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Article

Weight-Length Relationship and Condition Factor of Gibel Carp (*Carassius auratus gibelio var*. CAS V) at Different Growth Stages and Feed Formulations

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Abstract: Accurate recording of growth indicators for aquaculture species at different stages is essential for evaluating aquaculture production effectiveness and the rationality of feed formulations. Due to their convenience and non-invasiveness, weight, length, and condition factor are commonly used to assess the growth of aquaculture species . However, fish growth indicators, can vary significantly with age structure and feed components(nutrition), and relying on a single indicator may lead to misjudgments . In this study we investigated the growth indicators of gibel carp (*Carassius auratus gibelio var*. CAS V) at different growth stages (juvenile and adult) and different feed formulations. Meanwhile, fish weight-length relationship ($W = bL^a$) was used to assess the growth indicators. The results showed that the weight-length relationship of gibel carp varied significantly with age and feed formulations. Additionally, the condition factor calculated depended on the weight-length relationship was more consistent with weight/length changes than measured. Weight analysis indicated that both weight, length, height, back thickness, and carcass ration had higher weights in analyzing fish growth. Therefore, during aquaculture production, fish growth evaluating requires considering diverse indicators such as weight, length,body height, back thickness, carcass ration,as well as condition factor to avoid misjudging the actual growth situation. Meanwhile, the use of the condition factor should consider the sufficient amount of data and whether the assumptions (such as being in a isometric growth period) are met.

Keywords: gibel carp; growth indicators; weight-length relationship; condition factor; growth stage; feed formulation

1. Introduction

In aquaculture, morphological and physiological indices of cultured species are used to assess their physiological or nutritional status. Weight, length, and condition factor are commonly used evaluation indicators due to their convenience and non-invasiveness. The weight (W) of fishes is exponentially related to their length (L) according to the weight-length relationship (WLR) equation $W = bL^a$ [1], which was established by Keys, 1928[2] and widely used since then for determining fish condition and comparing fish growth (***a***=3, isometric growth; ***a***<3, negative allometric growth ; ***a***>3, positive allometric growth)[3]. Another indicator, condition factor(also know as Fulton's condition factor *K*), was intertwined with WLR because Fulton (1904) noted this factor as$K = 100\frac{W}{L^3}$[4], which somehow restricted to condition of isometric growth. The condition factor is an empirical indicator based on the positive correlation between the physiological or nutritional status of animals and the energy storage in their bodies, which, in turn, is positively correlated with body weight[5]. Among individuals of the same body size (length), those with higher weight are generally considered to have better physiological and nutritional status[6]. However, in practical production, the growth stages of fish, such as the juvenile and adult stages, and different feed formulations can lead to deviations from this ideal growth status[7], and relying solely on the condition factor to assess the growth of cultured species may cause misjudgments. Therefore, research suggested that using a range of diverse indicators to evaluate cultured species [8].

Thus, the aim of this research is to provide a more precise assessment of WLR, applicable conditions of the condition factor ,as well as various indicators,such as body weight, length, height, back thickness, and carcass ration for evaluating gibel carp growth characteristics at different growth stages (juvenile and adult) and under different feed formulations (fish meal replacement, FMR; plant protein replacement, PPR). This research have potential to enhance the production management and feed formulations design in aquaculture.

2. Materials and Methods

2.1. Ethical Statement

This research was approved by the Animal Ethics Committee of Key Laboratory of microecological resources and utilization in breeding industry, Ministry of Agriculture and Rural Affairs and all experiments were conducted according to the protocols and procedures of the Laboratory Animal Management Ordinance of China.

2.2. Feeding Management

2.2.1. Juvenile Stage

Larva gibel carp (yolk sac) were purchased from Bairong Company(Huanggang city, Wuhan province, China), transported to Xinghua nursery factory (Xinghua city, Jiangsu province, China), and divided into self-farm (Xinghua nursery factory) and commercial farm (Yancheng aquaculture farm, Yanchen city, Jiangsu province, China) parts, with a stocking density of 450 fish/m^2 .After temporary cultured for 10 days, commercial feed purchased from Taizhou Biological Feed Co., Ltd. (Jiangsu province, China) was used with a feeding rate of 6% for another 120 days. To ensure the stability of feeding, the feeding frequency and amount were consistent between the self-farm and commercial farm.

2.2.2. Adult Stage

After raising to the adult stage (63.04±6.70g), the gibel carp were transferred to net cages (2.5m×2.5m×3m) for cultivation, with 45 fish per cage and a total of 76 cages. These cages were randomly divided into 19 groups, with 4 replicates per group.19 different formulation feeds were fed at 4% body weight/day, 3 times/day for 60 days.

2.2.3. Feed Formulation

Fish meal replacement is one of the important research directions to cope with the current shortage of fish meal. At the same time, different plant proteins are widely used in feed formulation design to avoid nutritional and cost imbalances caused by single plant protein source[9]. Therefore, this experiment used two approaches, fish meal replacement (FMR) and plant protein replacement (PPR), to create different feed formulations. The feed formulations design approach for the adult stage is shown in Table 1. The details of feed formulations for the adult fish were as shown in Table S1-S2 and the proximate composition of commercial feed for juvenile fish was as shown in Table S3.

Table 1. Feed formulations design approach for the adult stage.

Main approach	Control group	Groups	Feed formulations design approach
fish meal replacement	1	2	50% fish meal replaced by expanded soybean
		3	Fish meal replaced by a combination of expanded soybean and corn protein powder
		4	Fish meal replaced by cottonseed meal

plant protein replacement	4	5	Fish meal replaced by corn gluten meal
		5	Cottonseed meal replaced by corn gluten meal
		6, 7, 8	Soybean meal replaced gradually by peanut meal
		9, 10	Rapeseed meal (Canada) replaced gradually by sunflower seeds meal
		11, 12, 13	Soybean meal replaced gradually by sunflower seed meal
		14, 15	Soybean oil replaced by wheat with equal energy
		16, 17, 18, 19	Rapeseed meal (Canada) replaced by fermented rapeseed meal

2.3. Data Collection and Processing

2.3.1. Juvenile Stage

Data Collection and Analysis

Fish were taken after 120 days and and were anesthetized with MS-222 (25 mg/L). Then fish were measured for weight, length and classify them by cultivation area. The recorded and measured data were statistically analyzed using SPSS and EXCEL software. the parameters (***a*** and ***b***) of weight-length relationship (WLR) Equation in aquaculture (equation 1-1) was calculated by SPSS regression analysis [10].

Weight-length relationship $$W = bL^a \qquad \text{1-1}$$

W: weight; L: length; ***a*** and ***b*** are parameters

In order to evaluated whether the WRL equation could fit the fish during juvenile stage, the fitted weight data was inversely calculated from the measured length collected by commercial farm using the WLR equation. Independent sample t-test analysis was performed with the measured weight and fitted weight to evaluate the differences.

2.3.2. Adult Stage

Data Collection and Analysis

The net cage experiment lasted for 60 days. Ten fish were randomly selected from each cage and were anesthetized with MS-222 (25 mg/L) and then killed by a lethal blow on the head. Then fish were measured for weight, length, height, back thickness, carcass ration, and calculate the measured condition factor (MCF). The equations for carcass ration and MCF are as follows:

Carcass ratio $$= \frac{\text{body weight} - \text{viscera weight}}{\text{body weight}} \times 100\% \qquad \text{1-2}$$

Condition factor $$= \frac{\text{body weight}}{\text{length}^3} \times 100\% \qquad \text{1-3}$$

The recorded and measured data were statistically analyzed using SPSS and EXCEL software. Growth indicators data from each group and entire population were used individually to calculate the parameters of WLR (equation 1-1) by regression analysis. Afterwards, weight was fitted by WLR equation of the entire population and each group, respectively. Along with the measured length data, the entire population fitted condition factor (ECF) and group fitted condition factor (GCF) was calculated using fitted weight and equation 1-3. One-way ANOVA was used to test the differences in various indicators of gibel carp under different feed formulations. Principal component analysis (PCA) was used to analyze the weight (normalized) of weight, length, height, thickness, MCF,ECF and GCF. All the data source could see in supplements as Table 2 described

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Table 2. Data source of Figure/table/equation.

Figure/Table/Equation	Data source	Sheet
Equation 2-1/Figuer S1	Data source for Juvenile fish.xlsx	sheet 1: Data from self-farm
Table 3- Juvenile fish	Data source for Juvenile fish.xlsx	sheet 2: Data from commercial farm
Table 3- Adult fish	Data source for Adult fish.xlsx	Sheet 1: Weight analysis
Table 4-Table 9	Data source for Adult fish.xlsx	sheet 2 : All data
Table 6	Data source for Adult fish.xlsx	sheet 2 : All data/sheet3: WLR

3. Results

3.1. Juvenile Stage

3.2. Growth-Weight Relationship in Juvenile Stage

A regression analysis was performed on the data sampled from self-farm, and the values of ***a*** and ***b*** were calculated by regression analysis, resulting in an exponential relationship (r=0.978) (Equation 2-1). This exponential equation fits well with equation 1-1 (Figure S1). When the data collected by commercial farm were used, the fitted weight based on the WLR was not significantly different from the measured weight (p=0.87,Table 3), indicating that Equation 2-1 is consistent with the actual situation.

$$W = 3.023E^{-5}L^{3.023}(r = 0.978) \quad 2\text{-}1$$

Table 3. Statistically significance between measured and fitted weight of juvenile and adult fish.

Data Source	Statistically significance between measured and fitted weight	
Juvenile fish from commercial farm	-	p=0.87
Adult fish	**	p=0

p >0.05:"-".0.01< p <0.05 :"*". p <0.01 :"**"

3.3. Adult Stage

3.3.1. Length-Weight Relationship of Juvenile Fish Did Not Fit the Adult Fish

The weight data of the adult fish was fitted using the WLR of gibel carp at juvenile stage (equation 2-1). The difference between the fitted weight and the measured weight was analyzed and found to be significant different (p<0.01, Table 3), indicating that the WLR established during the juvenile stage was not applicable to the adult stage of gibel carp.

3.3.2. Growth Indicators under Different Feed Formulations Had Varying Degrees of Impact

The results showed that different feed formulation had varying degrees of impact on several commonly used fish growth indicators. However, the trends in the MCF were inconsistent with other indicators (weight, length, height, carcass ration, and back thickness). In the FMR group, group 2 and 3 showed significant differences in weight, length, height, carcass ration, and back thickness, while the MCF showed no significant difference (Table 4). In the PPR group, all groups except group 9 and group 11 showed significant differences in the MCF compared to the control group (Table 5), while most groups showed no difference in weight, length, height, carcass ration, and back thickness compared to the control group. This indicates that using the condition factor alone to assess the growth characteristics of gibel carp under different feed formulations may cause misjudgments.

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Table 4. The effect of fish meal replacement on gibel carp growth.

Control	Group	Statistically significance					
		Weight	Length	Body height	Carcass ratio	Back thickness	MCF
1	2	**	**	**	**	**	-
	3	**	**	**	**	**	-
	4	-	*	**	**	**	**
	5	-	-	-	*	-	-
total of sd/n-sd group		2/2	3/1	3/1	4/0	3/1	1/3

1) p >0.05:"-".0.01< p <0.05 :"*". p <0.01 :"**"

2) MCF: measured condition factor

3) sd:Significant differences；nsd: non-Significant differences

Table 5. The effect of plant protein replacement on gibel carp growth.

control	group	statistically significance					
		weight	length	body height	carcass ratio	Back thickness	MCF
4	5	-	-	*	-	**	*
	6	-	-	-	-	-	*
	7	-	-	-	-	*	**
	8	-	-	**	-	**	**
	9	*	*	-	*	-	-
	10	-	-	**	-	**	**
	11	-	-	-	-	-	-
	12	-	-	-	-	**	**
	13	-	-	-	-	*	**
	14	-	-	-	-	-	**
	15	-	**	-	-	-	**
	16	-	-	*	-	-	*
	17	-	-	**	-	**	**
	18	-	-	-	-	-	**
	19	-	**	**	*	**	**
total of sd/n-sd group		1/14	3/12	6/9	2/13	8/7	13/2

1) p >0.05:"-".0.01< p <0.05 :"*". p <0.01 :"**"

2) MCF: measured condition factor

3) sd:Significant differences；nsd: non-Significant differences

3.3.3. Weight-Length Relationship Fitted Condition Factor Showed Similar Trends to Growth Indicators

The WLR of entire population and each group of adult fish were established (Table 6). In the WLR, the constant ***b*** is dimensionally consistent with the condition factor, and when ***a***=3, ***b***'s definition premise and biological significance are consistent with the condition factor[11]. Weight was fitted by WLR equation of the entire population (Equation 2-2,Table 6) and each group (Equation 2-3 to 2-21,Table 6) by measured length data. Then, ECF and GCF was calculated using fitted weight ,measured length and equation 1-3. The results showed that the GCF had similar trends to weight

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and length. In contrast, the trends of the MCF and ECF differed significantly from the these indicators (Table 7 and Table 8).

Table 6. Weight-length relationships of entire population and each group.

Groups	Weight-length relationships	r	
Entire population	$W = 7.178e^{-5}L^{2.826}$	0.872	2-2
Group1	$W = 8.164e^{-5}L^{2.800}$	0.794	2-3
Group2	$W = 4.251e^{-5}L^{2.930}$	0.879	2-4
Group3	$W = 1.397e^{-4}L^{2.693}$	0.760	2-5
Group4	$W = 1.416e^{-4}L^{2.694}$	0.839	2-6
Group5	$W = 1.019e^{-4}L^{2.756}$	0.815	2-7
Group6	$W = 1.846e^{-5}L^{3.102}$	0.948	2-8
Group7	$W = 7.178e^{-5}L^{2.826}$	0.908	2-9
Group8	$W = 1.319e^{-4}L^{2.699}$	0.854	2-10
Group9	$W = 8.384e^{-5}L^{3.267}$	0.903	2-11
Group10	$W = 1.095e^{-4}L^{2.738}$	0.938	2-12
Group11	$W = 8.620e^{-4}L^{2.326}$	0.815	2-13
Group12	$W = 5.712e^{-5}L^{2.872}$	0.929	2-14
Group13	$W = 3.142e^{-5}L^{2.988}$	0.909	2-15
Group14	$W = 2.038e^{-5}L^{3.078}$	0.837	2-16
Group15	$W = 5.021e^{-5}L^{2.913}$	0.892	2-17
Group16	$W = 5.063e^{-5}L^{2.896}$	0.930	2-18
Group17	$W = 3.826e^{-5}L^{2.950}$	0.926	2-19
Group18	$W = 7.178e^{-5}L^{2.826}$	0.902	2-20
Group19	$W = 1.124e^{-4}L^{2.734}$	0.875	2-21

Table 7. The effect of fish meal replacement on weight, length and condition factors.

Control	Group	Statistically significance				
		Weight	Length	MCF	GCF	ECF
1	2	**	**	-	-	**
	3	**	**	-	**	**
	4	-	*	**	**	*
	5	-	-	-	**	-
total of sd/n-sd group		2/2	3/1	1/3	3/1	3/1

1) p >0.05:"-".0.01< p <0.05 :"*". p <0.01 :"**"
2) sd:Significant differences; nsd: non-Significant differences
3) MCF: measured condition factor; GCF:group fitted condition factor ; ECF:entire population fitted condition factor ;

Table 8. The effect of plant protein replacement on weight, length and condition factors.

Control	Group	statistically significance				
		Weight	Length	MCF	GCF	ECF
4	5	-	-	*	**	-
	6	-	-	*	**	-
	7	-	-	**	**	-
	8	-	-	**	**	-
	9	*	*	-	**	*
	10	-	-	**	**	-
	11	-	-	-	*	-
	12	-	-	**	**	-
	13	-	-	**	**	-

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14	-	-	**	**	-
15	-	**	**	**	**
16	-	-	*	**	-
17	-	-	**	**	-
18	-	-	**	**	-
19	-	**	**	**	**
total of sd/n-sd group	1/14	3/12	13/2	15/0	3/12

1) p >0.05:“-”.0.01< p <0.05 :“*”. p <0.01 :“**”

2) sd:Significant differences; nsd: non-Significant differences

3)MCF: measured condition factor; GCF:group fitted condition factor ; ECF:entire population fitted condition factor ;

3.3.4. Weight Analysis of Growth Indicators

Weight Analysis of Growth Indicators indicated that body weight, length, height, back thickness, and carcass ration had higher weights in analyzing fish growth characteristics (Table 9).

Table 9. Weight analysis of gible carp growth Indicators.

Factors	Weight（Normalization）
Body weight	0.211
Carcass ratio	0.211
Height	0.179
Length	0.175
Back thickness	0.124
Measured condition factor	0.99

4. Discussion

4.1. Weight-Length Relationship of Gibel Carp Juvenile and Adult Stages

This study collected growth data of gibel carp from Xinghua nursery factory, calculated the WLR of gibel carp, and verified it using the growth data collected from a commercial farm. The results showed that the WLR (equation 1-1) can fit well, with a value of ***a***=3.023. From the definition of the equation, the coefficient ***a*** represents the ratio of weight gain to length growth in fish. From a mathematical perspective, when a undergoes a small change, ***b*** will change significantly, and even when a is relatively stable, ***b*** can still undergo frequent changes. Therefore, the value of ***a*** reflects the growth characteristics of fish in different stages and environments[1][3]. Another physical interpretation of equation 1-1 is that the relationship between fish weight (W), fish density (ϱ), and volume (V) is W=ϱV, and the volume is an exponential function of length. Generally, the power exponent is close to 3, indicating that fish growth is isometric[12]. In this study, the value of ***a*** is 3.023, indicating that gibel carp is close to isometric growth during the juvenile stage, which may explain why the weight-length relationship fits well with equation 2-1 in both farms.

The results also showed significant differences in the WLR between the juvenile and adult stages. This is because factors such as fish species, age, and food can influence the value of ***a*** and ***b*** of WLR [13][8][14][15][16]. The results also showed that the ***a*** values of individual groups and the entire population data of the adult stage were smaller than 3 (Table 6), possibly because gibel carp was in a hypoallometric growth period.

4.2. Limitations of the Condition Factor in Evaluating Fish Growth Characteristics under Different Feed Formulations

The condition factor is often used to analyze the growth status or reproductive capacity of fish under different conditions [17]. If approximately assume that the expected weight of animals increases uniformly with length growth, for example, with the increase of the long axis of the body;

and the body radial size increases proportionally, then the expected weight will be positively correlated with the cube of the body, which is the original concept of the condition factor (also known as the Fulton index)[11]. Combining equation 1-1 and 1-3, when fish are in a isometric growth period (a=3), the biological significance of b and the assumption premise of the condition factor are consistent and numerically identical. However, in practical production, fish growth can deviate from this ideal growth state due to changes in environmental conditions such as temperature and food[18][7][19]. As shown in this study, the WLR of various groups and the entire data in the adult stage showed a < 3, indicating that gibel carp may be in a hypoallometric growth period.under different feed formulations,.The MCF of various groups did not show significant differences, and its trend was inconsistent with other indicators (weight, length, height, back thickness, carcass ration). This further indicates that the use of the condition factor should consider whether its premise assumption (e.g., isometric growth stage or a = 3) is met to avoid misjudgments.

In this study, the regression equation of the entire population of adult fish WLR was used to calculate the fitted weight based on the measured length and then calculate the fitted condition factor. The trend of this ECF description showed more similar to other growth indicators (weight, length,) than GCF and MCF. This result indicates that the sufficient amount of data is an important condition for the biological significance of the condition factor . Therefore, when using the condition factor for evaluation, the sufficient amount of data needs to be considered to ensure the accuracy of this indicator's evaluation.

The weights of fish weight, length, height, back thickness, and carcass ration were also analyzed for evaluating fish growth. The results showed that these indicators had higher weights. Therefore, in aquaculture production, the evaluation of fish growth under different feed formulations should comprehensively consider diverse indicators such as weight, length, height, back thickness, carcass ration, and condition factor to avoid misjudgments caused by a single indicator.

5. Conclusions

This study demonstrated that it is necessary to use diverse indicators, such as weight, length, height, back thickness, carcass ration, and condition factor for evaluating fish growth in aquaculture production. And the applications of condition factor in practical needs to consider the sufficient amount of data and whether its premise assumption (e.g., isometric growth stage) is met.

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