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Morphological variability of individual colour forms of *Cyprinus carpio haematopterus* of different origin

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Abstract. The relevance of the work on the study of morphological indicators of koi lies in the increased attention at international koi exhibitions to such external indicators as colour, shape, and body proportions of fish that occupy high prize places and receive monetary rewards of hundreds of thousands of US dollars. The purpose of the work was to study the morphological features of various coloured forms of various origins. Such indicators are not taken into account in traditional fish breeding, which also adds novelty to the conducted research. 280 koi samples were selected for analysis. The work evaluated the variability of plastic features of fish of individual colour forms (*magoi, kumonryu, utsurimono, kohaku, kawarimono, bekko, doitsu bekko, doitsu kawarimono*) of different origins (Japanese, Turkish, Israeli, and Ukrainian). As a result of the work, it was established that there was not found a statistically significant difference between different colour forms of the same origin. At the same time, a reliable difference was established in fish of Israeli origin in terms of features characterizing the shape and proportions of the head in relation to the proportions of the body. The distribution of morphological indices of the studied individuals of different samples in the space of the main components also confirms the reliable differences of the Israeli morphotype from fish of Japanese, Turkish, and Ukrainian origin according to the characteristics related to the ratios of the head parts and body proportions. The obtained data is the basis for the work of breeders and breeders of koi carp who wish to grow valuable specimens – potential winners of international koi carp competitions

Keywords: koi carp; who; nishiki-goi; method of principal components

Introduction

Common carp was traditionally rised in ponds of various sizes and used for human consumption. It is known that in the isolated mountainous area of Japan between the cities of Nagaoka and Ojiya, about 180 years later, selection and crossing of different colour variations of carp began. The selection and formation of coloured forms began approximately in the 50s of the last century, when decorative fish farming spread massively in Japan. The carp that is known now is a colour variation of common carp (*Cyprinus carpio L.*), which is confirmed by modern genetic studies X. Li *et al.* (2023). In modern conditions, about 80 breeds of carp are known. For convenience, they are divided into main groups based on the characteristics of their colour, the number of which does not have a single point of view. Most researchers distinguish 15 such groups, which are combined by one or more characteristics. Most of the studies characterizing various aspects of koi carp relate to the study of colour inheritance, the study of the genetics of colour forms, thanks to which the common carp was differentiated from the coloured forms of koi (Dong *et al.*, 2020, Luo *et al.*, 2023). At the same time, the individual lines themselves are not differentiated from each other (Jawad *et al.*, 2022; Du *et al.*, 2022). In the process of painstaking selection work, the bulk of the fish is consumed as food, and only single individuals with the most promising and "standard" colour are selected for further work and receive the name "nishiki-goi" or koi (Kaur *et al.*, 2022). In general, the larval period of the life of these fishes is quite well studied (Hajibeglou *et al.*, 2022), as well as their size-age characteristics in adulthood (Nazari *et al.*, 2023). There are a number of studies on the characteristics of survival under the influence of stress factors and diseases (Grynevych *et al.*, 2022; Hasnidar *et al.*, 2023).

Exhibitions and championships are held periodically among carp breeding specialists. When evaluating the "quality" of koi, special attention is paid to the structure of the fish's body. There are only general ideas about the principles of assessing the structure of a koi's body (Nazari *et al.*, 2023). The research of previous years established that koi carp from artificial ponds in

Japan with different abiotic conditions of existence reliably differ in indicators of the external structure of the body, which also affect the quality of standard forms (Huan Yang *et al.*, 2022).

At the same time, the question of the peculiarities of the morphological structure of coloured carp is rather poorly studied. In particular, comparisons of koi carp from wild and domesticated populations indicate an increase in phenotype deviations in the latter. If in the domesticated populations of Japan, the necessary specimens are constantly selected, then in the populations of Israel, Turkey, Iraq, and other countries, there is an opportunity to consolidate the obtained deviations from the standard due to less control (Jawad *et al.,* 2022). The relevance of the conducted research is explained by the fact that the obtained data will help specialists in the breeding of decorative koi carp in achieving better indicators of the morphology of future koi carp. In this regard, the purpose of the work was to study the morphological indicators of different colour forms of carp of various origins, which are not measured during traditional fish boning.

Taking into account many years of human economic and breeding activities and different approaches to assessing the quality of koi breeders in different countries under the condition of the constant complex action of abiotic and biotic factors of the habitat, the authors of the study assumed the presence of certain differences in the body structure of fish, which the authors tried to highlight in this study.

Materials and Methods

280 specimens of koi of different colour forms and different origin were selected for analysis. All of them were taken from the corresponding decorative ponds with similar abiotic conditions and feeding regimes. The work was carried out in strict accordance with the existing norms of bioethics (Directive 2010/63/EU), and the research design itself complied with the recommendations of "Animal Research: Reporting of In Vivo Experiments"– ARRIVE (Percie du Sert *et al.*, 2020). No fish were harmed or exposed to toxic chemicals during the research.

13 groups of fish were formed (Table 1) according to external features and origin by random selection from the corresponding group of fish. The analysis of the morphological variability of koi was carried out according to a set of plastic features: body length to the end of the scaly cover (*l*), head length (*c*), eye diameter (*do*), snout length (*lr*), extraneous space (po), height (*ho*) and width forehead (*io*), length of the upper (*mx*) and lower (*mn*) jaws, height of the head near the back of the head (*hc*) and through the middle of the eye (hc_2), the largest (*H*) and smallest (*h*) body heights, the length of the tail stem (*pl*); from a distance – andedorsal (*aD*), postdorsal (*pD*), antepectral aP*)*, anteventral (aV), anteanal (aA*),* pectroventral (PV), ventroanal (*VA*); length of the bases of the fins – pectoral (*lP*), dorsal (*lD)*, anal (*lA*); the greatest heights of fins – pectoral (*hP*), dorsal (*hD*), anal (*hA*); lengths of the upper (lC_1) and lower (lC_2) blades of the caudal fin (Romanenko, 2006).

Table 1. *Groups of koi of individual colour forms and different origins*

Group	Markings in the drawings	Colour form	Origin	Place of detention
I		*Magoi*	Japanese	Decorative pond of the Nemyshaiv Agrotechnical College
II		*Kumonryu*	+	
III		*Utsurimono*	+	
IV		*Kohaku*	+	
V		*Kawarimono*	Ukrainian	Decorative reservoir of the Arboretum "Olexandria"
VII		*Bekko*	+	
VI		*Doitsu Bekko*	Turkish	
VIII		*Doitsu Kawarimono*	+	

Table 1. Continued

Group	Markings in the drawings	Colour form	Origin	Place of detention
IX		*Bekko*	Ukrainian	Decorative pond of the Nemyshaiv Agrotechnical College
X		*Kawarimono*	+	
XI		*Doitsu Bekko*	Turkish	
XII		*Doitsu Kawarimono*	+	
XIII		*Kawarimono*	Israeli	Decorative reservoir of the Novokakhovsk fish breeding plant of partial fish

Source: author's data

Results and Discussion

Plastic features were measured with an electronic caliper with an accuracy of 0.1 mm. Minimization of the influence of age variability on the variation of signs was achieved by analysing a separate size-age group for each sample by one operator. A total of 280 specimens of koi with average linear dimensions of 61.44±0.20 mm (from 52.89 to 70.34 mm) aged 0+ were analysed. In the calculations, indices of plastic features were used (Pylypenko *et al.*, 2017). To reduce the dimensionality of the data and obtain a smaller number of significant indicators, the analysis of the distribution of the average values of the indices in the individuals of individual samples was carried out in the space of principal components (*PCA)* (English *Principal component analysis).* The above-mentioned analysis, as well as the calculation of the mean, error of the mean, squared deviation and others were carried out using the *Statistica data analysis system 8.0* for *Windows.*

The analysis of indices of morphological variability of koi carp of the studied samples using head (Table 2) and body (Table 3) features, using their comparison according to the Student's t-*test* (criterion), showed that there are no statistically significant differences in fish of individual colour forms of the same origin. In addition, for most of the main indices of the body of fish of different origins, namely, the largest (*H)* and smallest (*h)* body height; more distantly: antedorsal (*aD)*, postdorsal (*pD)*, antepectral (aP*)*, anteventral (aV), anteanal (aA), pectroventral (PV), ventroanal (*VA*); the length of the bases of the fins: pectoral (*lP*), dorsal (*lD)*, anal (*lA*); the greatest heights of fins: pectoral (*hP)*, dorsal (*hD)*, anal (*hA*); there are no statistically significant differences between the lengths of the upper (lC_1) and lower (lC_2) blades of the caudal fin. Statistically significant differences are present in tail stem length (*pl*) from samples of Israeli and Japanese origin.

Table 2. *Plastic signs of koi according to head indices, M±m / min–max*

	Koi_1. sta	Koi_2. sta	Koi_3. sta	Koi_4. sta	Koi_5. sta	Koi_6. sta	Koi_7. sta	Koi_8. sta	Koi_9. sta	Koi_10. sta	Koi_11. sta	Koi_12. sta	Koi_13. sta
c	26.97±0.12 25.90-28.24	27.46±0.67 13.86-32.57	27.30±0.25 25.66-32.00	26.88±0.17 25.81-29.10	25.93±0.27 23.08-27.96	26.21±0.36 24.97-27.49	25.79±0.27 24.23-27.32	25.95±0.36 24.57-27.90	27.54±0.30 25.12-32.57	27.69±0.17 25.83-29.15	26.96±0.21 25.21-29.07	27.22±0.22 24.56-28.93	27.11±0.30 24.67-30.46
	In % of p												
lr	35.77±0.38 31.84-39.91	38.09±1.72 29.66-77.14	34.52±0.51 28.92-39.09	34.61±0.45 31.94-41.31	36.52±0.65 30.67-42.54	38.84±0.82 36.53-43.20	37.38±0.43 34.13-39.63	36.98±0.60 35.55-40.69	37.81±0.57 32.77-43.25	38.94±0.44 35.27-44.20	37.47±0.54 31.94-41.80	36.39±0.53 32.38-42.17	38.52±0.45 34.89-43.32
do	25.74±0.50 21.01-34.32	28.19±1.33 22.41-57.14	25.94±0.34 22.69-28.97	24.73±0.31 21.60-27.33	24.90±0.37 22.65-29.14	24.58±0.75 20.66-26.88	24.38±0.69 19.29-28.71	24.26±0.69 19.71-26.43	22.74±0.42 18.82-26.50	23.37±0.33 20.15-26.64	22.69±0.44 19.11–27.07	22.06±0.40 19.34-26.61	20.75±0.34 17.12-24.54
po	42.18±0.31 40.09-45.58	45.39±2.09 36.21-90.00	42.28±0.36 37.50-45.09	43.27±0.41 37.97-48.09	43.91±0.45 40.36-48.56	43.58±0.67 40.27-46.00	43.58±0.46 40.50-46.89	43.98±0.68 40.53-46.91	44.02±0.56 40.35-50.05	44.20±0.43 39.03-48.51	44.30±0.36 40.38-47.19	43.42±0.55 39.10-48.46	44.01±0.39 39.68-47.51
ho	6.85±0.10 6.22-7.78	8.99±0.79 6.90-27.14	8.34±0.20 6.48-11.17	9.06±0.20 7.62-11.39	5.34±0.23 4.05-8.67	5.12±0.17 4.43-5.91	5.41±0.14 4.64-6.45	5.43±0.16 4.30-6.03	4.67±0.11 3.57-5.50	4.74±0.08 4.20-5.56	4.46±0.08 3.82-5.52	4.52±0.20 4.00-5.28	6.40±0.12 5.41-7.98
io	34.41±0.34 31.32–38.96	33.72±1.38 27.03–64.29	34.46±0.47 30.00-40.69	36.16±0.36 33.54–41.88	34.86±0.42 30.30–38.00	34.18±0.38 32.30–35.44	33.79±0.59 29.69-36.94	34.79±0.92 29.39-38.14	35.49±0.44 31.23-39.56	36.93±0.32 33.65-40.34	36.46±0.41 32.81-40.66	34.93±0.43 31.99–39.37	4.02±0.06 3.46-4.82
mx	24.16±0.30 21.20-26.51	27.01±1.06 20.26-50.00	25.53±0.32 22.08-29.19	26.62±0.34 23.98–30.95	25.87±0.50 21.19-31.31	26.02±0.67 22.51-28.00	26.00±0.59 20.78-29.28	25.42±0.79 21.08-29.52	24.65±0.35 21.05-28.13	24.75±0.53 18.84-28.73	23.71±0.18 21.74-25.32	23.63±0.77 15.23-28.36	27.34±0.32 25.34-29.47

Table 2. Continued

	Koi_1. sta	Koi_2. sta	Koi_3. sta	Koi_4. sta	Koi_5. sta	Koi_6. sta	Koi_7. sta	Koi_8. sta	Koi_9. sta	Koi_10. sta	Koi_11. sta	Koi_12. sta	Koi_13. sta
mn	20.50±0.32 17.10-22.79	22.70±1.02 15.03-42.86	21.81±0.28 18.75-24.84	23.17±0.33 19.62-26.19	22.64±0.44 18.54–26.64	22.54±0.67 19.19-25.00	22.81±0.68 17.65-26.71	21.39±0.86 16.67-24.67	21.18±0.36 17.19-25.00	21.59±0.45 16.83–24.79	20.08±0.33 16.73–23.15	18.93±0.67 12.19-23.26	22.74±0.35 19.69-26.47
hc	72.31±0.42 69.01-77.50	78.35±3.30 69.44-154.29	74.69±0.69 66.25-81.22	75.12±0.58 69.48-80.21	72.41±0.57 67.61-78.67	73.93±1.06 70.85-80.11	74.26±1.05 69.02-81.53	73.74±1.00 67.74-76.65	72.76±0.85 65.35–82.21	68.80±2.00 25.23–80.50	76.26±0.88 69.58-84.74	74.10±0.75 68.32-82.07	69.28±0.59 64.75-75.83
hc2	62.60±0.42 58.72-67.82	66.52±3.09 58.15-137.14	63.25±0.60 57.50-69.08	61.89±0.71 54.55-68.06	60.68±0.49 56.51–64.50	60.59±0.94 54.61–64.16	60.57±0.94 53.73–66.50	60.91±0.57 57.79-63.23	59.08±0.58 52.89-66.35	59.70±0.53 55.26-65.66	62.06±0.71 55.57-68.77	64.04±0.65 58.56-70.34	59.34±0.76 53.85-67.25

Source: author's development

Table 3. *Plastic signs of koi according to the indices of the body, M±m/min-max*

	Koi_1. sta	Koi_2. sta	Koi_3. sta	Koi_4. sta	Koi_5. sta	Koi_6. sta	Koi_7. sta	Koi_8. sta	Koi_9. sta	Koi_10. sta	Koi_11. sta	Koi_12. sta	Koi_13. sta
l	61.78±1.50 50.00-79.50	46.96±1.17 36.00-57.50	53.20±1.02 44.50-65.50	57.49±1.48 44.00-74.10	68.73±2.20 47.00-88.50	67.44±3.09 59.50-85.50	73.25±2.54 59.80-92.50	65.98±2.12 60.50-81.30	72.18±1.91 56.15-90.98	69.25±1.29 56.40-79.90	71.50±1.97 53.31-85.99	69.44±1.46 54.78-81.19	86.36±1.92 69.58-100.47
						In % of l							
lcor	54.45±0.38 48.91-59.46	53.74±0.73 49.15-67.79	53.84±0.33 49.17-56.18	54.06±0.36 50.98-57.41	54.83±0.56 49.74-63.78	54.92±0.26 54.04-55.96	55.13±0.59 51.09-58.26	54.72±0.64 51.70-58.89	54.76±0.50 49.15-62.63	55.11±0.40 51.14-58.42	56.50±0.37 52.12-59.42	56.87±0.35 53.69-60.33	55.25±0.56 49.24-60.45
H	27.94±0.16 26.43-29.73	26.89±0.44 22.40-33.63	27.48±0.23 25.54-30.27	27.70±0.30 23.61-30.00	25.87±0.35 23.12-28.27	23.75±1.42 14.44-27.95	26.01±0.34 24.07-27.66	25.39±0.37 24.26-27.60	27.87±1.08 4.92-37.62	29.03±0.19 26.79-30.48	26.49±0.18 24.79-28.11	27.10±0.35 22.84-29.81	25.88±0.28 23.93-28.60
h	9.99±0.11 8.92-10.73	9.72±0.15 8.51-12.04	10.08±0.09 9.16-11.26	10.23±0.10 8.89-10.98	9.76±0.16 8.15-11.34	9.66±0.22 8.76-10.46	9.37±0.19 8.19-10.51	9.51±0.22 8.52-10.86	10.31±0.12 9.39-11.77	10.73±0.10 9.86-11.76	9.77±0.15 8.64-11.29	10.05±0.15 8.57-11.41	10.20±0.15 8.90-11.78
ad	41.04±0.22 39.31-43.17	41.38±0.38 38.72-48.50	41.51±0.19 40.50-43.84	41.13±0.21 38.82-44.03	41.97±0.42 39.33-48.78	43.00±0.41 40.88-44.50	41.58±0.42 39.61-43.78	41.29±0.51 38.45-43.43	44.13±0.48 40.34-53.14	43.19±0.26 40.80-46.20	43.49±0.24 40.80-45.86	43.99±0.29 40.21-46.56	42.61±0.45 38.72-48.32
pD	39.80±0.31 37.23-43.51	39.78±0.56 35.41-51.33	38.28±0.61 25.00-41.33	39.40±0.27 36.76-41.94	40.25±0.49 32.15-42.84	38.76±1.43 29.67-43.26	39.88±0.41 37.67-42.95	39.82±0.51 37.11-41.97	39.55±0.39 34.01-44.00	39.74±0.40 35.77-44.24	40.56±0.25 37.89-42.82	40.75±0.31 38.15-43.49	41.32±0.35 37.18-44.68
pl	11.31±0.20 9.10-12.72	13.62±0.31 10.87-16.81	12.63±0.20 11.14-15.97	14.54±0.46 11.37-19.51	11.88±0.25 9.71-14.53	13.10±0.29 12.19-14.27	12.22±0.31 9.16-14.36	11.09±0.35 9.69-12.42	13.39±0.21 11.19-15.20	13.15±0.23 10.74-15.41	13.76±0.20 12.37-16.55	12.17±0.21 10.19-13.91	14.56±0.24 12.71-16.34
aP	26.87±0.15 25.81-28.31	27.13±0.27 24.20-31.15	27.24±0.14 25.86-28.57	26.21±0.18 24.59-27.91	26.00±0.28 23.55-28.80	26.04±0.44 24.31-27.81	25.81±0.25 24.14-27.43	25.89±0.25 24.71-27.20	25.43±0.25 22.37-27.93	25.35±0.22 23.47-27.57	25.22±0.30 22.83-28.27	25.76±0.27 23.53-28.12	27.01±0.31 23.05-29.85
aV	43.70±0.56 39.42-56.13	43.19±0.38 40.20-50.09	43.12±0.17 41.55-44.80	43.15±0.28 40.34-45.82	41.55±0.30 38.46-44.29	41.99±0.51 39.33-43.97	42.29±0.43 40.39-45.13	42.19±0.33 40.76-43.79	42.86±0.38 37.06-48.00	42.90±0.23 40.11-44.91	43.26±0.27 40.90-46.05	43.46±0.32 40.35-47.04	43.57±0.41 39.94-47.00
aA	60.67±0.17 58.65-61.94	60.19±0.55 57.10-70.97	60.29±0.26 57.74-62.40	60.31±0.31 57.56-63.75	60.09±0.27 56.62-62.14	61.11±0.44 59.43-63.18	61.98±0.35 60.48-64.92	60.54±0.27 59.22-61.85	62.32±0.59 54.58-71.09	62.09±0.31 58.78-64.73	61.43±0.28 58.84-64.04	62.87±0.31 59.62-65.65	60.94±0.45 56.78-65.42
lD	24.49±0.24 22.31-26.23	25.37±0.32 21.06-29.20	25.11±0.26 22.56-28.76	24.62±0.23 22.36-26.72	27.49±0.37 23.80-30.85	26.15±0.75 23.76-29.47	26.41±0.53 22.61-29.82	27.16±0.36 25.44-28.39	25.52±0.49 21.56-31.12	26.12±0.39 20.76-29.39	25.10±0.23 22.12-27.01	26.04±0.25 23.41-28.88	25.03±0.47 21.17-28.68
hD	16.14±0.19 13.76-17.92	16.33±0.19 13.75-18.51	16.31±0.25 13.44-18.67	15.96±0.18 14.38-17.56	13.49±0.36 10.00-16.50	12.79±0.59 9.82-14.83	12.78±0.38 9.72-15.09	13.78±0.76 9.70-16.21	13.33±0.24 9.34-15.07	13.72±0.19 12.16-15.63	13.13±0.26 11.09-15.25	12.50±0.30 9.91-15.22	14.89±0.26 12.74-17.39
lA	6.36±0.10 5.44-7.56	6.83±0.19 4.60-8.70	6.58±0.12 5.56-7.65	7.18±0.14 5.45-8.41	6.71±0.17 5.03-8.76	6.43±0.10 6.03-6.85	6.27±0.10 5.49-6.82	6.88±0.18 6.27-8.11	5.62±0.11 4.26-6.60	5.53±0.12 4.39-6.38	5.65±0.14 3.93-6.42	5.95±0.10 5.27-6.90	7.22±0.10 6.21-8.09
hA	13.70±0.13 12.14-14.76	14.21±0.21 12.68-17.88	13.68±0.18 12.18-15.33	13.37±0.13 11.45-14.26	13.27±0.25 9.31-14.88	12.31±0.26 11.13-13.33	12.83±0.29 11.10-14.97	13.51±0.27 12.24-14.64	12.48±0.15 10.81-13.90	13.21±0.29 9.70-15.87	12.58±0.28 9.13-14.84	13.91±0.25 11.55-16.01	15.15±0.23 13.54-18.08
lP	14.19±0.18 11.97-15.37	15.05±0.21 13.00-16.99	15.00±0.20 12.93-17.07	15.27±0.18 13.11-17.25	14.46±0.17 12.87-16.22	13.84±0.43 11.54-15.15	14.08±0.28 12.28-15.65	14.11±0.27 12.60-15.16	14.43±0.21 12.51-17.54	14.57±0.17 11.94-15.90	14.06±0.22 12.19-15.84	13.74±0.23 1.55-15.93	14.74±0.23 12.77-16.60
lV	13.23±0.10 12.38-14.04	13.59±0.18 12.16-16.46	13.19±0.16 11.61-14.71	13.46±0.17 12.17-15.14	12.88±0.14 11.66-14.00	12.30±0.31 10.87-13.25	12.46±0.25 10.84-14.04	12.56±0.33 10.64-13.85	13.62±0.18 12.44-16.57	13.62±0.18 10.96-15.08	13.81±0.15 12.15-15.11	12.98±0.20 11.37-15.21	14.27±0.25 12.01-16.98
PV	17.46±0.16 15.68-18.91	17.76±0.28 15.20-20.17	17.66±0.14 16.35-19.12	18.06±0.22 16.49-19.86	16.33±0.21 13.74-18.23	16.63±0.39 15.03-18.82	16.53±0.30 14.17-19.08	16.89±0.26 15.72-17.75	17.37±0.18 15.37-19.36	17.72±0.14 15.63-18.81	17.58±0.24 15.41-20.08	18.00±0.24 16.12-20.23	16.85±0.20 14.55-18.25
VA	18.06±0.15 16.27-19.14	17.75±0.23 16.00-21.24	18.43±0.15 17.12-20.31	18.56±0.17 16.75-20.63	18.54±0.18 17.32-20.69	18.37±0.29 17.13-19.47	19.41±0.27 17.78-20.97	18.46±0.21 17.36-19.42	19.72±0.24 17.18-23.31	19.90±0.20 18.27-22.06	18.92±0.26 15.72-20.98	19.85±0.20 18.01-21.69	18.14±0.20 16.15-19.89
IC1	18.88±0.22 17.31-20.83	19.64±0.22 17.34-21.28	19.24±0.24 16.61-21.98	20.10±0.30 16.79-22.66	19.23±0.33 16.34-21.74	19.44±0.35 17.75-21.19	18.41±0.36 17.14-22.22	18.95±0.32 17.35-20.50	19.36±0.28 14.80-22.63	20.49±0.21 17.94-22.74	18.79±0.27 16.29-20.98	19.36±0.28 14.80-22.63	19.41±0.33 15.62-22.13
IC2	20.11±0.16 18.21-21.64	20.71±0.30 18.59-25.49	20.25±0.20 18.22-22.48	20.90±0.31 18.29-23.91	20.02±0.44 12.87-22.45	20.10±0.40 18.09-21.99	19.14±0.42 16.10-22.48	19.52±0.30 18.41-21.00	19.81±0.30 15.03-24.11	21.20±0.19 19.27-23.30	19.71±0.20 18.21-22.17	19.81±0.30 15.03-24.11	21.06±0.34 18.08-24.98

Source: author's development

However, according to the indices of the head, a rather interesting picture is observed: there are statistically significant systematic differences between fish of Israeli and Japanese, as well as Ukrainian and Turkish origin in terms of the length of the snout (lr), the diameter of the eye (do), the absent *space* (po), the height of the forehead (*ho*), width of the forehead (*io*), length of the upper jaw (*mx*), height of the head near the back of the head (*hc*) and through the middle of the eye (hc_2). At the same time, fish of Japanese origin differ slightly from fish of Ukrainian and Turkish origin only in the height of the forehead (*ho*) and the length of the snout (*lr*).

The analysis of the variation of the obtained samples using the quadratic deviation (σ) also

showed that according to the features of the shape and proportions of the body of the fish, the studied groups were characterized by low indicators. At the same time, the indicators of the shape and proportions of the head had the maximum values. Therefore, in order to evaluate the quality of young koi carp, which are planned to be used for ornamental fish farming and international exhibitions, in addition to traditional normative indicators, special attention should be paid to the study and analysis of indicators characterizing the shape and proportions of the head.

For a more complete and clear understanding of the trends in the variability of plastic features of carp, the obtained samples were examined using the method of principal components. The distribution of studied koi individuals of different origin in the space of the main components demonstrated the reliability of the differentiation of the samples according to the set of studied morphological features according to the first (*Factor 1*) and third (*Factor 3*) main components, which provide about 30% of their morphological variability (Fig. 1).

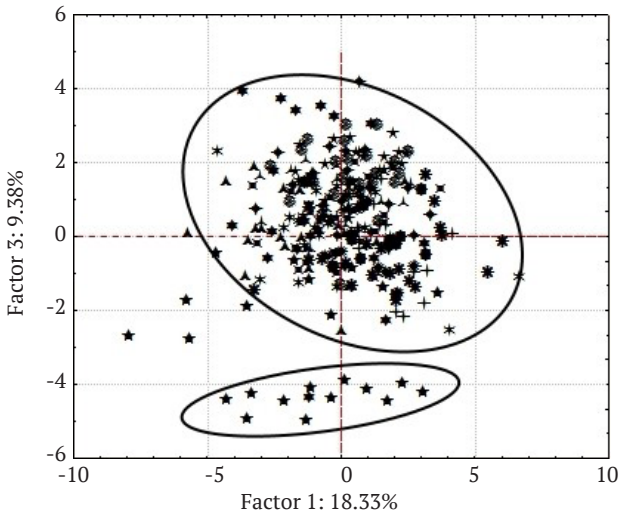

Figure 1. Distribution of individual groups of koi in the space of the first and third main components according to the set of plastic features

Note: designation of groups of which see in Table 1

In the space of the main components according to the set of indices of external signs, two scatterers are formed, clearly differentiated portion with a statistically reliable hiatus according to the first and third components (*Factor 1* and *Factor 3)*. The first scatter is formed by fish of Japanese, Turkish and Ukrainian origin, regardless of individual colour forms. The second scatter included fish of Israeli origin, which indicates the presence of some adaptive changes in the morphotype of the above-mentioned groups. The conducted analysis allows us to accurately state the presence of morphological differentiation of fish of Israeli origin from the fish of all other koi carp studied by us.

The analysis of the eigenvalues of the components shows that the greatest contribution to differentiation according to the first component is the largest (*H*) and smallest (*h*) body height, antedosal (*aD*), anteventral (*aV*) and anteanal (*aA*) distances, as well as the length of the base of the pectoral fin, and according to the third – the diameter of the eye (*do*), the width of the forehead (*io*) and the length of the upper jaw (mx) (Table 4).

Table 4. *Eigenvalues of the main components*

Indicators	Factor 1	Factor 2	Factor 3
lcor	-0.445715	-0.323915	-0.143927
lr	-0.201176	-0.313997	-0.393066
do	0.187197	0.405049	0.539620
po	-0.191437	-0.195516	-0.199854
ho	0.089693	0.800161	0.255138
io	0.164883	-0.297427	0.597280
mx	0.062909	0.467734	-0.517222
mn	0.136142	0.435543	-0.472400
lc	-0.774133	0.106925	0.207097
hc	0.093956	0.046720	0.468378
hc_2	0.112898	0.099871	0.532598
H	-0.553657	-0.006104	0.343649
h	-0.636626	0.031700	0.056675
aD	-0.676122	-0.475133	-0.025441
pD	-0.456830	-0.160428	-0.285199
pl	-0.264125	0.186603	-0.338132
aP	-0.512868	0.425999	0.085375
aV	-0.721078	0.066149	0.200807
aA	-0.751439	-0.421773	0.046978
lD	-0.116583	-0.162999	-0.205824
hD	-0.147218	0.755906	0.150866
lA	-0.054958	0.592956	-0.262066
hA	-0.368351	0.493726	-0.245714
lP	-0.417155	0.470516	0.071925
lV	-0.577681	0.303097	-0.152358
PV	-0.443651	-0.027143	0.395253
VA	-0.450057	-0.569926	-0.007821
lC_1	-0.442051	0.301600	0.088646
lC_2	-0.505441	0.398568	-0.017637

Source: author's development

Thus, the differentiation of the studied fish in the space of the main components is provided by the features characterizing the ratio of the proportions of the head and body. Long-term selection work, various approaches to assessing the quality of breeders and the predominant orientation of breeders to obtain offspring of a certain colour range contributed to the consolidation of certain "morphological deviations" in koi carp. These indicators are practically insignificant for fish breeding, and in traditional commercial fish farming they were not paid attention at all. In ornamental aquaculture, these aspects are of key importance and significantly affect the class, quality, and prospects of individual fish at international exhibitions, and, accordingly, the price of individual fish. The issue is that during international exhibitions, experts analyse such indicators as body shape, body proportions, swimmers' proportions, etc. So, for example, the shape of the head should be symmetrical and without any deviations, the length of the fins should be average, not long and not short (Kuroki, 1990; Axelrod *et al.*, 1996). That

is, such indicators are not measured on farms during traditional credit rating (Grynevych *et al.*, 2022; Nazari *et al.*, 2023), and these little things distinguish an ordinary fish from an exhibition winner. Thus, the farm, having good industrial herds and carrying out simple measurements, can receive significant additional income, which can even cover the entire product revenue of the enterprise for a year.

The issue is complicated by the fact that various housing conditions, feeding regimes and stresses during long-term transportation (including air travel) can induce directed adaptive changes in phenotypes, which determine intrabreed differentiation, which is manifested externally at the level of plastic (measured) body features. That is, there is an opinion that depending on the conditions of keeping, the same fish will have a different morphotype if it is kept in various conditions. In our research, this factor was negated by the fact that was chosen almost the same artificial decorative reservoirs in the same climatic zone with similar living conditions. At the same time, it is evident that if they are grown in different conditions, they can give a different result. The author's research differs in that the use of the ichthyological research method (biological sciences) was combined to achieve fishery goals (agricultural sciences). For the sake of fairness, it should be noted that fish farmers perform certain measurements during the grading of brooders, but they aim to determine the quality of the brooder and its size and weight characteristics in the fish farming sense of this term, which does not correspond to the values of decorative aquaculture (Balon, 2004; Ghosh *et al.*, 2012; Jawad *et al.*, 2022). For example, fish breeders do not study purely meristic (counting) ichthyological signs, namely, wine is a mathematical reflection of the shape and proportion of the body of fish, which play a key role in the evaluation of ornamental objects of aquaculture.

Artificial breeding of ornamental koi carp imposes a great responsibility on breeders and fish farmers to preserve the authentic body shape and colour of the fish. At the same time, there are quite a few real specialists and connoisseurs of koi. The prestige factor plays here: it is nice to have carp swimming in a fountain in the front yard of a wealthy house or in the office of a large company. This approach created the demand for koi carp. In the pursuit of obtaining koi carp of the required colour, there was a loss of preservation of their traditional morphological parameters of the external structure, which was confirmed in our work. Different approaches to the targeted selection of breeders for crossings also lead to certain changes in koi phenotypes of different origins, which determine the morphological differentiation of fish of individual branches, which is most evident at the level of plastic (measurement) body features, which are evaluated at international competitions. Established changes in head proportions in koi of Israeli origin are provided by stabilizing selection, which makes fish of this group more viable in certain abiotic conditions of existence due to increased hydrodynamic and trophological capabilities, which is necessary for life in a warmer climate. Thus, the increase of the head and gill covers increases the volume of water used for breathing, which is better in conditions of increased water temperature. An increase in the head has also been noted for Iraqi reservoirs (Kataoka, 1989; Jackson *et al.*, 2000; Jawad *et al.*, 2022).

Established differences in the appearance of Israeli koi carp confirm the hypothesis voiced by E.K. Balon (2004) about the possible fixation of individual deviations in appearance in koi populations, which may be connected with a less strict selection of broodstock morphotypes. The author's studies specify and confirm the above opinion, indicating that the existing changes are related to the features of the shape and proportions of the head and their relationship with the proportions of the body.

However, obtaining high-class, competitive prize-winning fish of international exhibitions

will be quite difficult even for a smaller number of individuals. Our research has shown that Israeli koi morphologically differ from fish of Japanese, Turkish and Ukrainian origin. The established differences are related to features of the shape and proportions of the head, as well as their relationship with the proportions of the body. Specialists should take this feature into account when selecting objects for ornamental fish farming, one of which is the variegated koi carp.

Conclusions

Research on assessing the quality of young koi carp, which are intended for ornamental fish farming and participation in international exhibitions, revealed that in addition to traditional normative indicators, special attention should be paid to the analysis of body shape and head proportions. These indicators are of key importance for achieving a positive result at international exhibitions. To study the external structure of various forms of koi, traditional ichthyological meristic morphological measurements are used. These measurements are a numerical representation of the body shape and proportions of the fish, which is an important aspect in ornamental aquarism. The analysis showed that no statistically significant differences were found in fish of different colour forms, but of the same origin. However, statistically significant differences were found between the appearance of Israeli carp, related to the shape and proportions of the head, as well as their relationship with the body proportions. This is confirmed by the analysis of the spatial distribution of the main components, which indicates systematic differences in appearance. Taking into account these results, it is recommended that nurseries and koi carp fans pay attention to morphological characteristics in addition to evaluating the colour range during the evaluation of breeders. This will help select individuals with the most appropriate body shapes and proportions that have the greatest potential for successful participation in international competitions. Summarizing, the research provides important guidelines for improving the breeding of koi carp in order to obtain the highest quality and aesthetically attractive specimens for decorative fish farming and participation in international exhibitions.

One of the promising future directions of research is the establishment of clear genetic markers that would indicate fish with body proportions close to the ideal standards of international exhibitions. Such markers would help breeders to more effectively select breeders for further breeding and improvement of the genetic pool. In addition, the question of imitation of colour in carp remains open. Given the fact that only a small part of the fish has the correct colour, there are prospects to move from random breeding to the purposeful selection of only those individuals that meet all the necessary parameters. This task is possible in the future if there is more detailed knowledge about the genes responsible for colouring. The novelty of the conducted research is that, for the first time, ichthyological methods of studying the morphology of fish species were applied for the digital expression of the morphological structure of the body of fish in ornamental aquaculture.

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Conflict of Interest

None.

References

[1] Axelrod, H.R., Balon, E.K., Hoffmann, R.C., Rothbard, S., & Wohlfarth, G.W. (1996). *The completely illustrated guideto koi for your pond*. New Jersey: TFH Publications.

[2] Balon, E.K. (2004). About the oldest domesticates among fishes. *Journal of Fish Biology*, 65(1), 1-27. doi: 10.1111/j.0022-1112.2004.00563.x.

[3] Directive 2010/63/EU. (2010, September). *"On the Protection of Animals Used for Scientific Purposes"*. Retrieved from https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:276:0033:0079:en:PDF.

[4] Dong, Z., Luo, M., Wang, L., Yin, H., Zhu, W., & Fu, J. (2020). MicroRNA-206 regulation of skin pigmentation in koi carp (*Cyprinus carpio L.*). *Frontiers in Genetics*, 11, article number 47. doi: 10.3389/fgene.2020.00047.

[5] Du, Y., Han, Y., Zhang, R., Zhang, Y., Bao, S., & Cao, Y. (2022). Dietary baicalein improves growth performance, antioxidant activity, and intestinal flora of koi carp (*Cyprinus carpio*). *Aquaculture Reports*, 27, article number 101421. doi: 10.1016/j.aqrep.2022.101421.

[6] Ghosh, A.K., Biswas, S., Sarder, L., Sabbir, W., & Rahaman, S.M.B. (2012). Induced breeding, embryonic and larval development of Koi carp (*Cyprinus carpio*) in Khulna, Bangladesh. *Mesopotamian Journal of Marine Science*, 27(1), 1-14.

[7] Grynevych, N.E., Khomiak, O.A., Sliusarenko, A.O., Trofymchuk, A.M., Zharchynska, V.S., Osadcha, Y.V., & Tkachenko, O.V. (2022). Adaptive response of koi carp (*Cyprinus carpio koi*) to low and high temperatures in experimental conditions. *Scientific Messenger of LNU of Veterinary Medicine and Biotechnologies. Series: Agricultural Sciences*, 24(97), 137-145. doi: 10.32718/nvlvet-a9724.

[8] Hajibeglou, A., Sudagar, M., Mazandarani, M., & Machanlou, M. (2022). Study on feasibility of sperm injection in ovarian for induced propagation of Koi carp (*Cyprinus carpio* var. Koi). *Aquatic Animals Nutrition*, 8(2), 43-51. doi: 10.22124/janb.2023.24081.1191.

[9] Jackson, K., Goldberg, D., Yehuda, Y., & Degani, G. (2000). Molecular DNA variation in koi (Cyprinus carpio) of various color patterns. *Israeli Journal of Aquaculture. – Bamidgeh*, 52, 151-158.

[10] Jawad, L.A., Abed, J.M., Ibáñez, A.L., & Al-Faisal, A.J. (2022). Morphometric and meristic characters of cultured and wild carp, *Cyprinus carpio L.*, populations (Southern Iraq). *Fisheries & Aquatic Life*, 30(2), 95-103. doi: 10.2478/aopf-2022-0009.

[11] Kataoka, M. (1989). *Nishikigoi dangi (Short stories)*. Kumagaya: Takayoshi Kataoka.

[12] Kaur, G., Kaur, V.I., Khairnar, S.O., & Shanthanagouda, A.H. (2022). Optimizing stocking density for rearing ornamental koi carp in pond cage aquaculture system. *Indian Journal of Ecology*, 49(3), 873-878. doi: 10.55362/IJE/2022/3609.

[13] Kuroki, T. (1990). *Manual to Nishikigoi*. Shimonoseki: Shuji Fujita.

[14] Li, X., Zheng, D., Luo, M., Yang, Zh., Guo, J., Wang, L., & Dong, Z. (2023). Genetic variation analysis of mtDNA D-loop sequences in different body color koi carp and FFRC No. 2 strain common carp. *Journal of Shanghai Ocean University*, 32(2), 266-274. doi: 10.12024/jsou.20211103632.

[15] Luo, M., Shi, X., Guo, J., Lin, K., Zhu, W., Fu, J., Wang, L., & Dong, Z. (2023). Deep spatiotemporal transcriptome analysis provides new insights into early development of koi carp (*Cyprinus carpio* var. koi). *Aquaculture*, 575, article number 739767. doi: 10.1016/j.aquaculture.2023.739767.

[16] Hasnidar, Nai, A.T., & Dentalisarni, A. (2023). Effect of feed enrichment with probiotics on vitality koi fish (*Cyprinus rubrofuscus*). *International Journal of Life Science and Agriculture Research*, 2(6), 124-128. doi: 10.55677/ijlsar/V02I06Y2023-07.

[17] Nazari, K., Hosseini Shekarabi, S.P., & Sahihi, S. (2023). Effect of different stocking density on some growth performance and skin color of Koi carp fry (*Cyprinus carpio var. Koi Linnaeus*, 1758) reared in concrete, earthen and fiberglass ponds. *Journal of Aquaculture Development*, 16(4), 115-125. doi: 10.52547/aqudev.16.4.119.

[18] Percie du Sert N. *et al*. (2020) Reporting animal research: Explanation and elaboration for the ARRIVE guidelines 2.0. *PLOS Biology,* 18(7), article number e3000411. doi: 10.1371/journal.pbio.3000411.
[19] Pylypenko, Yu.V., Shevchenko, P.G., Tsedyk, V.V., & Kornienko, V.O. (2017). *Methods of ichthyological research*. Kherson: OLDI-PLUS.
[20] Romanenko, V.D. (Ed.). (2006). *Methods of hydroecological research of surface waters*. Kyiv: LOGOS.
[21] Huan Yang, M.D., Wang, Q., Zhao, R., Li, Q.S., Cui, M.S., Zhang, Y., & Li, J.T. (2022). *Cyprinus carpio* (common carp). *Trends in Genetics*, 38(3), 305-306. doi: 10.1016/j.tig.2021.11.002.

Морфологічна мінливість окремих кольорових форм *Cyprinus carpio haematopterus* різного походження

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Анотація. Актуальність роботи з вивчення морфологічних показників кої полягає у підвищеній увазі на міжнародних виставках кої до таких зовнішніх показників як забарвлення, формі і пропорціям тіла риб, що займають високі призові місця і отримують грошові винагороди у сотні тисяч американських доларів. Метою проведених робіт

було вивчити морфологічні особливості різних кольорових форм різного походження. Подібні показники не враховуються у традиційному риборозведенні, що також додає новизни проведеним дослідженням. Для аналізу було відібрано 280 зразків кої. В роботі оцінювалась мінливість пластичних ознак риб окремих кольорових форм (*magoi, kumonryu, utsurimono, kohaku, kawarimono, bekko, doitsu bekko, doitsu kawarimono*) різного походження (японського, турецького, ізраїльського і українського). У результаті роботи було встановлено що статистично достовірної різниці між різними кольоровими формами однакового походження нами не виявлено. При цьому, встановлено достовірну різницю у риб ізраїльського походження за ознаками, що характеризують форму і пропорції голови у співвідношенні із пропорціями тіла. Розподіл морфологічних індексів вивчених особин різних виборок в просторі головних компонент також підтверджують достовірні відмінності ізраїльського морфотипу від риб японського, турецького і українського походження за ознаками, що пов'язані із співвідношеннями відділів голови та пропорцій тіла. Отримані дані є основою для роботи селекціонерів і розплідників коропів кої, які бажають виростити цінні екземпляри – потенційних переможців міжнародних змагань коропів кої

Ключові слова: короп кої; кой; нішікі-гой; метод головних компонент