

Truss morphometric and meristic analysis of Nile tilapia (*Oreochromis niloticus*) strains from cultivation ponds in Samarinda City, Indonesia

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Abstract. Currently, many strains or varieties of Nile tilapia (*Oreochromis niloticus* Linnaeus, 1758) are kept by fish cultivators in Indonesia, such as red tilapia, white tilapia, black tilapia, and various hybrid crosses. These strains have been selectively bred or naturally occurring variants that exhibit different colors, patterns, growth rates, and other desirable traits. The large diversity of phenotypes in the form of strains in Nile tilapia opens opportunities to be utilized in breeding and aquaculture programs. However, the utilization of phenotypic diversity for breeding and cultivation purposes requires an introduction to the characteristics of these strains. The purpose of the study was to determine the morphological diversity between the varieties of Nile tilapia, including black tilapia, white tilapia, red tilapia, stocky tilapia, and larasati tilapia, from the collection and to estimate their relationships based on the level of diversity and similarity between populations. Morphological characterization was carried out using truss morphometric and meristic methods. Truss morphometric data were applied to principal component analysis (PCA), while meristic character data were analyzed descriptively by reviewing the literature. Kinship of five strains was tested by cluster analysis. The results of this study show that the character that strongly contributes to the differences in morphological shape in black and stocky tilapia are characters B1 (the distance from the front of the base of the ventral fin to front of the anal fin) and characters B3 (the distance from the front end of the base of dorsal fin rays to the front of the anal fin base), while the body shapes of red tilapia, white tilapia, and larasati tilapia tend to be more similar. Based on cluster analysis, it reveals that larasati tilapia, red tilapia, and white tilapia cluster into a single group, whereas stocky tilapia and black tilapia tend to form a distinct group. There are no significant differences between red tilapia, white tilapia, larasati tilapia, stocky tilapia, and black tilapia based on meristic characters.

Key Words: fish introduction, morphological characterization, truss morphometrics, scales.

Introduction. Nile tilapia (*Oreochromis niloticus* Linnaeus, 1758) is a freshwater fish that exhibits high adaptability and tolerance to environmental changes, particularly salinity. The species is commonly found in rivers, lakes, reservoirs, and other freshwater bodies. This omnivorous fish has a wide vertical distribution, ranging from the upstream areas of rivers with relatively low temperatures to estuaries, waters with higher temperature conditions, and saline aquatic environments (Lowe-McConnell 2000). According to El-Sayed & Fitzsimmons (2023), the natural habitat of Nile tilapia is the upper reaches of the Nile River in the Uganda region of Africa.

In Indonesia, Nile tilapia is a species of fish imported from several countries. It has been imported to Indonesia as an excellent commodity fish for consumption because it has thick flesh, quite a tasty flavor, can reach a large size, has high protein content, and has relatively affordable price (Wahyudewantoro & Rachmatika 2016).

Nile tilapia was first introduced to Indonesia from Taiwan in 1969, known as the strain (or variety) Tilapia 69. In 1981, Indonesia introduced another strain of Nile tilapia from the Philippines with the aim of improving its genetic quality, known as Red NIFI. In 1984, after the importation of Red NIFI tilapia, Indonesia introduced another Nile tilapia strain from Thailand, known as Black Citralada. In 1994, the Freshwater Fisheries Research Centre in Jakarta introduced the 'superior' Nile tilapia strain from the Philippines known as GIFT tilapia (Genetic Improvement of Farmed Tilapia) 4th generation, and 6th

generation in 1997. Furthermore, in 2006, Indonesia developed domestically selected Nile tilapia varieties such as Nirwana (Nila Strain Wanayasa) and GESIT (Genetically Supermale Indonesian Tilapia). In 2009, the Indonesian government developed another Nile tilapia variety named BEST (Bogor Enhancement Strain Tilapia) tilapia (Ariyanto et al 2011).

Currently, numerous strains or varieties of Nile tilapia have been developed in the Indonesian community, especially fish farmers, such as red tilapia, white tilapia, black tilapia, and other crosses (Wahyudewantoro & Rachmatika 2016). The phenotypic diversity of Nile tilapia varieties provides an opportunity to be utilized in breeding and aquaculture programs. However, utilizing the diversity of Nile tilapia varieties for breeding and farming purposes requires an understanding of the morphological characteristics of these varieties.

The simplest method of characterisation involves making morphological observations. One such method that can provide highly accurate results is truss morphometric measurement. Measuring morphometric characters using a truss network pattern provides a more comprehensive picture of body shape. The truss network pattern is a series of measurements between landmarks, arranged horizontally, vertically, and diagonally to enable a detailed and specific analysis of the fish's body shape (Chakraborty 2022). According to Strauss & Bookstein (1982), the truss network pattern produces a more systematic geometric characterization of fish body shape and shows an increased ability to characterize differences in body shape. Moreover, Turan (1999) stated that the truss network pattern is better than traditional morphometrics because in the traditional morphometric method, the number of trusses provided is very restricted, so it is less able to provide an overview of body shape.

In contrast to morphometric characters, which focus on the body parts measurement for characterization, meristic characters are related to the number of body parts of a fish (counting methods). Variables included in meristic characters are the number of scales on the lateral line, below the lateral line, and above the lateral line, the number of gill rakers, and the number of hard and soft rays on the dorsal fin, pectoral fin, pelvic fin, anal fin, and caudal fin (Jusmaldi et al 2016).

Several characterization studies using the truss morphometric method have shown to be able to provide better results compared to characterization using conventional methods. Ariyanto & Imron (2002) utilized this approach to characterize Nile tilapia strain 69, GIFT G-3, and GIFT G-6. Nuryadi et al (2008) applied the truss morphometric method to assess seventeen third-generation Nile tilapia strains (G-3). Similarly, Ariyanto et al (2011) employed this technique to study several tilapia varieties in West Java. Muhotimah et al (2013) further demonstrated its efficacy by characterizing the larasati F5 tilapia strain and its parent generation in Klaten Regency, Indonesia. Additionally, the truss morphometric method has been recognized as a valuable tool for fish stock identification, as reported by Rawat et al (2017). This study aims to characterize several Nile tilapia varieties using both truss morphometric and meristic methods to better understand their phenotypic differences.

Material and Method. Nile tilapia samples were taken from three aquaculture ponds owned by fish farmers in Samarinda City, namely Pak Dayat, Sido Berkah Unggul Joyo, and Mina Sembada Berdikari during April 2023 (Figure 1). Details of the varieties of tilapia and their collection places are as follows: three varieties of tilapia fish were collected from Pak Dayat's aquaculture pond, namely red tilapia, white tilapia, and larasati tilapia; the stocky tilapia variety was collected from the Sido Berkah Unggul Joyo aquaculture pond, and the black tilapia variety was collected from the Mina Sembada Berdikari aquaculture pond. A total of 30 individual samples of each tilapia variety were collected. The individual of Nile tilapia varieties were collected randomly to avoid unwanted selection processes. Nile tilapia samples representing each variety were photographed using a Canon-brand digital camera (Figure 2). Collected tilapia individuals were killed using the rapid cooling method by placing the fish in a container of water at $\pm 2^{\circ}\text{C}$. Furthermore, each Nile tilapia varieties was stored separately in a plastic box containing 10% formalin. Samples of tilapia varieties were then taken to the Animal Ecology and Systematics Laboratory at Mulawarman University for truss morphometry measurements.

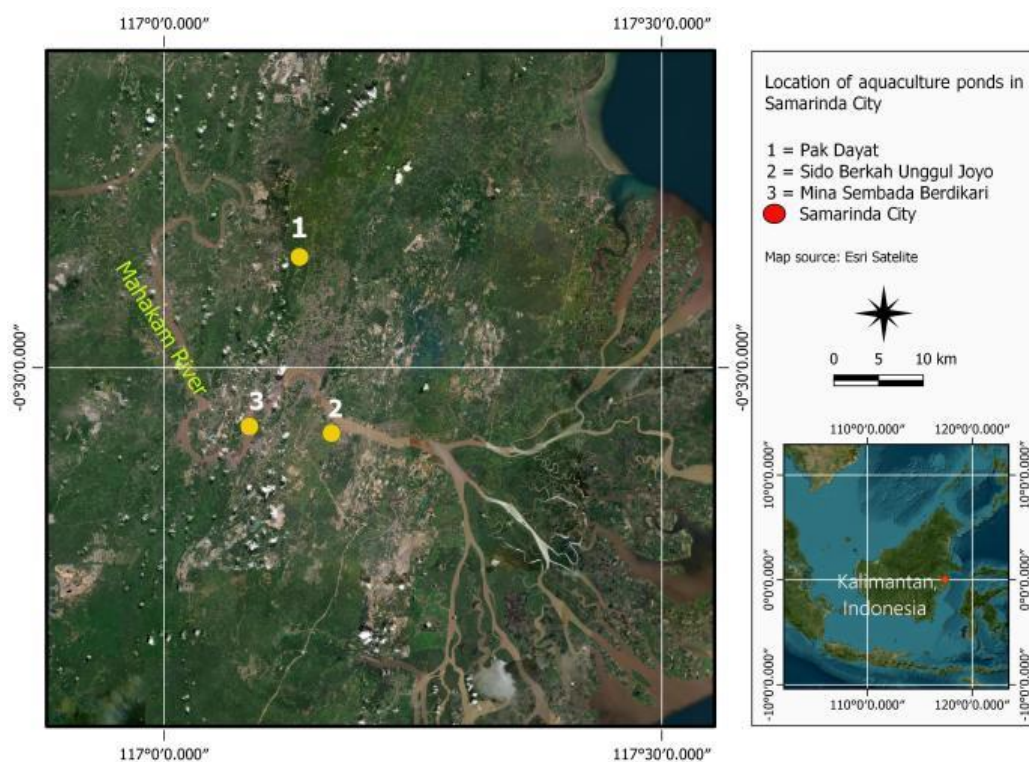


Figure 1. Map location of aquaculture ponds in Samarinda City.

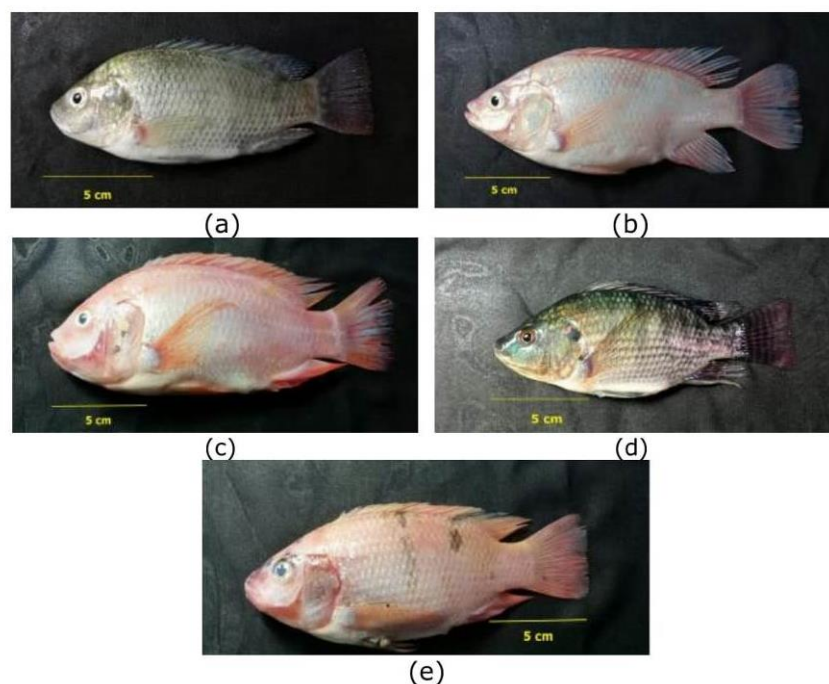


Figure 2. Five of Nile tilapia varieties collected from three cultivation ponds in Samarinda City, Indonesia: (a) black tilapia (b) white tilapia (c) red tilapia (d) stocky tilapia (e) larasati tilapia.

Truss morphometric measurements. The Nile tilapia samples were positioned on a styrofoam board covered with waterproof paper, with the head to the left. A total of ten points (landmarks) were marked using a pen needle around the outline of the fish's body shape. Furthermore, vertical, horizontal, and diagonal lines were drawn by connecting the points. The points on the outline of the fish's body shape are shown in Figure 3.

Truss characters were obtained based on the distance between landmark on the edge of the fish's body, both vertically, horizontally, diagonally (Figure 4). The distance between the landmarks (truss) was measured using digital calipers to an accuracy of 0.01 mm, resulting in twenty-one truss measurements for each individual fish (Table 1).

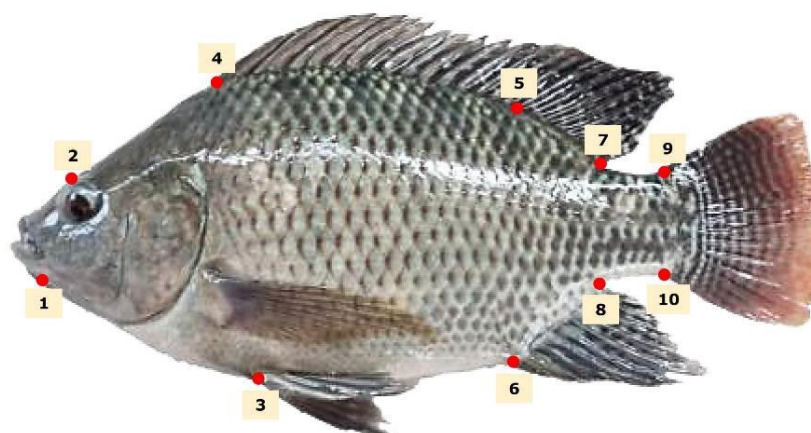


Figure 3. Position of ten landmarks on the outline of the Nile Tilapia's body shape. Description: (1) below the mouth, (2) above the eye, (3) front base of the ventral fin, (4) front base of the dorsal hard fin rays, (5) front base of dorsal soft fin rays (6) front base of the anal fin rays, (7) back base of the dorsal soft fin rays, (8) the base of the anal fin rays, (9) the upper base of the caudal fin, (10) the lower base of the caudal fin.

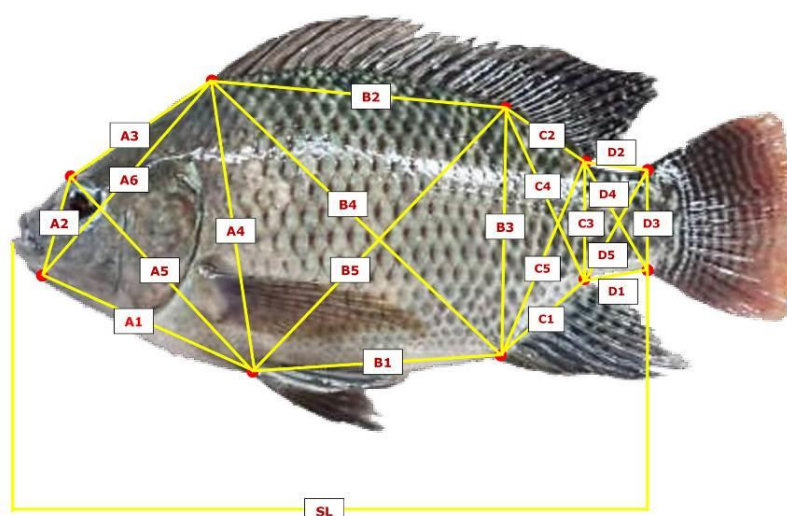


Figure 4. The complete truss network of Nile tilapia showing the 21 truss characters.

Table 1

Description of 21 truss characters on the body part of Nile tilapia

No	Body part	Truss character/code	Description of distance between landmarks
1.	Head	A1	Below the mouth - front base of the ventral fin
		A2	Below the mouth - above the eye
		A3	Above the eye - front base of the dorsal hard fin rays
		A4	Front base of the ventral fin - front base of the dorsal hard fin rays
		A5	Front base of the ventral fin - above the eye
		A6	Below the mouth - front base of the dorsal hard fin rays

2.	Anterior part of the body	B1	Front base of the ventral fin - front base of the anal fin
		B2	Front base of the dorsal hard fin rays - front base of the dorsal soft fin rays
		B3	Front base of the dorsal soft fin rays - front base of the anal fin
		B4	Front base of the dorsal hard fin rays - front base of the anal fin
		B5	Front base of the ventral fin - front base of the dorsal soft fin rays
3.	Posterior part of the body	C1	Front base of the anal fin - back base of the anal fin
		C2	Front base of the dorsal soft fin rays - back base of the dorsal soft fin rays
		C3	Back base of the dorsal soft fin rays - back base of the anal fin
		C4	Front base of the dorsal soft fin rays - back base of the anal fin
		C5	Back base of the dorsal soft fin rays - front base of the anal fin
4.	Caudal region	D1	Back base of the anal fin - lower base of the caudal fin
		D2	Back base of the dorsal soft fin rays - upper base of the caudal fin
		D3	Upper base of the caudal fin - lower base of the caudal fin
		D4	Back base of the dorsal soft fin rays - lower base of the caudal fin
		D5	Upper base of the caudal fin - back base of the anal fin

Meristic characters. The meristic characters calculations were performed manually using a magnifying glass. This included counting the number of scales on the lateral line, above the lateral line, and below the lateral line, as well as the number of rays in the ventral, caudal, pectoral, anal, and dorsal fins, and the number of gill rakers.

Data analysis. The body length data of each Nile tilapia varieties was analyzed using Microsoft Excel 2013 software for minimum, maximum, mean, standard deviation, and coefficient of variation. The truss morphometric character data on each Nile tilapia were divided by the standard length (SL) and expressed as morphometric ratio data. The obtained morphometric ratio data were analyzed using the principal component analysis (PCA). PCA analysis was performed based on the covariance matrix of the morphometric data, resulting in a set of principal components representing the major variations in the data. Principal component score plots (Principal Component 1 and Principal Component 2) were then used to visualize the grouping of Nile tilapia varieties based on morphometric characters. (Bookstein et al 1985) and (Gustiano et al 2004).

Cluster analysis was constructed using the average measurement data of morphometric characters. The results obtained were in the form of a dendrogram referring to the Euclidean distance. The smaller the distance value between Nile tilapia varieties, the higher the kinship between populations and vice versa. Visualize the cluster results in the form of a dendrogram, which is a tree diagram showing the similarity between Nile tilapia varieties. PCA and clustering analysis was conducted using MINITAB software version 22.

Results. Thirty individuals were randomly selected from each variety for morphometric analysis. This sample size is expected to be representative of each population due to their relatively uniform size, as indicated by the coefficient of variation of population relatively small (< 15%) (Table 2).

Table 2

The varieties, numbers, standard body length and coefficient of variation of five Nile tilapia varieties from cultivation ponds in Samarinda City, Indonesia

No	Variety	Aquaculture ponds	Number (individual)	Body lengths (mm) ($\bar{x} \pm SD$)	CV (%)
1	Larasati tilapia	Pak Dayat	30	129.42 $\pm$ 14.81	11.45
2	Red tilapia	Pak Dayat	30	129.86 $\pm$ 12.04	9.27
3	White tilapia	Pak Dayat	30	137.51 $\pm$ 18.29	13.30
4	Black tilapia	Mina Sembada Berdikari	30	99.25 $\pm$ 10.59	10.67
5	Stocky tilapia	Sido Berkah Unggul Joyo	30	100.44 $\pm$ 8.39	8.35

Description: $\bar{x}$ = mean, SD = standard deviation, CV = coefficient of variation.

Table 3 shows the results of PCA using truss morphometric data on five populations of tilapia samples.

Table 3

Principal component (PC) loadings of 21 truss morphometric characters of five varieties of Nile tilapia

Truss characters	Principal components (PC)		
	PC1	PC2	PC3
A1	0.130	0.112	0.189
A2	-0.076	-0.073	-0.290
A3	0.181	0.155	0.034
A4	0.340	-0.111	-0.114
A5	0.283	-0.074	-0.077
A6	0.171	0.172	0.015
B1	0.109	-0.435	-0.305
B2	0.070	-0.155	-0.208
B3	0.354	-0.039	-0.008
B4	0.302	-0.215	-0.186
B5	0.254	-0.334	-0.227
C1	0.160	0.050	0.289
C2	0.156	0.239	0.100
C3	0.286	0.284	-0.019
C4	0.285	0.213	0.025
C5	0.307	0.091	0.146
D1	-0.168	0.254	-0.355
D2	-0.204	0.148	-0.348
D3	0.176	0.196	-0.178
D4	0.118	0.228	-0.328
D5	-0.002	0.409	-0.367
Variability proportion (%)	31.4	11.8	10.5
Cumulative variability (%)	31.4	43.2	53.7

Description: numbers in **bold** represent scores that are considered significant, where the absolute value is more than half of the maximum coefficient value on the PC in question.

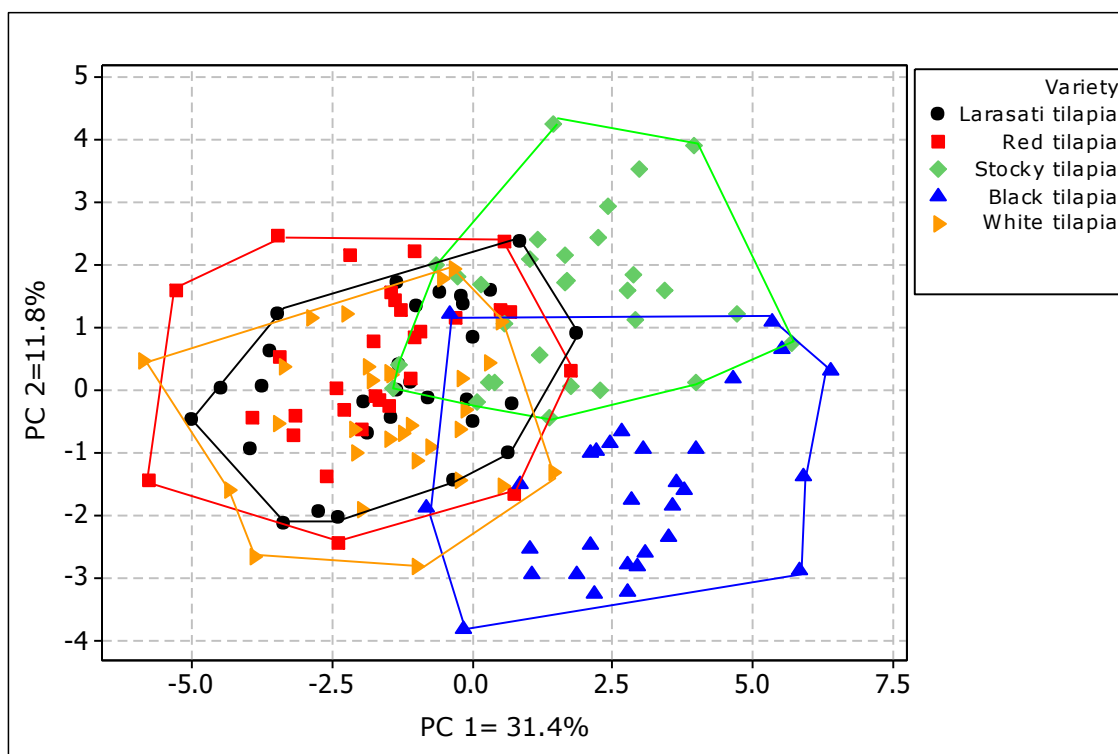
The coefficient values of the components scores in Table 3 indicated that the body shape variation of 5 varieties of tilapia is influenced by the characters that form the body shape. The body shape variation of the five Nile tilapia varieties can be found in the head region, anterior part of the body, posterior part of the body, and caudal region. In PC1, most of the tested characteristics contributed to differentiating the body shape of tilapia. Specifically, the head (A4), anterior part of the body (B3 and B4), and posterior part of the body (C5) were able to contribute to differentiating the body shape of tilapia by 31.4%. In PC2, the anterior part of the body (B1 and B5) and the caudal region (D5) were the characteristics that contributed to the differentiation of tilapia body shape. The

contribution of these characters to the overall variation was about 11.8%. In PC3, the anterior part of the body (B1) and the caudal region (D1, D2, D4, and D5) contributed the most to differentiating Nile tilapia body shape, accounting for 10.5% of the variation. In general, PC 1, 2, and 3 were able to distinguish body shape among tilapia varieties by 31.4%, 11.8%, and 10.5% respectively, with a cumulative variability value of 53.7%.

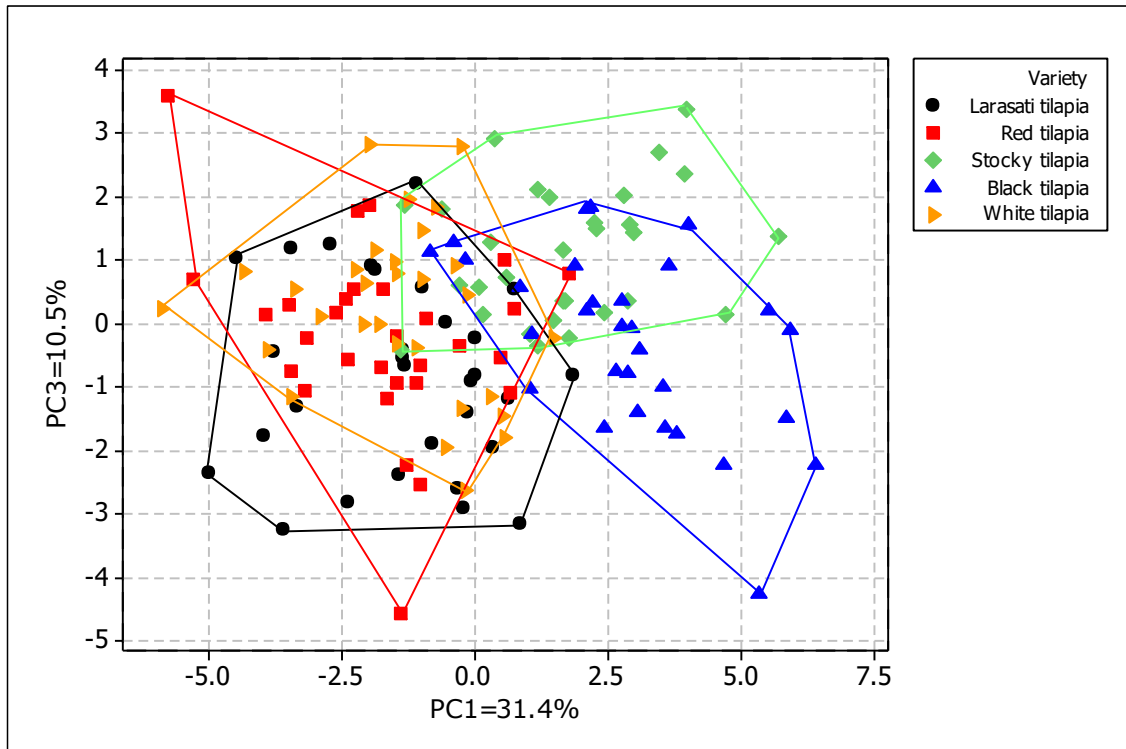
Figures 5 and 6 present scatter diagrams of individual tilapia scores on PC 1 and 2, and PC 1 and 3, respectively. Both diagrams consistently show a clustering pattern between populations. Based on Figure 5, there is a phenomenon that shows the grouping of three varieties into one group, namely red tilapia, white tilapia, and larasati tilapia, while the varieties of stocky tilapia and black tilapia tend to have different body shapes. The body shape of red tilapia, white tilapia, and larasati tilapia tends to be general in the sense that it does not have a specific or different shape. This analysis is supported by the results of the scatter diagram analysis of PC 1 and 3 presented in Figure 6. Based on the PC axis 2 in Figure 5 and PC axis 3 in Figure 6, it is clear that the body shape of stocky tilapia tends to have an increased difference from black tilapia. The position of the sample points of the stocky tilapia population is predominantly on the positive axis of the PC 2 and 3, while the black tilapia is on the negative axis.

The scatter plot between character B3 in the PC1 component and character B1 in the PC2 component is shown in Figure 7. Based on the scatterplot, it can be seen the body shape of stocky tilapia and black tilapia can be distinguished on the B1 axis, while larasati tilapia, white tilapia, and red tilapia tend to have a uniform shape. Furthermore, the B3 axis can distinguish larasati tilapia, white tilapia, and red tilapia from stocky and black tilapia.

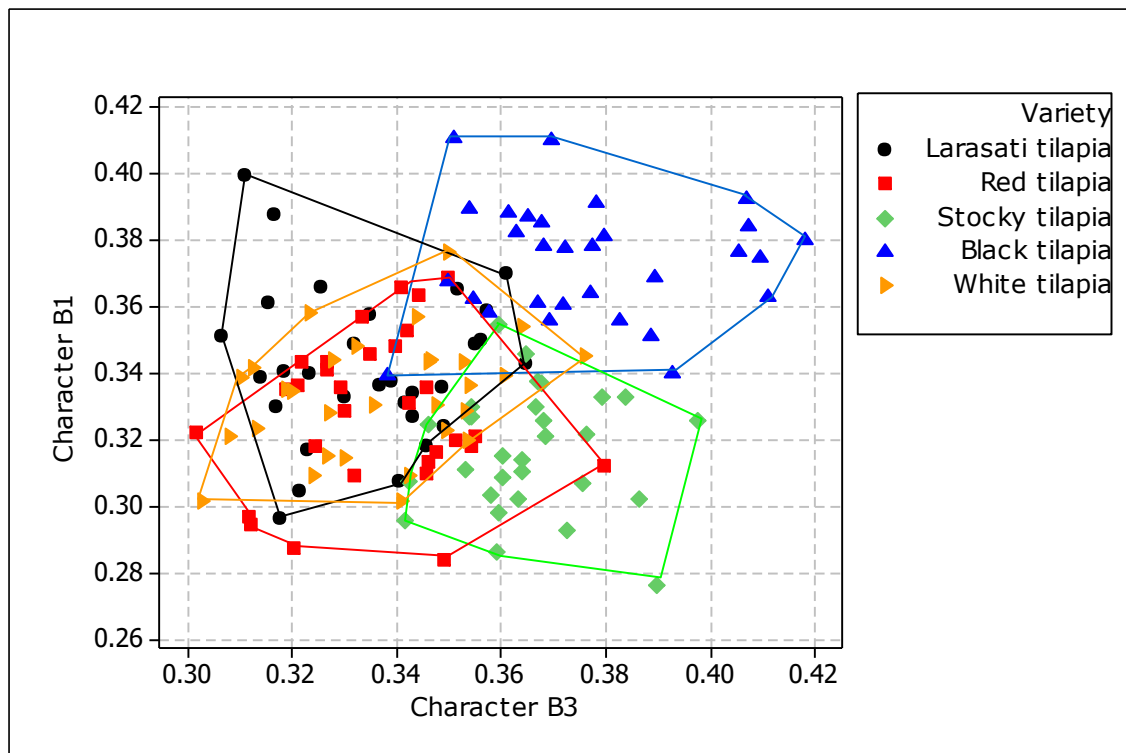
A dendrogram can be constructed based on the results of the PCA above, which groups the tilapia varieties based on the level of similarity of body shape between varieties. The result of grouping the five tilapia varieties in the form of a dendrogram is shown in Figure 8. The dendrogram indicates that the larasati tilapia, red tilapia, and white tilapia varieties are clustered together due to their high similarity, while black tilapia and stocky tilapia are relatively dissimilar to the three tilapia varieties. This clustering analysis using the dendrogram is consistent with the results of the scatter diagram analysis.



Figures 5. Scatter plot of PC scores along the first and second component of 5 varieties of tilapia using 21 truss morphometric characters.



Figures 6. Scatter plot of PC scores along the first and third component of 5 varieties of tilapia using 21 truss morphometric characters.



Figures 7. Scatter plot of B1 and B3 character components in five tilapia varieties.

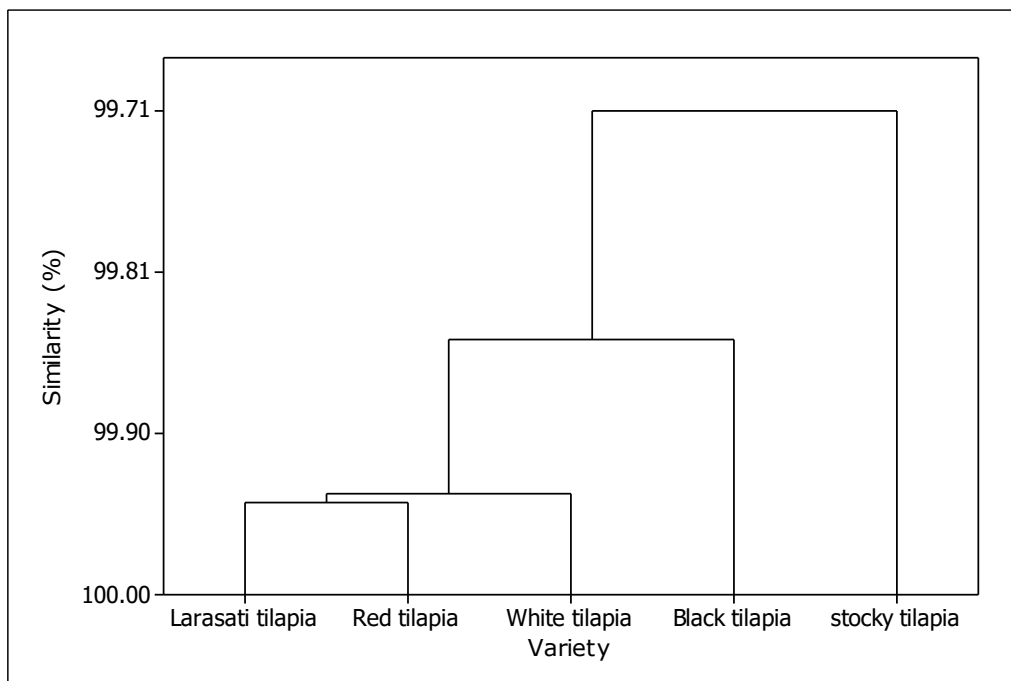


Figure 8. The dendrogram clustering the morphological similarity among five varieties of tilapia.

The results of the meristic characters counts of five varieties of tilapia are presented in Table 4. The range of meristic characters calculated on each character overlaps between varieties, making it impossible to distinguish between tilapia varieties using these characters.

Table 4
Meristics characters of larasati tilapia, red tilapia, stocky tilapia, black tilapia, and white tilapia

Meristics (range)		Variety				
		1	2	3	4	5
scales	Above the lateral line	4-5	3-5	3-5	3-4	3-5
	Below the lateral line	3-4	3-4	3-4	3-4	3-4
	On the lateral line	29-43	28-42	33-39	31-41	30-39
Fin rays	Dorsal fin	D.XVI-XVIII. 12-13	D.XVI-XVIII. 11-13	D.XV-XVIII. 11-12	D.XVI-XVIII. 12-13	D.XV-XVIII. 11-14
	Pectoral fin	P.11-13	P.11-13	P.12-13	P.13-14	P.13-14
	Anal fin	A.III.9-11	A.III.9-10	A.III.9-10	A.III.8-10	A.III.9-11
	Ventral fin	V.I.4-5	V.I.4-5	V.I.5	V.I.4-5	V.I.3-5
	Caudal fin	C.16-18	C.16-18	C.16	C.16	C.16-18
Gill rakers		21-36	27-35	28-35	25-31	24-35

Description: 1 = larasati tilapia, 2 = red tilapia, 3 = stocky tilapia, 4 = black tilapia, 5 = white tilapia.

Discussion. The mean range and standard deviation of body length in the five tilapia varieties showed that all samples belonged to the sub-adult age class, with slight variation in body length between individuals. According to the study by Ariyanto et al (2011), an increase in fish length or age can lead to greater variability in body shape due to allometric growth patterns and differential morphological development. In this study, the sample of tilapia varieties measured was in the sub-adult class, so the morphometry was very well used to distinguish between varieties.

The coefficient of variation of body length was highest for the white tilapia variety and lowest for the stocky tilapia. The high value of the coefficient of variation of body length in white tilapia indicates that the growth rate of individuals is more variable, unlike the uniform growth rate of stocky tilapia. According to Crook & Gillanders (2013), the main external factors affecting fish growth are water temperature, dissolved oxygen,

ammonia, salinity, irradiance, and duration of irradiance. These factors interact with each other and with other factors: competition, food quantity and quality, age, species or variety. In this study, differences in individual size of tilapia varieties are probably due to differences in varieties influenced by genetic factors, as all samples of tilapia varieties were collected from controlled farming environments.

In this study, the characters measurements that contributed strongly to the differences in body shape of the five tilapia varieties spread over the head, middle, and back of the body and the caudal region. In the PC1 component, characters that strongly contribute to differentiate the body shape of tilapia varieties are scattered in the head and anterior part of the body with a high coefficient of variation of 31.4%, while characters that strongly contribute to PC2 and PC3 are mainly in the anterior part of the body and caudal region with coefficients of variation of 11.8% and 10.5% respectively. Ariyanto et al (2011) reported that the differences among the five tilapia varieties nirwana wanayasa, gmt Sukabumi, gift Sukamandi, best Bogor and red nifi are influenced by characters on the head and anterior part of the body, starting from the tip of the front snout then to the top of the forehead, continuing to the dorsal and towards the back, which was able to contribute to the difference in body shape of tilapia by 25.82%.

Based on the scatter results, the character components that strongly contribute to the differences in morphological shape in black and stocky tilapia compared to larasati tilapia, red tilapia, and white tilapia are characters B1 (anterior part of the body length) and B3 (anterior part of the body width). This result is also supported by the clustering on the dendrogram which shows that larasati tilapia, red tilapia and white tilapia varieties are in one cluster, while black tilapia and stocky tilapia are in separate clusters.

According to Jusmaldi et al (2014), the phenotype is related to genetic distance, the closer the genetic distance, the more uniform the population in the species, otherwise the greater the genetic distance between individuals, the more diverse the species. In this study, it is assumed that the larasati tilapia, red tilapia, and white tilapia varieties are genetically closer than the stocky tilapia and black tilapia varieties.

The meristic characters on the five tilapia varieties cannot be used to detect differences among the varieties. The same results were reported by Muhotimah et al (2013) and Yeremia (2015), who stated that there were no significant differences in meristic characteristics in larasati, white, and black tilapia varieties, and further stated that the morphological characters of fish species with a meristic approach do not have much influence. In addition, meristic characters are independent of fish size and do not change during growth.

Conclusions. The tilapia varieties collected from the aquaculture ponds of Samarinda City consisted of three groups of varieties based on the body shape: red tilapia, larasati tilapia, and white tilapia belong to one group, while black tilapia and stocky tilapia are two other separate groups. Body shape of stocky tilapia and black tilapia distinguished on the characters B1 (the distance from the front of the base of the ventral fin to front of the anal fin), while the characters B3 (the distance from the front end of the base of dorsal fin rays to the front of the anal fin base) can distinguish larasati tilapia, white tilapia, and red tilapia from stocky and black tilapia. All tilapia varieties did not have significant differences based on meristic characters. The findings of this study provide a strong basis for future research on the morphological variation and selective breeding of Nile tilapia varieties. The observed differences in body shape among the three groups suggest potential genetic and environmental influences on morphological traits, which could be further explored using molecular markers and quantitative genetics approaches.

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Conflict of interest. The authors declare that there is no conflict of interest.

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