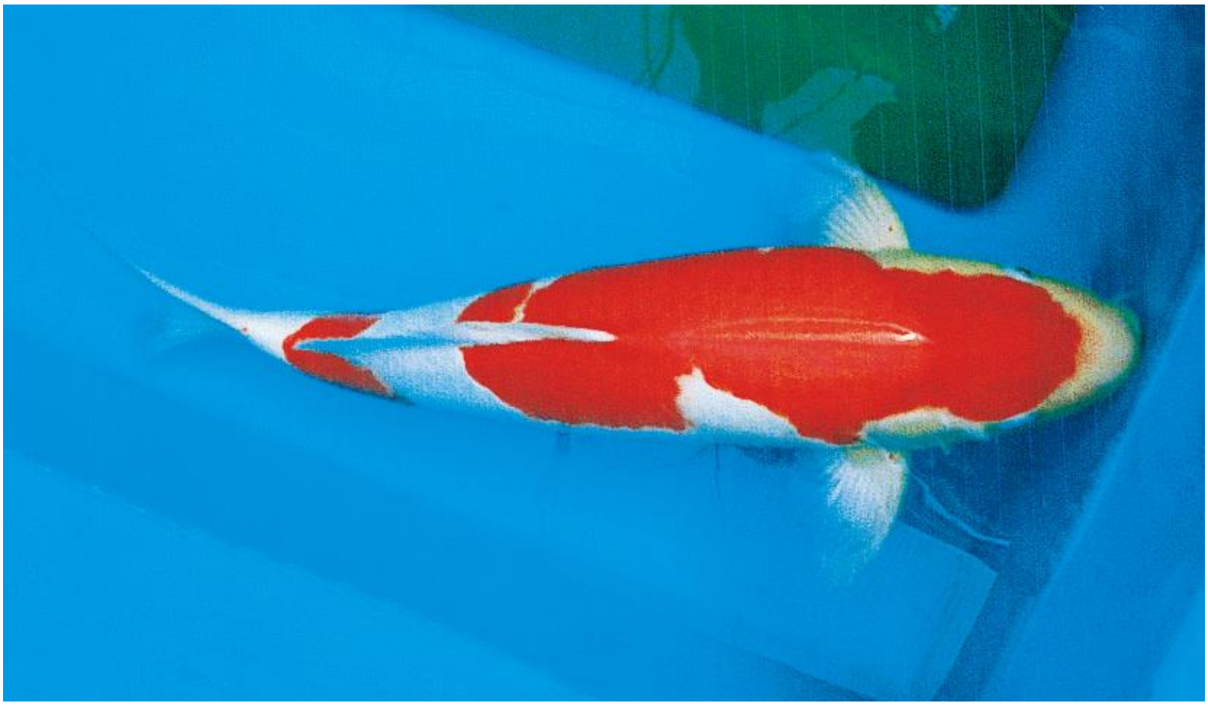

Figure 13. An example of a noisy Kohaku koi image.

All these shortcomings can lead to a negative effect on the quality of experiments and on the results. Therefore, in order to eliminate the negative effect, it was necessary to identify all unsuitable photographs and remove them from the collection. Determining inappropriate photos is a rather complicated process. Determining such defects in software and mathematics is a task for a separate study. For these reasons, there was no other choice but to use human visual analysis of images to determine which images were inappropriate and which were suitable for use in this study. Thus, we carefully analyzed each image for defects and selected only those photos that are suitable in quality. After operation of selecting suitable photos, the number of remaining photos is presented in the following Table 4.

Table 4. Table of the number of photographs in the experimental groups after filtering from unsuitable photos.

Group	Number of Photos
Winners	73
Losers	145

2.2.2. Photos Cropping

For a competent analysis of the features of the structure and color of the body, it is especially important to use photographs in which koi are depicted in a static straight body pose. This is important, because in this case all carps have the same symmetrical appearance in all photographs, conveying the maximum amount of useful information, and in addition, it is possible to carry out the correct measurement of body sizes and their comparison. At the stage of photo selection, all photos in which the tail of the koi was bent were removed, so we received as a result photos in which all koi have a straight body posture.

But unfortunately, another drawback that greatly affects the correctness of measurements when analyzing the size of the koi's body, its shape and color was discovered. Such a disadvantage is the incorrect posture of the fins of the Kohaku. Since koi are agile fish, whose fins are constantly in motion, it is very difficult to get a good shot in which the body is straightened, and the fins are open at the same time. Thus, this leads to the fact that in the photographs often the fins have a different level of opening and inclination. This makes it impossible to accurately measure the size of the fins and analyze their color. This is because for a reliable measurement of alignment with each other, the fins must be in the same position – spread open and must have the same angles of inclination.

In the present study, the ideal posture is defined as the posture when the koi's body and tail fin in the picture are in a straight position, and the pectoral fins are spread and symmetrical and in the same position and angle. Counting photographs of koi with perfect posture showed that there are no more than a few dozen in each group, which is critically small for statistical analysis. Therefore, the decision was made not to include fins in the analysis for this study.

An example of non-symmetrical opening of the pectoral fins can be seen in Figure 14. This figure shows two fins: left and right, belonging to the same individual and cut from the same image.

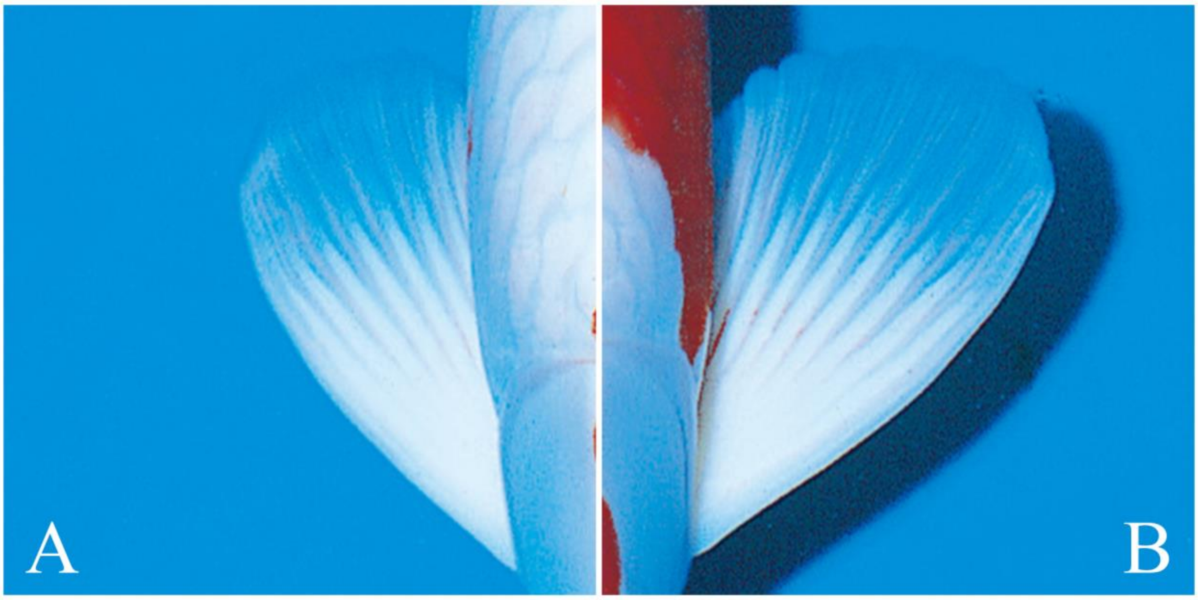

Figure 14. An example of non-symmetrical pectoral fins of the one individual:

right fin (A) and left fin (B).

An example of different levels of fin opening in different individuals can be seen in the following Figure 15.

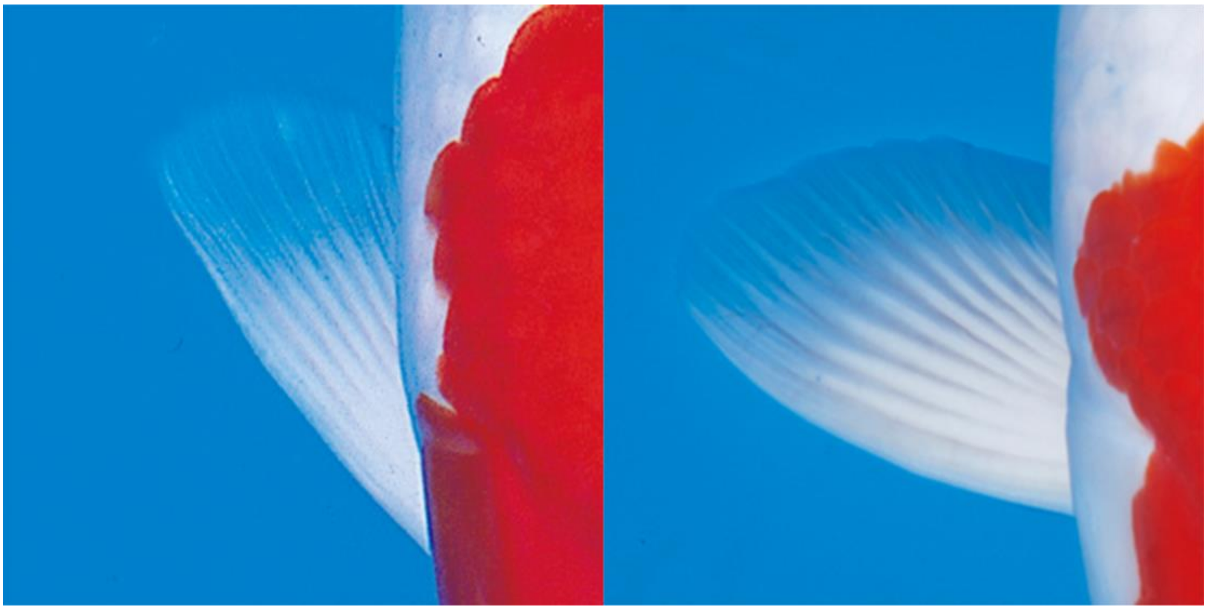

Figure 15. An example of distinct levels of pectoral fins opening in different individuals.

Sometimes there is also a difference not in the opening of the pectoral fins, but in their turn from a horizontal to a vertical position. An example of such differences of pectoral fins rotation can be seen in the following Figure 16. In this figure, it can be noted that the fin of the arrangements on the right is turned down compared to the fin on the left, despite the fact that they are both open.

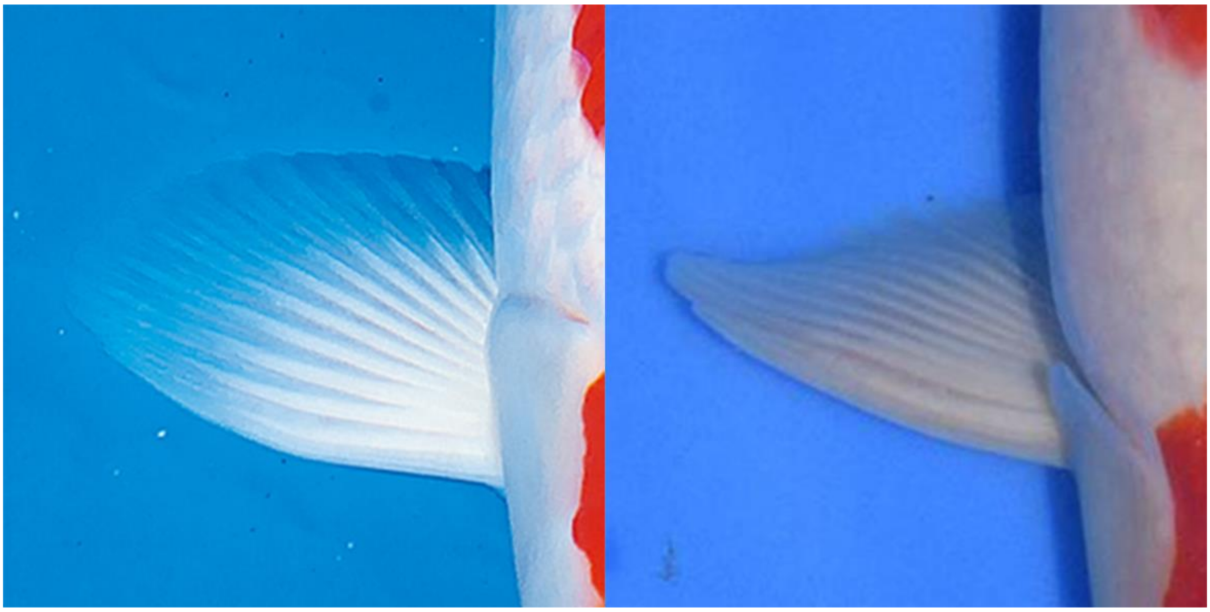

Figure 16. An example of differences of pectoral fins rotation of different individuals.

In addition to the problem of asymmetry of the pectoral fins posture, the caudal fins are generally also in motion. Many photos have an unwanted feature such as bent or partially rotated caudal fin, which cannot be accurately measured or used for the general color analysis. Fins in such posture may increase the total body area of the koi and adversely affect the analysis results. An example of this issue can be seen in Figure 17.

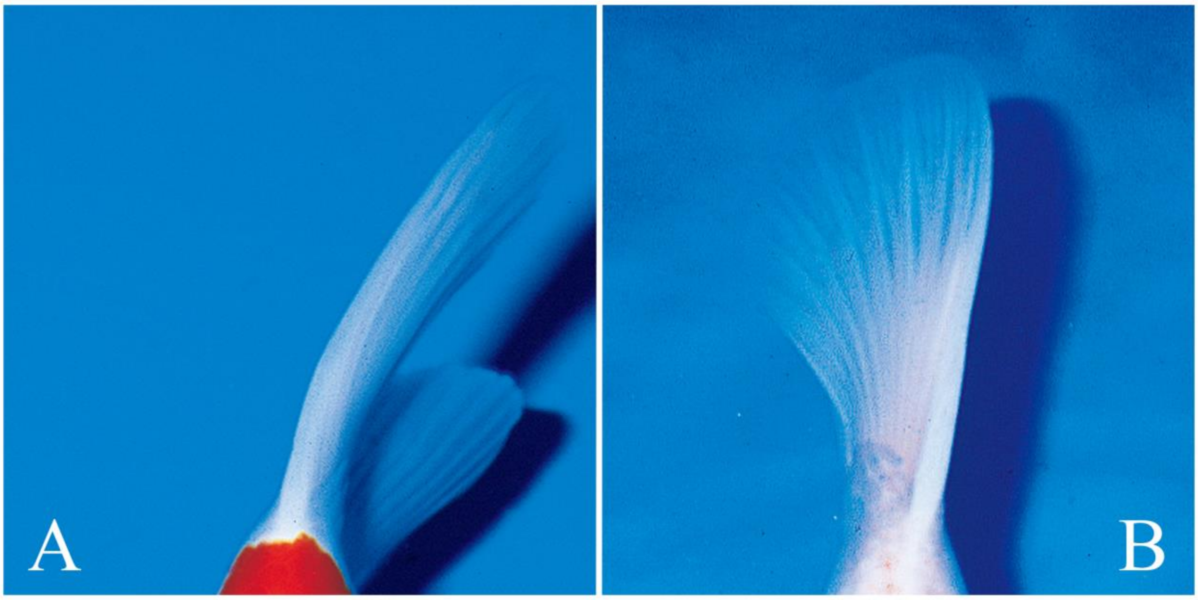

Figure 17. (A) Bent caudal fin; (B) Rotated caudal fin.

The number of images containing the deficiencies described above is high enough for this to be a problem. An attempt to take into account the fins and tail in the measurement creates a calculation error, which leads to a decrease in the quality of the statistical analysis. Thus, to solve this problem, it was decided not to take the fins into account, so I expected to solve this problem. Unfortunately, this will lose the opportunity to study the influence of the shape and color of the fins on the quality of the koi. However, in the absence of other options, it was decided to do just that. The fins were removed from the calculations by cropping the photographs.

This also had a positive effect on getting rid of the participation of unnecessary parts of the image that should not be taken into account in the calculations and are of no interest. In addition, measurements of the width and height of which in this case can be performed directly by measuring the dimensions of the image.

An example of a carefully cropped photo can be seen in Figure 18. So, we cropped the photos in such a way that the new borders of the image matched the edges of the body of the koi, and the border in the tail area crossed the flan at the point of greatest thinning of its thickness.

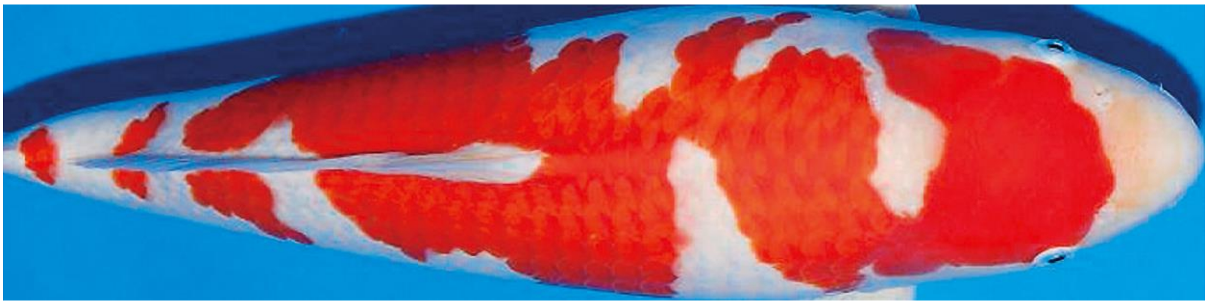

Figure 18. An example of the photo cropping.

2.2.3. Background Removing

The background is not an important, interesting, or useful part of the image. Moreover, the presence of a background in the image can lead to errors during the calculation and analysis of colors. In addition, in the presence of a background, it is difficult to use some features that could help in the analysis. So, for example, if you remove the background part of the image, all the remaining pixels will belong to the body of the koi. Naturally, as such, pixels are not removed from the image, this role is played by the alpha channel of the color, which is responsible for transparency. This way we can make all pixels that are not part of Kohaku's body transparent and use the transparency component of the pixel to calculate the amount of color in Kohaku's coloration. Thus, I made the background part of the images transparent and used this in the calculations. An example of deletion can be seen in Figure 19.

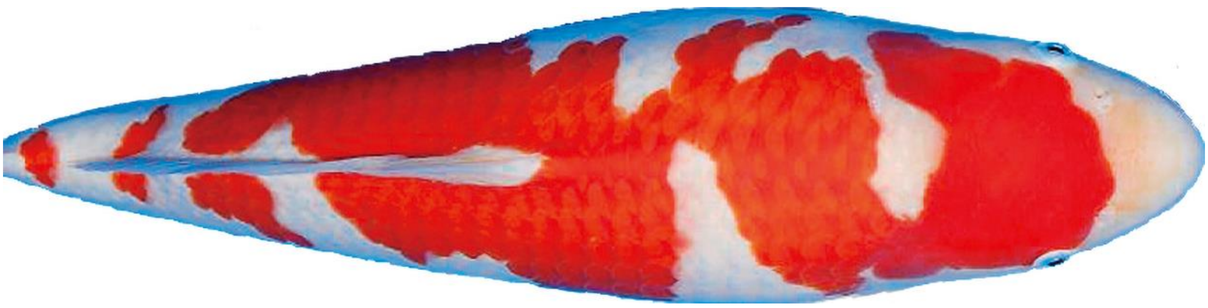

Figure 19**.** Example of background removal. The blue hue in the image is the reflection of the background on the fish scales.

Thus, all the photographs selected for analysis were carefully processed. The Adobe Photoshop editor was used in materials preparation (Evening, 2020).

2.3. HSVA Color Model

The standard color representation in the classic RGB color model is realized by mixing three component colors: Red, Green, Blue. Thus, when these three components are mixed, any color accessible to human perception is obtained. In addition, the RSL model often has a modification represented by the addition of a component responsible for the transparency of the image. This color model is called RGBA. As a rule, each component can usually be represented in different ranges, for example, in the range of [0, 255]. As part of this study, we use the representation of the components of the RGBA color space in the range of [0, 1]. The RGBA color model is used, including in the PNG image format, which is just used by us in this study. The RGB color model principles can be seen in the following Figure 20.

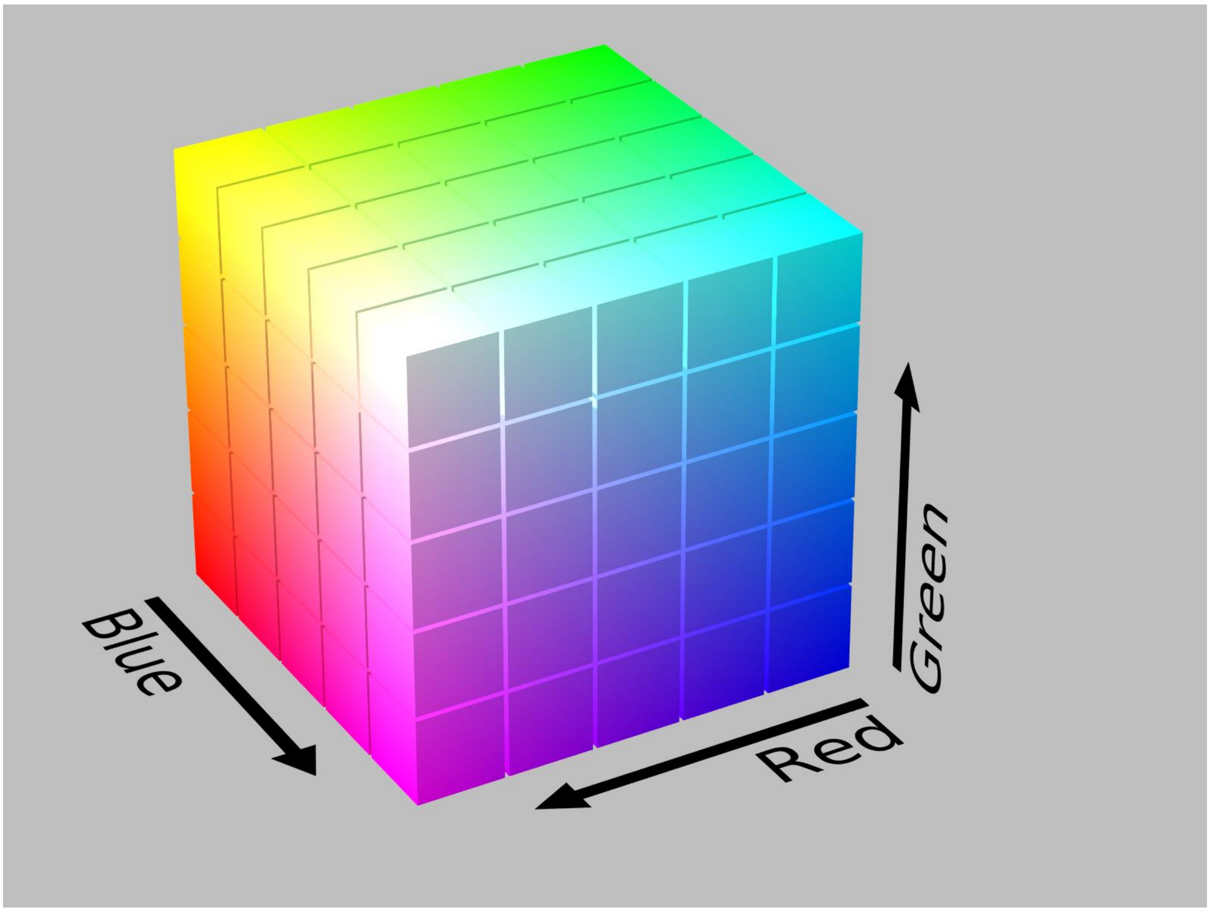

Figure 20. The RGB color model principals.

Using the RGBA color model to calculate the number of pixels in images of a certain color and, in particular, a certain range of shades of a certain color, is quite a difficult task due to the complexity in representing the RGBA color model for the human eye and consciousness.

This problem is solved by using more advanced color models such as HSV. The HSV color model has three components: hue (color), saturation, and value (brightness). The HSV model as well as RGB can represent any color available to human perception. But the HSV color model uses only one component to represent any color of the rainbow while the other two components are responsible for saturation and value (brightness). In addition, we can also optionally add an additional component that is responsible for transparency (alpha), thereby turning HSV into HSVA. The HSV color model principals can be seen in the following Figure 21.

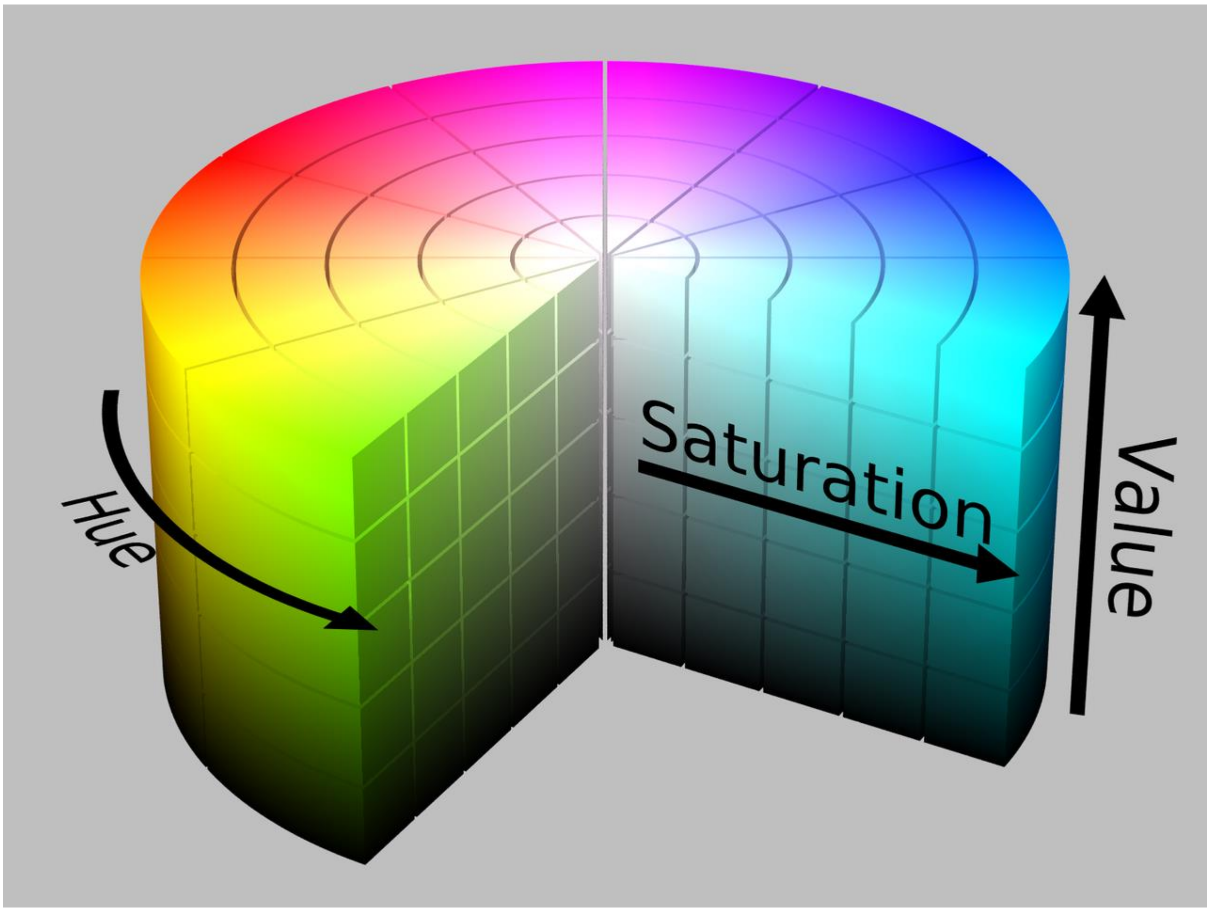

Figure 21. The HSV color model principals.

Thus, this color model was very useful in the study and we used it to analyze the quantities and characteristics of the colors contained in the Kohaku pattern.

The following Figure 22 explains the principles of mixing RGB color space components to obtain HSV color components.

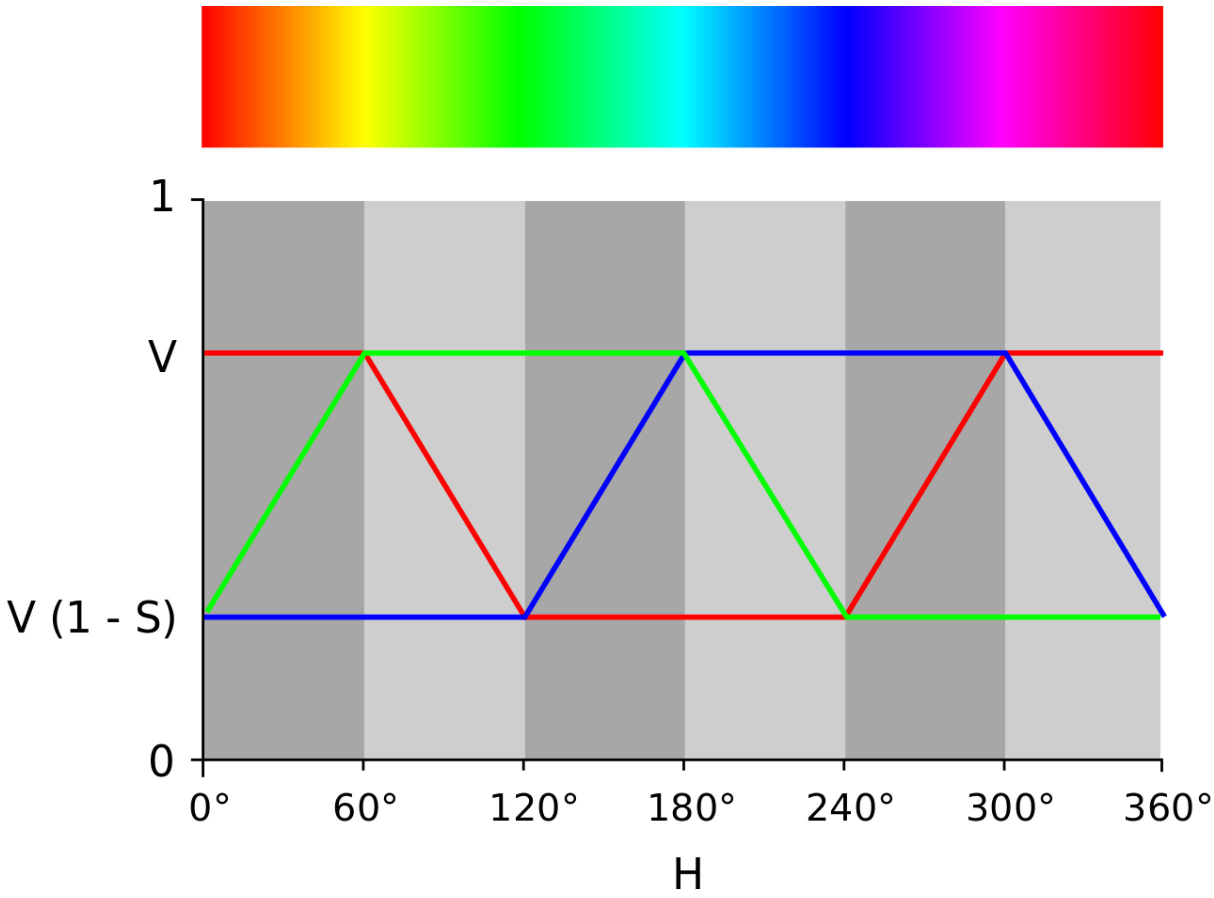

Figure 22. The prepresentation of RGB coordinates given values for HSV.

So, if we want to select pixels of only red and its shades, we can select pixels whose *H* component is in the range [0, 60] or [300, 360]. If we want to select pale red, we need to add to this condition a check that the *S* component belongs to a certain interval, for example, at *S* in the range of [0.2, 0.6], the pixel is a pale red color. The example of the HSV gradient for these conditions is present in the following Figure 23.

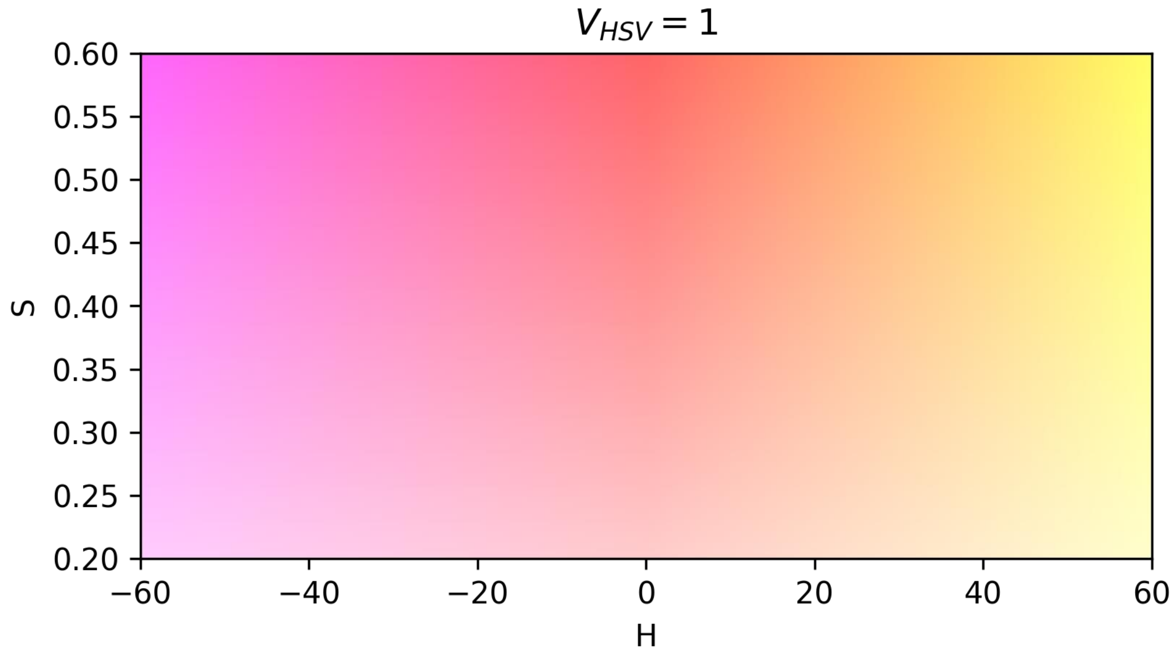

Figure 23. The HSV gradient for conditions:

H in range [300, 360] and [0, 60], S in the range [0.2, 0.6].

The following equations define conversion from the RGBA (red, green, blue, alpha) color model to the HSVA (hue, saturation, value, alpha) color model (Chen et al., 2007; Kartika & Herumurti, 2016; Smith, 1978):

$$Max = max(R, G, B)$$

$$Min = min(R, G, B)$$

$$\Delta = Max - Min$$

$$H = 60 \begin{cases} 2, & if\ \Delta = 0 \\ \frac{G - B}{\Delta} mod\ 6, & if\ Max = R \\ \frac{B - R}{\Delta} + 2, & if\ Max = G \\ \frac{R - G}{\Delta} + 4, & if\ Max = B \end{cases}$$

$$V = Max$$

$$S = \begin{cases} \frac{\Delta}{Max}, & if\ Max \neq 0 \\ 0, & if\ Max = 0 \end{cases}$$

$$A = A,$$

where RGBA color model components are in the range [0, 1] and HSVA color model components defined in partially normalized version, where the H component is in the range [0, 360] and S, V, A components are in the range [0, 1]. To avoid undefined values of the H component when the Δ equals to 0 it is necessary to assign some value to H. In the present study the H component assigned to 120 when Δ equals to 0 because this value represents pure green color which almost not present in images, and therefore this value provides better analysis accuracy (Chernov et al., 2015).

2.4. Feature Analysis

2.4.1. Body Aspect Ratio

The actual sizes of the koi in the images are unknown. Consequently, it was decided to use a relative value for analysis, which does not depend on the actual size of the koi's body, but nevertheless can reflect the feature of the body structure, for example, the rate of a body slimness. The aspect ratio of a body can be such relative value. Thanks to the preparation of the photos, especially cropping, the borders of the images bound Kohaku bodies exactly as we needed. In the present study all photos were rotated vertically, so the tail of the koi pointed up and the head – down. Accordingly, the body aspect ratio (AR) was defined by the following equation:

$$AR = \frac{image\ height}{image\ width},$$

where image height and image width are measured in pixels. Using the tools of Python programming language (Guzdial & Ericson, 2015; Johansson et al., 2019), the AR values were extracted from the images for analysis of aspect ratio impact on Kohaku quality.

2.4.2. Body Proportions

Body proportions of koi can vary widely: koi individuals can have different thicker parts of the body: closer to the head, closer to the center of the body, and sometimes even closer to the area of center-tail transition (Watson et al., 2004). It was necessary to analyze this feature of the koi's body and how it affects the quality of the koi. Due to the lack of information about the actual sizes of the body, it was decided to analyze the relative values which can describe body proportions. For this purpose, five relative values for each koi image were used. Each image was divided into five equal rectangles (R1, R2, R3, R4, R5; $R_{1\ldots5}$) adjacent to each other along the body of the koi (Figure 24).

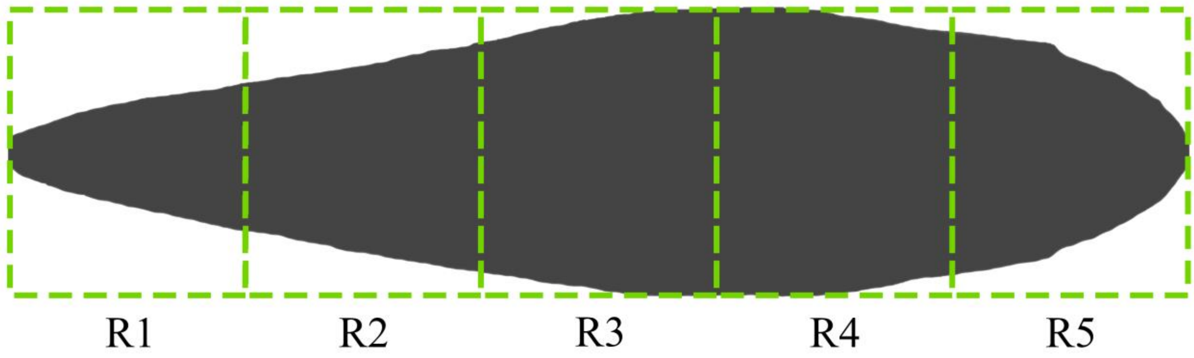

Figure 24. Body division with rectangles ($R_{1...5}$). The five green rectangles represent the division of the Kohaku body into five equal parts along the body length.

The bounds of the rectangles were used to calculate the areas of the body contained within the bounds. In our case area is measured in number of pixels. Accordingly, the five body areas formed by the rectangles ($R_{1...5}$) correspond to five values $BA_{1...5}$ according to the following equation:

$$BA_i = |\{P | P \ present \ in \ R_i \ rectangle \ bounds \land P_A > 0.5\}|,$$

where P is a pixel in RGBA color space and P_A is alpha component of a pixel. The obtained $BA_{1...5}$ values are equal to numbers of pixels are contained in the $R_{1...5}$ rectangles respectively. Because images have different resolutions and actual sizes of body are unknown, $BA_{1...5}$ values cannot be used directly for the analysis. For this reason, relative values ($RBA_{1...5}$) were used, defined by the following equations:

$$BA = \sum_{i=1}^{5} BA_i$$

$$RBA_j = \frac{BA_j}{BA} * 100,$$

where RBA_j (%) is relative body area in bounds of R_j rectangle in the range [0, 100] and j = 1…5. In this way, relative values that able to represent body proportions of the koi have been obtained. The $RBA_{1…5}$ values were used for analysis individually.

2.4.3. Red Coverage Rate

Analysis of the Kohaku coloration using RGBA color model is difficult due to the difficulty in interpreting the RGBA component values. Because it is easy to represent all colors of the rainbow with H component and adjust saturation and brightness with S and V components respectively the HSVA color model was used. Kohaku koi have two colors in the coloration: red and white. The red coverage rate in the coloration could differ between individuals. The red coverage rates were analyzed because it may affect the quality of the Kohaku. Three groups of pixels were defined according to the following equations:

$$RP = \{ P \mid (0 \le P_H \le 60 \lor 300 \le P_H \le 360) \land P_S \ge 0.5 \land P_A \ge 0.5 \},$$

$$WP = \{ P \mid P \notin RP \land P_A > 0.5\},$$

$$BP = \{ P \mid P_A > 0.5 \},$$

where P represents pixels in the HSVA color space, RP group represents red pixels of body coloration, WP represent white pixels of body coloration and BP represent all pixels of the body. Example of color groups rendered separately shown in Figure 25.

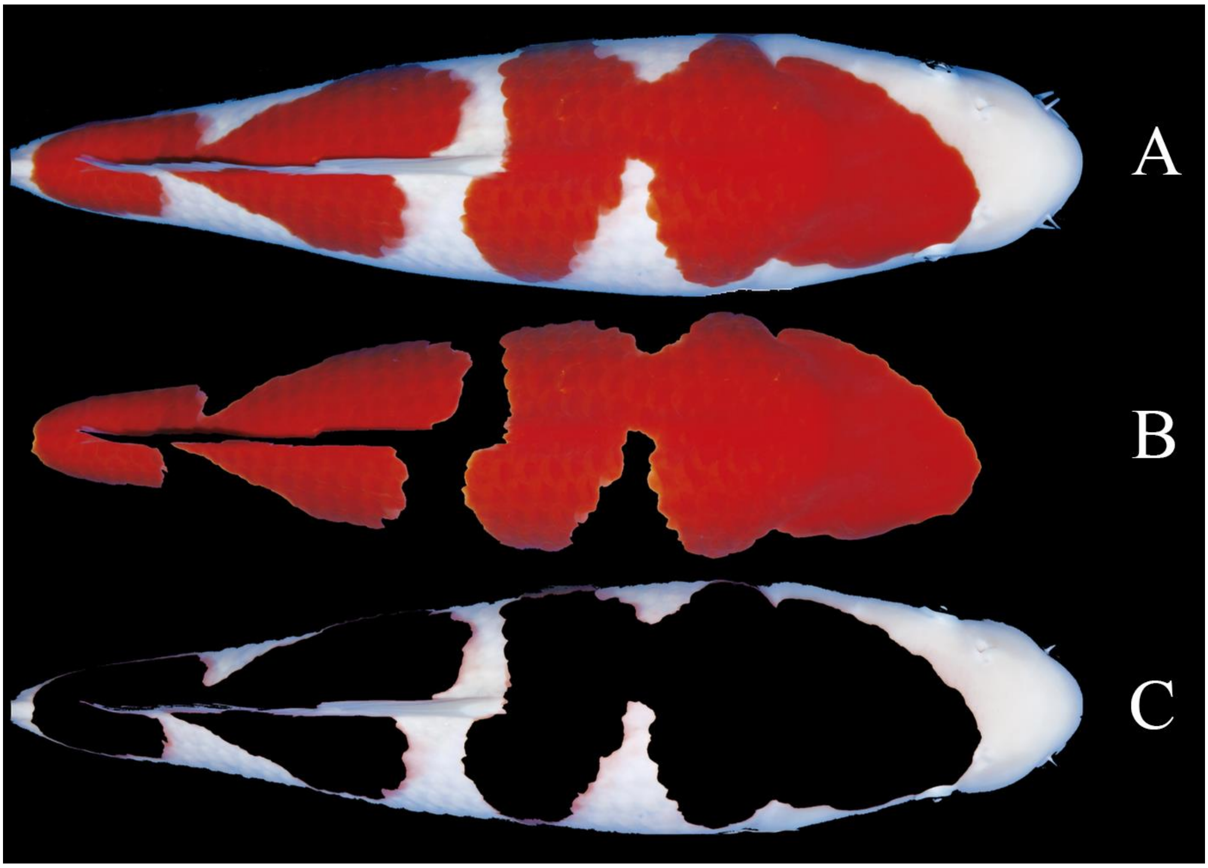

Figure 25. An example of color groups rendered separately. The BP group (A) represents all body pixels, the RP group (B) represents red pixels in body coloration and WP group (C) represents white pixels in body coloration.

With using visualization shown on example in Figure 3 applied for images, correctness of equations that define RP, WP, and BP groups was validated. To calculate red coverage rate (RCR) the following equation were used:

$$RCR = \frac{|RP|}{|BP|} * 100,$$

where RCR (%) is in the range [0, 100]. The RCR values was calculated for all images using tools of the Python programming language and was used to analyze how it affects the Kohaku quality.

2.4.4. Pale Red Coverage Rate

During visual inspection of the images, it was found that very often Kohaku from the *losers* group has pale red areas along the edges of the red spots or within some areas of white areas. It has been assumed that the presence of a large amount of pale red color in the Kohaku coloration negatively affects the Kohaku quality. To analyze this assumption, the pale red coverage rate was calculated according to the following equations:

$PRP = \{ P \mid (0 \leq P_H \leq 60 \vee 300 \leq P_H \leq 360) \wedge (0.2 \leq P_S \leq 0.6) \wedge (P_A > 0.5) \}$,

$BP = \{ P \mid P_A > 0.5 \}$,

where P represents pixels in HSVA color space, PRP represent group of pale red pixels, BP represents group of all pixels of the body. Example of groups rendered separately shown in Figure 26.

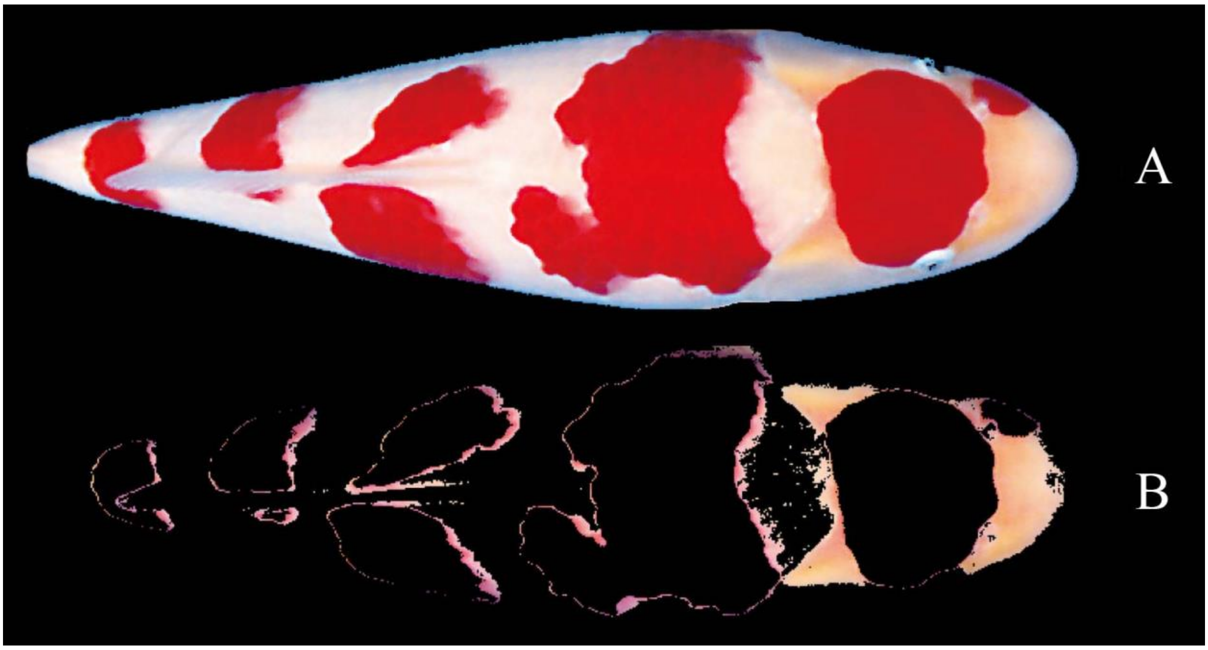

Figure 26. An example of color groups rendered separately. The BP group (A) represents all body pixels and the PRP group (B) represents pale red pixels in body coloration.

Using visualization showed in Figure 26 applied for images, correctness of equations that define PRP and BP groups was validated. To calculate pale red coverage rate (PRCR) the following equation were used:

$$PRCR = \frac{|PRP|}{|BP|} * 100,$$

where PRCR (%) in the range [0, 100]. The PRCR values was calculated for all images using tools of the Python programming language and was used to analyze how it affects the Kohaku quality.

2.5. Statistical Analysis

AR, $RBA_{1...5}$, RCR and PRCR values, calculated for all images, were individually subjected to one-way analysis of variance (ANOVA) using the R statistical software (James et al., 2013; Wickham & Grolemund, 2016) to discover how features which they represent affect the Kohaku quality. Due to the lack of other available data, in the context of present study Kohaku belong to the *winners* group was considered as high quality Kohaku and opposite: Kohaku belong to the *losers* group was considered as low quality Kohaku. The difference in means was considered statistically significant at $p < 0.05$.

Multiple linear regression was conducted to investigate the relationship between features which affect quality rate. Quality rate is artificial value that was used for multiple linear regression to describe the Kohaku quality score. Individuals of the *winners* group had quality rate value equal to 1 and vice versa individuals of the *losers* group had value equal to 0. In this way values close to 1 mean good quality Kohaku and values close to 0 mean poor quality of Kohaku. The multiple regression analysis was conducted with R statistical software.

3. Results and Discussion

3.1. Feature Analysis Results

3.1.1. Body Aspect Ratio

The average value of the body aspect ratio (AR) of *winners* and *losers* is 3.825 and 3.982 respectively. The conducted one-way analysis of variance (ANOVA) showed that the difference in the average value of the ratio values is statistically significant ($p < 0.001$). The distribution of individuals within their groups shown in Figure 27.

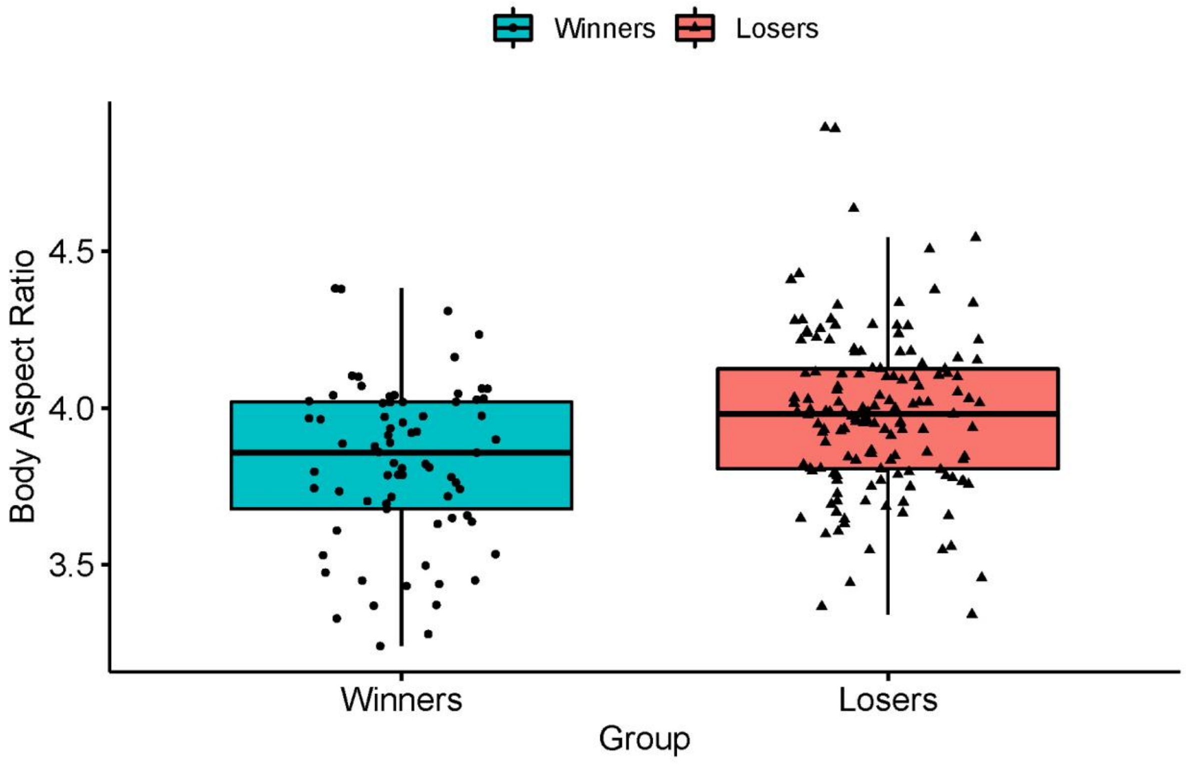

Figure 27. Body aspect ratio distribution.

The higher aspect ratio value corresponds to the Kohaku with slenderer body shape and vice versa, the lower the aspect ratio value corresponds to the Kohaku with more massive body shape. Therefore, results show that Kohaku which have massive body are higher quality Kohaku than slender ones.

3.1.2. Body Proportions

The average values of $RBA_{1...5}$ of the *winners* group and the *losers* group shown in Table 5, where Δ is the absolute difference between RBA_i of the *winners* group and RBA_i of the *losers* group.

Table 5. Averages of $RBA_{1...5}$ values and their absolute differences (Δ) in percentage.

RBA_i	Winners (%)	Losers (%)	Δ (%)
RBA_1	9.6	9.6	0
RBA_2	19	19	0
RBA_3	26.2	26.2	0
RBA_4	27.1	27.2	0.1
RBA_5	18.1	18	0.1

The highest value from all Δ is equal to 0.1%, which means that the highest difference within averages do not excide 0.1%. There is no significant difference between the *winners* group and the *losers* group because p-values of $RBA_{1...5}$ are following: $p = 0.61 > 0.05$, $p = 0.85 > 0.05$, $p = 0.89 > 0.05$, $p = 0.11 > 0.05$ and $p = 0.52 > 0.05$ with respect to RBA_i order when i = 1…5. Therefore, effect of the body proportions on Kohaku quality wasn't discovered in such manner.

3.1.3. Red Coverage Rate

The average value of the red coverage rate (RCR) of winners and losers is 60.4% and 58.4% respectively. There is no statistically significant difference between groups ($p = 0.062 > 0.05$). Therefore, effect of the red coverage rate on Kohaku quality wasn't discovered in such manner.

3.1.4. Pale Red Coverage Rate

The average value of the pale red coverage rate (PRCR) of winners and losers is 3.14% and 10.23% respectively. The conducted one-way analysis of variance (ANOVA) showed that the difference in the average value of the ratio values is statistically significant ($p < 0.001$). The distribution of individuals within their groups shown in Figure 28.

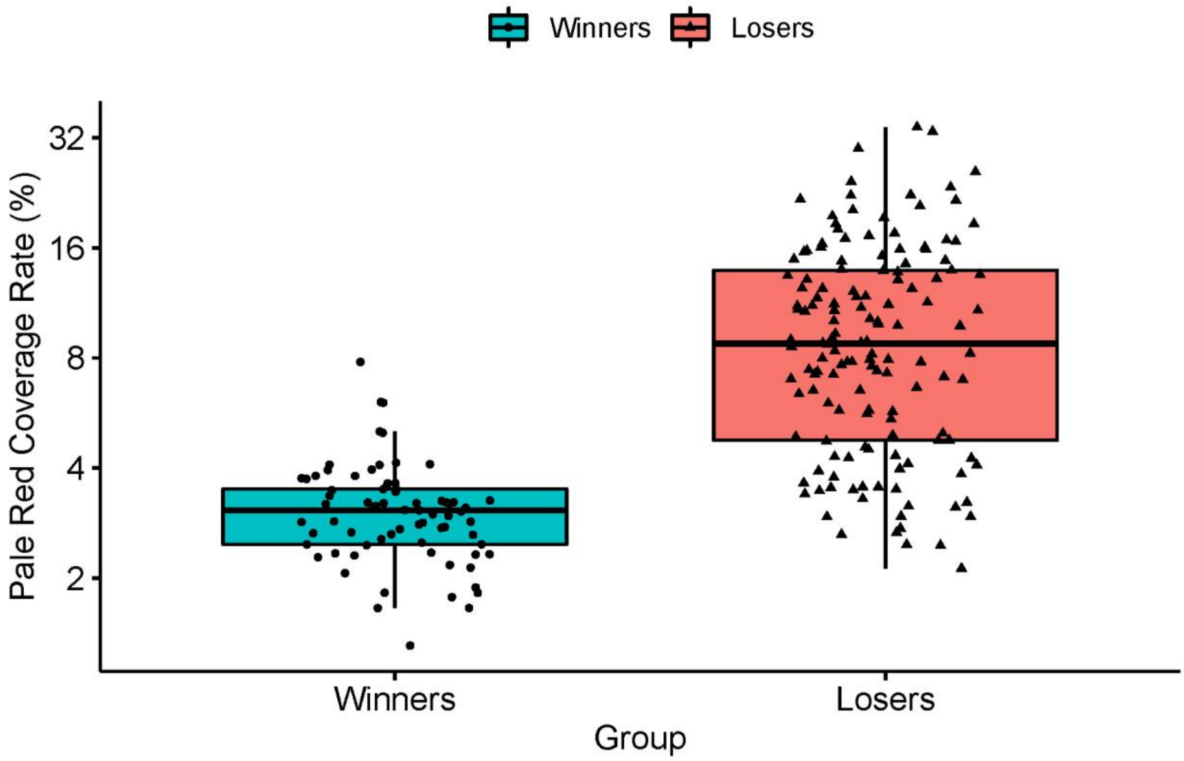

Figure 28. Pale red coverage rate values distribution.

The high pale red coverage rate (PRCR) value corresponds to the Kohaku with higher overall pale red color area persisted in body coloration and vice versa, the low pale red coverage rate (PRCR) value corresponds to the Kohaku with lower overall pale red color area persisted in body coloration. Therefore, results show that Kohaku with lower overall pale red color area in their body coloration has higher quality than koi with higher overall pale red color area in body coloration.

3.1.5. Multiple Linear Regression

Multiple linear regression was carried out to investigate the relationship between body aspect ratio, pale red coverage rate and quality rate. There was a significant relationship between body aspect ratio and quality rate ($p < 0.05$), pale red coverage rate and quality rate ($p < 0.001$). For the body aspect ratio, there was a -0.236 (± 0.105) decrease of the quality rate for each extra unit of aspect ratio. For each extra percent of pale red coverage rate, the quality rate decreases by -0.037 (± 0.004). According to these results pale red coverage rate is more important feature than body aspect ratio. The following equation corresponds to multiple linear regression analysis result:

$$QR = 1.558 + (-0.236 \times AR) + (-0.037 \times PRCR),$$

where *AR* is aspect ratio, *PRCR* is pale red coverage rate and *QR* is approximation of quality rate. In most cases *QR* in the range [0, 1], but in some cases may be out of range. A higher *QR* value means better quality.

3.2. Discussion

3.2.1 Results Discussion

The results of this study indicate that there are structural and color characteristics of koi that positively or negatively affect koi quality. Some features, such as the aspect ratio of the body and the degree of pale red coverage, have been found to directly affect the quality of the Kohaku. The importance of various factors on the quality of Kohaku was also assessed. So, it was found that the pale red color factor is more important for the quality of koi than the body aspect ratio factor. The results obtained provide an estimate of the significance of some Kohaku characteristics that are important for the quality of the fish. In reality, all possible factors are still unknown, it was possible to establish a system for accurate and detailed assessment of the quality of Kohaku.

During this study, we encountered many problems and repeated experiments that had to be carried out in order to get the best result. Some of the described problems have been successfully solved, however, these problems are of a more global nature affecting the possibility of using the methods described in this study for evaluating Kohaku koi. No doubt these methods can be applied and will be useful to some extent. However, the knowledge and experience gained during this study is more important. Thus, many problems in assessing the quality of koi have become known, which will be discussed further. With this information, it is possible to develop new methodologies for studying the quality of koi that will solve all problems and be more useful for practical application: this issue will also be discussed further. Without this research, so much useful information would not have been obtained to advance and improve the science of koi quality evaluation.

There are many sources describing koi, but there is no detailed information about the koi evaluation process and features of koi body shape and body color and how these features affect the quality of koi. Thus, the results presented here serve as a basis for future work on koi quality assessment. The following section presents several hypotheses regarding the results of this study and discusses the shortcomings of this approach, ways to improve the methodology for studying koi quality, various directions for future research into koi body shape and color, and their impact on quality.

3.2.2. Problems of Materials

In the present study, photographs were used that had the disadvantages described in the preparation section. Appropriate photographs were selected and processed to eliminate all shortcomings. These deficiencies included: imperfect body posture of the koi, reflections from the water, image noise, the effect of the color emission of surrounding objects on the koi's lighting, or human factors such as differences in camera angles, lighting, and excessive shadows. Photos with minor problems, such as bent or twisted fins, were processed, and thus the imperfections were leveled. Photos that had more significant flaws that could affect the course of the study were excluded from the data collection and were not used in this study. Nevertheless, hidden shortcomings could remain, difficult to detect by a person and capable of reducing the accuracy of the analysis by their presence.

In addition, there is the problem of assessing the quality of photographs. So, it is difficult to assess whether the camera had the correct position at the time the picture was taken, whether the color reproduction and lighting were correct. All this is difficult to evaluate mathematically and programmatically, which also creates an additional problem when evaluating the quality of koi using image analysis. In the framework of this study, we assessed the suitability of the material for experiments manually. Improving the methodology for assessing the quality of images as such and their suitability for use in quality assessment is a separate task that can be studied in more detail.

In this study, data collected over the years of koi shows was used, and the selection of this data is a challenging task. In addition, these data are limited in quantity and time of collection. So, we can't get additional or new data and it also creates a problem for koi quality research.

Collecting photos is a complex process, it is needed to meet a huge number of conditions in order to get a photo of suitable quality: wait for the perfect pose of the koi body, ensure a good level of quality of illumination of the subject (so that there is no excessive overlighting or darkening of the koi body), maintain the correct strictly vertical position of the camera at the time of shooting , maintain the absence of glare on the water, ensure the absence of reflected light, and ensure high resolution photographs and correct color reproduction. This work of collecting materials requires high skills, good equipment, a lot of time and financial resources.

Thus, using higher quality photographs as material can improve the quality of the analysis. High color fidelity, soft lighting, information about the actual size of the koi, information about the position and orientation of the camera at the time of shooting: all this will serve as a positive factor that will improve the quality of the analysis. In addition to using special color correction techniques to replicate real koi colors, it will also have a positive effect. Potential methods for solving these problems are discussed below.

3.2.3. Kohaku Features

In the present study, only some of the features of the shape and color of the body of the Kohaku were analyzed, which can be detected on the basis of the data that we used. Some of the traits analyzed have been found to affect the quality of the koi, but it is likely that there are other features that can be detected and analyzed through photographs. Over time, by discovering new features of the koi's body structure, and improving the available methods of analysis, it will be possible to use more than two functions together, and, knowing their influence, fully evaluate the quality of Kohaku and, perhaps, formalize the rules of evaluation.

3.2.4. Missed Features

It is likely that many possible signs of koi quality were missed. This could happen both due to their non-detection during the analysis of images and due to the circumstances of obtaining photographs as materials for research. So, probably, koi breeders themselves are aware of the obvious signs that affect quality negatively and obviously they choose the best individuals from the collection for performance at the exhibition. Thus, the most significant signs of koi quality may simply not be included in the exhibition, and we cannot get information about such signs from the exhibition because it is not there.

Since all the photographs used in this study were taken during koi shows, it is likely that we have not received important information about the qualities of koi that most negatively affect their quality. Such qualities can be the asymmetry of the body shape, damage to the scales, fins, defects in coloration etc.

So, we have found several photographs in the collection that contain some flaws that could affect the quality of the koi. Evaluation of such traits based on the available data is difficult due to the small number.

For example, we found several photographs in which the fin of a koi has minor damage. An example is shown in Figure 29.

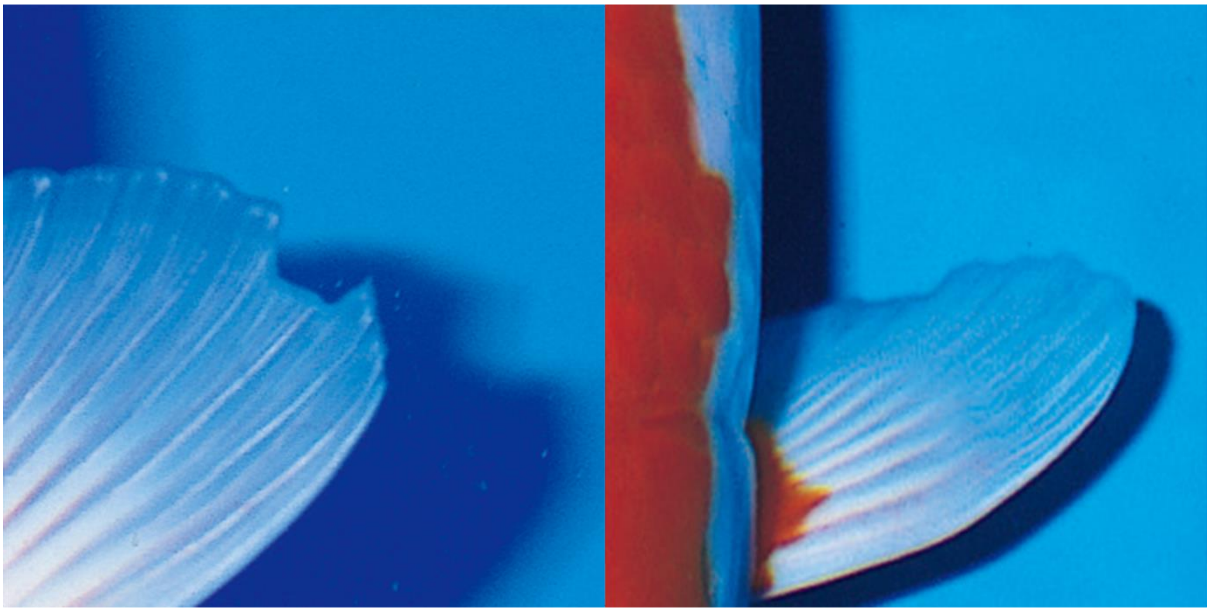

Figure 29. An example of minor pectoral fin damage.

Evaluation of the impact of this type of fin damage on the quality of koi is not possible based on the available data due to their small number.

Even more poorly identified potential scale flaws have been found. Only a few such photographs were found, and their evaluation also causes difficulties in this regard. An example is shown in Figure 30.

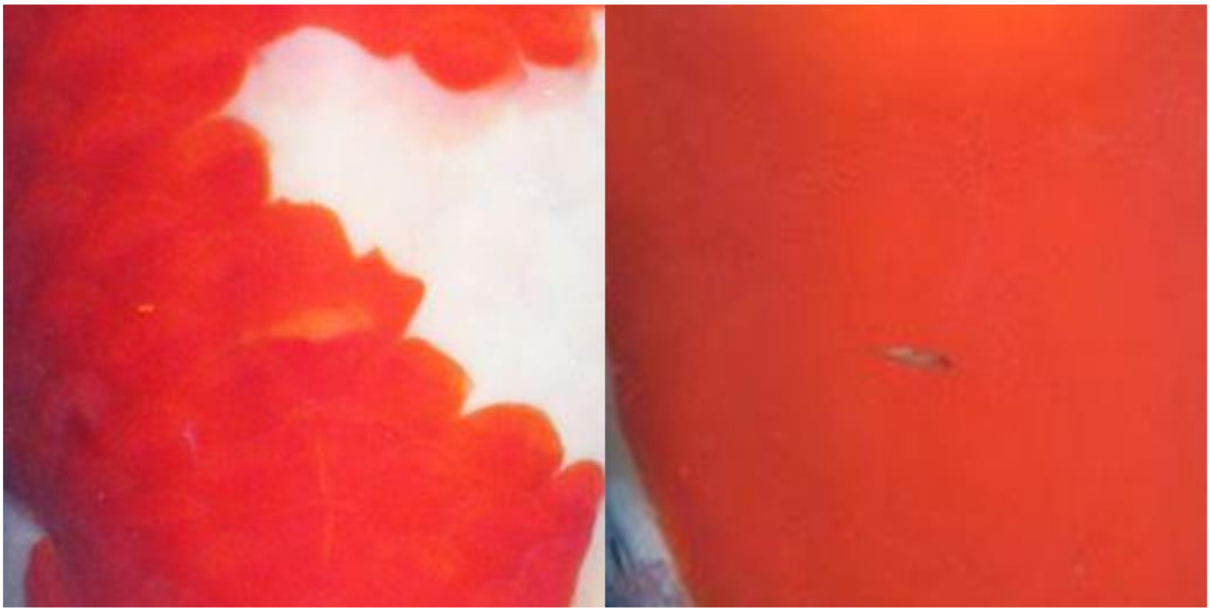

Figure 30. An example of potential defects of skin.

Thus, it is highly likely that some koi flaws that negatively affect the quality of the individual simply did not come to us as materials. Thus, this issue requires further study.

3.2.5. Image Restrictions

Photographs cannot fully convey information about the actual shape of a koi's body, but only convey a view limited by the camera's perspective. Using such images, it is problematic to analyze the body shape of a koi in three dimensions. Thus, there are limitations in the analysis of koi body shape: only a limited number of features can be analyzed in the two-dimensional space represented by images.

This creates a significant limitation for evaluating the quality, as we cannot be sure that we will evaluate the shape and color of the Kohaku in full, because we may not have enough information about the body of the koi.

New types of materials that can be used for koi quality evaluation, can provide additional information about body shape, allowing for more complex analysis and possibly discovering new features that affect koi quality. An example of an improved approach to material collection would be the use of photogrammetry techniques to gain insight into the body structure of a koi in three-dimensional space by creating 3D models. The 3D model may represent the 3D shape of koi body in details comparing with images (Alfio et al., 2020; Lange & Perry, 2020; Pepe & Costantino, 2020). This technique would allow for a detailed analysis of the body shape and perhaps discover new valuable features that affect the quality of the koi.

3.3. Photogrammetry for Quality Analysis

As mentioned earlier, photos do not fully convey information about koi body shape and color. The photogrammetry algorithms can transform a set of photographs or video footage into a 3D model of a koi that is shaped and textured in a way that fully captures the body structure of the koi (Linder, 2009; Mikhail et al., 2001). This will allow measurements not of the koi's physical body, but of its 3D model (Galbany et al., 2016). In theory, this will allow in-depth study of a koi specimen, to do it at any convenient time and remotely without access to the real body.

As a rule, to create a three-dimensional model of an object based on photographs, many pictures of the object taken from angles are used, so it allows to combine them and get an idea of the three-dimensional structure of the object and generate its three-dimensional model. The most modern technologists do it in real time. For example, “AliceVision Meshroom” allows to create three-dimensional models of real objects based on photographs or videos (Griwodz et al., 2021). As a rule, these algorithms are used to generate static objects (Baltsavias, 1999; Omar et al., 2018). The reason for this is that in order to create a 3D object, the object must be in the same states in all images. Thus, this poses a problem when using these algorithms to generate 3D koi models.

Theoretically, this problem can be solved by placing many cameras around the koi that will take pictures at the same time. In this way, the koi specimen will be captured in the same position in all pictures (capturing object will become static). In Figure 31 shows a schematic example of such a solution concept.

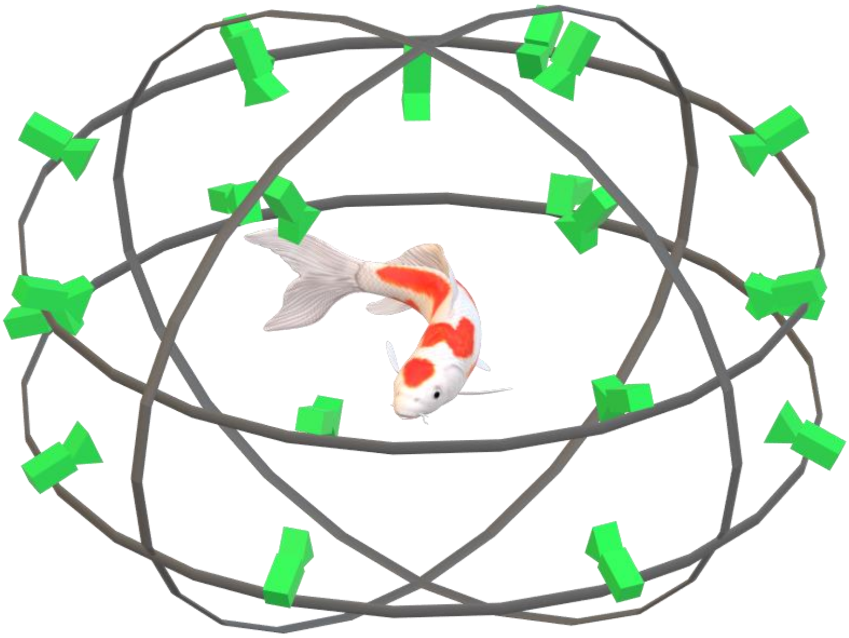

Figure 31. Cameras are placed symmetrically on many sides of the koi to simultaneously take a picture to create a 3D carp model.

This technology is currently being used to create 3D human models that are then used in movies, TV series, video games and so on (Zeraatkar & Khalili, 2020). Figure 32 is a photograph of the process of scanning a person to create a three-dimensional model.

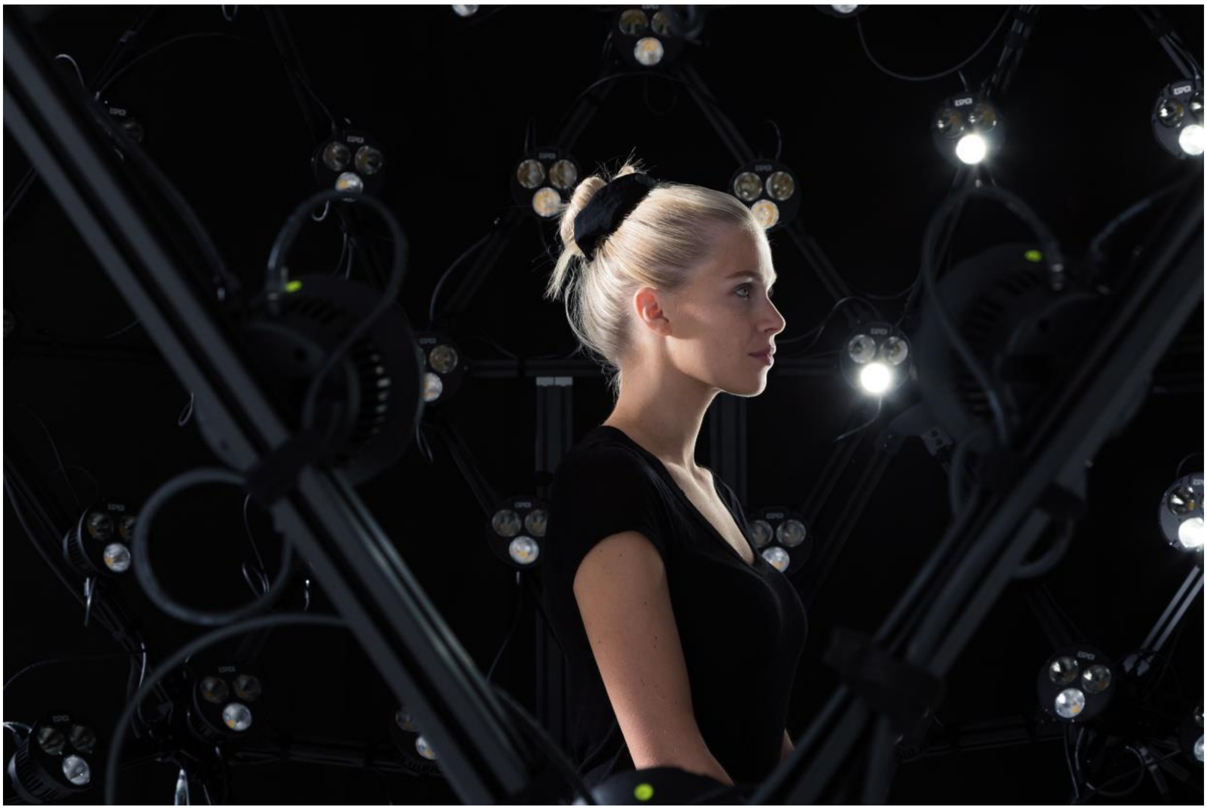

Figure 32. Process of 3D human model generation (www.esperhq.com).

This way of creating three-dimensional models is overly complicated and financially expensive. So, it is necessary to use many cameras and assemble a complex structure that is difficult to move and use in the water conditions in which the koi are kept (Zeraatkar & Khalili, 2020). Thus, although this approach is the most promising, it is associated with many difficulties that make one think about other ways to solve the problem.

One way to ease the process of creating 3D models is to use the hybrid method. So, a three-dimensional model is not created for each individual koi from scratch; instead, a certain template three-dimensional model is always used, which is prepared in advance and contains several predefined properties (shape keys for shape interpolation) that allow to change the model: stretch and compress in different places in a pre-thought-out way (Alexa et al., 2000; Lewis et al., 2000). Such properties are named differently depending on the 3D model editor. So, in one of the most popular editors of three-dimensional models, Blender, these properties are called “Shape Keys” (Figure 33) (Blain, 2017; Kent, 2015).

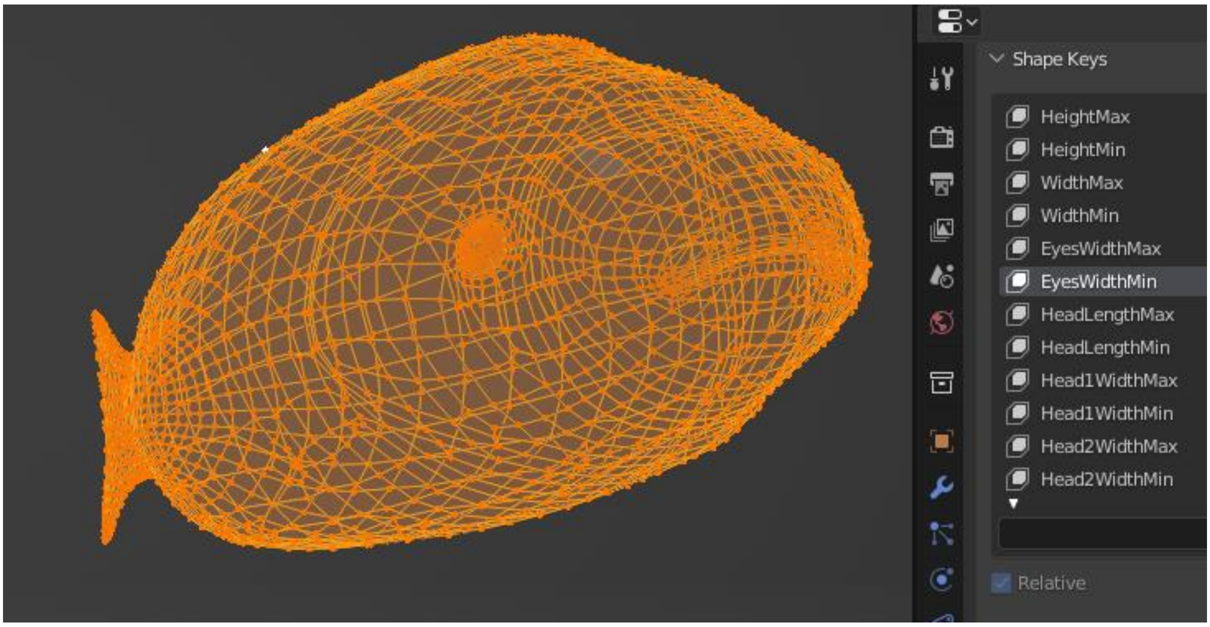

Figure 33. The Shape Keys properties of 3D model in the Blender.

This will reduce the number of expected outputs for the 3D modeling algorithm. So, teaching a neural network to set up the template model should not give a problem. Also, the texturing of the model will also have a lighter character because the expected output parameters will be smaller in number and will be strictly predetermined by the UV coordinates.

The development of this solution at the time of writing this work is in progress. A successful solution to this problem will allow to create three-dimensional models using, for example, a smartphone. The user of the application would walk around the koi individual with a smartphone camera and would take a picture, the images will be fed to an algorithm that will set up a template model and perform texturing. In this simplified way, 3D models which will be used to analyze the quality of the koi will be created. In addition, this will allow the process to be widely disseminated to the masses and bring a competitive moment for koi lovers who can create models of their pets and share them on the Internet and compare them with each other using a koi quality rating system.

3.4. Prospects

As mentioned, there is a lack of knowledge in the community about koi quality assessment. The nonexpert cannot judge the quality of a koi. And since koi are ornamental fish, quality is an important characteristic.

Unfortunately, building a quality evaluation system is a complex and time-consuming process. Given the limited data available, it is essential to collaborate with experts in the koi industry to develop a system for evaluating and studying koi qualities. As mentioned before, the data collection process and analysis methods need to be improved.

Current and future research will be of benefit to koi enthusiasts and koi breeders around the world. This study and additional work on the body shape and color features of koi and their qualities can have a significant positive impact on the entire koi industry as a whole and contribute to its development.

4. Conclusions

In the present study, the features of the body shape and color features of the Kohaku koi were analyzed. Certain features were discovered and analyzed to find out how important they are to the quality of Kohaku. Thus, several feature have a significant impact on the quality of Kohaku.

So, Kohaku with a rather massive body turned out to be better individuals. In addition, the presence of a large amount of reddish color has a negative impact on the quality of Kohaku. It has been established that the most strongly influencing trait on the quality of Kohaku is a pale red coating index, with a high index of which the quality of the koi decreases faster than with a decrease in the massiveness of the Kohaku body.

Based on this study, a similar analysis of body shape and coloration can be made for other varieties of koi or other ornamental fish, which will provide more useful knowledge about the features of the structure and color of it. Thus, this study is an important foundation for further research on the features of the shape and color of koi and quality evaluation of koi.

In addition, problems and failures and how to solve them are equally important information and experience gained from this work. The work revealed many problems in the source materials and methods of analysis of these materials. Finding solutions to these problems has allowed us to get innovative ideas and insight into where we need to go next to develop this topic. For example, it has been found that significant improvements are needed in the methodology for collecting koi materials for analysis, which can be done by creating 3D models of koi. Work on the implementation of these ideas is currently underway.

It also became clear that it was necessary to cooperate with experts in the field of koi evaluation to work together fruitfully to create a complete koi assessment methodology for the development of the science of the koi industry.

Thus, it is necessary and will continue to work on: improving the methodology for collecting materials for analysis, identifying new features of the body shape and color of Kohaku, improving the quality of analysis, as well as studying other varieties of koi and their features.

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Appendices

Appendix A: Python Code

A-1 Body Aspect Ratio

Thanks to preliminary preparation, the analysis of the aspect ratio of Kohaku's body is not difficult. To do this, it was enough to measure the resolution of the image using the Python code. This was done with the following method:

```
import csv
import matplotlib.pyplot as plt

def get_ratio(resultCSVFilePath, images):
    with open(resultCSVFilePath, 'w', newline='') as csvFile:
        csvWriter = csv.writer(csvFile)
        csvWriter.writerow(['Ratio', 'Group'])
        for imagePath, imageGroup in images.items():
            rgbaImage = plt.imread(imagePath)[:, :, :4]
            height = rgbaImage.shape[0]
            width = rgbaImage.shape[1]
            ratio = height / width
            csvWriter.writerow([ratio, imageGroup])
```

The resultCSVFilePath argument is a path to result CSV file and the images argument is a dictionary where key is path to image and value is group string. The get_ratio method was used to extract ratio value from all prepared images for the statistical analysis.

A-2 Body Proportions

The preparation of the materials proved to be very helpful in extracting information about the body proportions of the koi. So, the images were divided into rectangles which were used to count the number of pixels within each of the rectangles. The following Python code was used to extract koi body proportion information from an image:

```
import csv
import matplotlib.pyplot as plt

def get_proportions(resultCSVFilePath, images):
    RECTANGLES = 5
    with open(resultCSVFilePath, 'w', newline='') as csvFile:
        csvWriter = csv.writer(csvFile)
        headerRow = []
        for sector in range(RECTANGLES):
            headerRow.append(f'R{sector + 1}')

        headerRow('Group')
        csvWriter.writerow(headerRow)
        for imagePath, imageGroup in images.items():
            rgbaImage = plt.imread(imagePath)[:, :, :4]
            height = rgbaImage.shape[0]
            width = rgbaImage.shape[1]
            heightPerSector = height
            sectors = []
            count = 0
            for sector in range(RECTANGLES):
                for h in range(heightPerSector * sector, heightPerSector * (sector + 1)):
                    for w in range(width):
                        if rgbaImage[h, w, 3] > 0.5:
                            count += 1

                sectors.append(count)
                count = 0

            sum = sectors[0] + sectors[1] + sectors[2] + sectors[3] + sectors[4]
            for sector in range(RECTANGLES):
                sectors[sector] /= sum

            sectors.append(imageGroup)
            csvWriter.writerow(sectors)
```

The resultCSVFilePath argument is a path to result CSV file and the images argument is a dictionary where key is path to image and value is group string. The get_proportions method was used to extract proportion values from all prepared images for the statistical analysis.

A-3 Red Coverage Rate

Extraction of the Kohaku red body coverage rate was performed using the following Python code, where the *rgb_image_to_hsv_image* method was used to convert an image in the RGB color space to the HSV color space:

```
import csv
import numpy as np
import matplotlib.pyplot as plt
import matplotlib.colors as colors

def rgb_image_to_hsv_image(rgb_image):
    rgb_image = rgb_image.copy()
    hsv_image = colors.rgb_to_hsv(rgb_image[:, :, :3])
    hsv_image[:, :, 0] = hsv_image[:, :, 0] * 360.0
    hsv_image[:, :, 1] = hsv_image[:, :, 1]
    hsv_image[:, :, 2] = hsv_image[:, :, 2]
    return np.dstack((hsv_image, rgb_image[:, :, 3]))
```

```
def get_red_coverage(resultCSVFilePath, images):
    with open(resultCSVFilePath, 'w', newline='') as csvFile:
        csvWriter = csv.writer(csvFile)
        csvWriter.writerow(['Coverage', 'Group'])
        for imagePath, imageGroup in images.items():
            rgbaImage = plt.imread(imagePath)[:, :, :4]
            hsvImage = rgb_image_to_hsv_image(rgbaImage)
            height = rgbaImage.shape[0]
            width = rgbaImage.shape[1]
            countRed = 0
            countAny = 0
            for h in range(height):
                for w in range(width):
                    pixel = hsvImage[h, w, :]
                    if pixel[3] > 0.5 \
                        and (0 <= pixel[0] <= 60 or 300 <= pixel[0] <= 360) \
                        and pixel[1] >= 0.5:
                        countRed +=1
                    if pixel[3] > 0.5:
                        countAny += 1

            coverage = countRed / countAny * 100
            csvWriter.writerow([coverage, imageGroup])
```

The *resultCSVFilePath* argument is a path to result CSV file and the *images* argument is a dictionary where key is path to image and value is group string. The *get_red_coverage* method was used to extract red coverage rate values from all prepared images for the statistical analysis.

A-4 Pale Red Coverage Rate

Extraction of the Kohaku pale red body coverage rate was performed using the following Python code, where the *rgb_image_to_hsv_image* method was used to convert an image in the RGB color space to the HSV color space:

```
import csv
import numpy as np
import matplotlib.pyplot as plt
import matplotlib.colors as colors

def rgb_image_to_hsv_image(rgb_image):
    rgb_image = rgb_image.copy()
    hsv_image = colors.rgb_to_hsv(rgb_image[:, :, :3])
    hsv_image[:, :, 0] = hsv_image[:, :, 0] * 360.0
    hsv_image[:, :, 1] = hsv_image[:, :, 1]
    hsv_image[:, :, 2] = hsv_image[:, :, 2]
    return np.dstack((hsv_image, rgb_image[:, :, 3]))
```

```
def get_pale_red_coverage(resultCSVFilePath, images):
    with open(resultCSVFilePath, 'w', newline='') as csvFile:
        csvWriter = csv.writer(csvFile)
        csvWriter.writerow(['Coverage', 'Group'])
        for imagePath, imageGroup in images.items():
            rgbaImage = plt.imread(imagePath)[:, :, :4]
            hsvImage = rgb_image_to_hsv_image(rgbaImage)
            height = rgbaImage.shape[0]
            width = rgbaImage.shape[1]
            countPaleRed = 0
            countAny = 0
            for h in range(height):
                for w in range(width):
                    pixel = hsvImage[h, w, :]
                    if pixel[3] > 0.5 \
                        and (0 <= pixel[0] <= 60 or 300 <= pixel[0] <= 360) \
                        and 0.2 <= pixel[1] <= 0.6:
                        countPaleRed +=1
                    if pixel[3] > 0.5:
                        countAny += 1

            coverage = countPaleRed / countAny * 100
            csvWriter.writerow([coverage, imageGroup])
```

The *resultCSVFilePath* argument is a path to result CSV file and the *images* argument is a dictionary where key is path to image and value is group string. The *get_pale_red_coverage* method was used to extract pale red coverage rate values from all prepared images for the statistical analysis.