

**EFFECT OF STOCKING PARAMETERS ON  
GROWTH, SURVIVAL AND PRODUCTION OF  
*PANGASIUS HYPOPHthalmus* (SAUVAGE, 1878)  
IN INTENSIVE CAGE CULTURE SYSTEM**

Thesis submitted in part fulfillment of the requirements for the  
Degree of **Master of Fisheries Science in Aquaculture**  
to the Tamil Nadu Dr. J. Jayalalithaa Fisheries University,  
Nagapattinam

**HARSHITA SAHU, B.F.Sc.,**

**ID. No. I-18-TN-03-002-M-F-026**



**DEPARTMENT OF AQUACULTURE  
FISHERIES COLLEGE AND RESEARCH INSTITUTE  
TAMIL NADU Dr. J. JAYALALITHAA FISHERIES  
UNIVERSITY  
THOOTHUKUDI - 628 008**

**2021**

## CERTIFICATE

This is to certify that the thesis entitled, "Effect of stocking parameters on growth, survival and production of *Pangasius hypophthalmus* (Sauvage, 1878) in intensive cage culture system" submitted in part fulfillment of the requirements for the award of the degree of **Master of Fisheries Science in Aquaculture** to the *Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Nagapattinam* is a record of bonafide research work carried out by **Ms Harshita Sahu, ID. No. I-18-TN-03-002-M-F-026**, under my supervision and guidance and that no part of thesis has been submitted for the award of any other degree, diploma, fellowship or similar titles or prizes and that part of the thesis has been published in peer reviewed journal(s) and copy / copies appended.

Place: Thoothukudi

**CHAIRMAN**

Date:

**RECOMMENDED**

Place:

Date:

**EXTERNAL EXAMINER**

**APPROVED**

**CHAIRMAN** : **Dr. J. Stephen Sampath Kumar**  
**Director,**  
**Directorate of Sustainable Aquaculture,**  
**Thanjavur**

**MEMBERS** : **Dr. V. Senthilkumar**  
**Assistant Professor and Head i/c**  
**Thanjavur centre for Sustainable**  
**Aquaculture, Thanjavur**

: **Dr. C. Judith Betsy**  
**Department of Aquaculture**  
**Fisheries College and Research Institute,**  
**Thoothukudi**

Place:

Date:

*Dedicated to*

*The God*

*And My Dear Parents*

## ACKNOWLEDGEMENTS

First of all, I am grateful to the **God** and my dear **parents** for the great support to complete this work. Hopefully in future too, I can explore new heights with their blessings.

I express my deepest dense of gratitude to my Chairman, **Dr. J. Stephen Sampath Kumar**, Director, Directorate of Sustainable Aquaculture, Thanjavur for his constant love, support, encouragement, motivation and perfect guidance together with sincere efforts to make me a good human being. His guidance helped me throughout the research and writing of this thesis. It was a great opportunity to do my Master's degree research under his guidance.

I am indebted to my Advisory Committee Member, **Dr. C. Judith Betsy**, Assistant Professor, Department of Aquaculture, FC&RI, Thoothukudi for her limitless support and motivation during the research. I am thankful for her selfless efforts in monitoring the research, analyzing data correcting the manuscript. Her encouragement, guidance and support from the first day to the final, made this research work possible.

I express my gratitude to the Member of Advisory Committee **Dr. V. Senthilkumar**, Assistant Professor and Head i/c, Thanjavur Centre for Sustainable Aquaculture, Soorakkottai, Thanjavur for his moral support, helps with manpower and materials and encouragement throughout the research work.

I thank **Directorate of Sustainable Aquaculture** for supporting me with all the facilities to complete my research. I also thank **Tamil Nadu Dr. J. Jayalalithaa Fisheries University** for providing financial support during my research work.

I express my deepest sense of gratitude to **Dr. Cheryl Antony**, Professor & Head, Department of Aquaculture, FC&RI, Ponneri, who was earlier at FC&RI, Thoothukudi for her admirable guidance, support and valuable suggestions. I deem it as my privilege to receive her guidance.

I wish to thank P.G Coordinator, **Dr. N.V. Sujathkumar**, Professor and Head, Department of Fisheries Extension, Economics and Statistics, Fisheries College and Research Institute, Thoothukudi for his advice, help and guidance.

I express my gratitude to the Dean, **Dr. B. Sundaramoorthy**, Fisheries College and Research Institute, Thoothukudi for providing all the facilities during my course work.

I sincerely thank **Tmt. R. Ezhilrani**, Assistant Librarian for valuable help during the collection of reference materials and checking.

I would like to express my special thanks to **Mrs. R. Rathika, Mrs. V. Latha, Mrs. P. Ruby, Mr. P. Senthil Kumar, Mr. Venice Selvam, Neelkandan Anna, Ayyasamy Anna** and all other staff members in Thanjavur Centre for Sustainable Aquaculture for their care, support and constant help during my research work.

I sincerely thank to **Mr. Senthil Pandi**, farm owner at Madurai, who helped me in getting the Pangasius seeds for my research work during the pandemic situation.

I express my special thanks to my senior **Mr. Pankaj Gargotra, Mr. Rameshwar Bhosle, Mr. Dharmakar, Mrs Anjusa, Miss Priyanka Dhruv, Miss Puii and Miss Alish Debbarma** for their various helps and suggestions in my research work.

I also thank my junior **Miss Ebcifa, Miss Chetana and Mr. Hari Khrishna**

**Gorka** for their help and support during my thesis writing.

I would like to thank my batch mates, **Mr. Harshvardhan, Mr. Shubham, Mr. Raviprasad, Mr. Pico, Mr. Zuala, Mr. Bijayanand, Mr. Jobin, Mr. Shivashankar and Mr. Bheemeshwar** for their kind support during my study period.

I extend my deepest gratitude to my friends, **Miss Anjali Balanayak, Miss Bijaylaxmi Murmu, Miss Chayanika Das, Miss M.R. Sindhu, Miss Triveni T.S., Miss Sweety Singh, Miss Vishaka Gurung, Miss Devati, Mr. Anand Vaishnav, Mr. Domendra Dhruve, Mr. Sumant Chandravanshi, Mr. Sumit Chandravanshi and Mr. Vedprakash Ratrey** for being with me during the happy and hard moments to push me and motivate me. I will be grateful forever for their love.

At last but not the least, I must express my very profound gratitude to my parents, my brother and all family members for providing me with unfailing support and continuous encouragement, blessing and grace. Thank you all.

There might be a few more personalities, who have done their best during the come of my research and thesis writing. I record my sincere thanks to all of them.

**(Harshita Sahu)**

## ABSTRACT

**Title** : **Effect of stocking parameters on growth, survival and production of *Pangasius hypophthalmus* (Sauvage, 1878) in intensive cage culture system**

**Name of the student** : **Harshita Sahu**

**Degree** : **M.F.Sc., (Aquaculture)**

**Chairman** : **Dr. J. Stephen Sampath Kumar**

**Department** : **Aquaculture**

**College** : **Fisheries College and Research Institute, Thoothukudi**

**Year and University** : **2021, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Nagapattinam**

The present study was conducted at Thanjavur Centre for Sustainable Aquaculture (TCeSA) in the existing freshwater cage culture system to investigate the effect of stocking density and stocking size on growth and survival of *Pangasius hypophthalmus*. The experiment was carried out for 150 days (90 days for the 1<sup>st</sup> experiment + 60 days for the 2<sup>nd</sup> experiment).

In first set of experiment, the seeds of *P. hypophthalmus* were stocked under three different stocking densities such as 20 nos/m<sup>3</sup> (T<sub>1</sub>), 40 nos/m<sup>3</sup> (T<sub>2</sub>) and 60 nos/m<sup>3</sup> (T<sub>3</sub>). Fishes were fed twice a day (10 am and 4pm) with commercial pellet feed and sampled every fortnightly. Physico - chemical parameters were recorded every day.

At the end of 90 days, the survival of fishes was found to be in the order of 97.50±0.00, 95.6±0.00 and 93.9±0.30 % for 20, 40 and 60 nos/m<sup>3</sup>, respectively.

The highest final mean body weight ( $110.03 \pm 0.11$  g) was recorded with the lowest stocking density group ( $T_1$ ) and the lowest mean body weight ( $95.01 \pm 0.23$  g) was recorded in the highest stocking density group ( $T_3$ ). The maximum Weight Gain ( $107.19 \pm 0.54$  g), Daily Weight Gain ( $1.08 \pm 0.00$  g) and Specific Growth Rate (SGR) ( $4.07 \pm 0.17$ ) were recorded in the lowest stocking density group ( $T_1$ ) and the lowest values of Weight Gain ( $92.39 \pm 0.23$  g), Daily Weight Gain ( $1.00 \pm 0.01$  g) and Specific Growth Rate (SGR) ( $3.98 \pm 0.01$ ) were recorded in the highest stocking density group ( $T_3$ ). The Food Conversion Ratio (FCR) ( $2.25 \pm 0.00$ ) and Food Conversion Efficiency (FCE) ( $45.10 \pm 0.03$ ) were found to be higher in  $T_1$  than that of other two groups.

The maximum net biomass production ( $21.42 \pm 0.02$  kg) were recorded in the highest stocking density group ( $T_3$ ) and the least ( $8.35 \pm 0.04$  kg) was recorded in lowest stocking density group ( $T_1$ ). The highest biomass produced per unit area ( $5.36 \pm 0.00$  kg) was found to be with the highest stocking density group ( $T_3$ ) and the least biomass production per unit area ( $2.15 \pm 0.00$  kg) was in lowest stocking density group ( $T_1$ ). As it is evident, the lowest stocking density trial ( $20$  no/ $m^3$ ) helped in better growth performance and higher survival of *P. hypophthalmus* in cages.

In the second set of experiment, *P. hypophthalmus* seeds of three different stocking sizes 2" ( $T_4$ ), 4" ( $T_5$ ) and 6" ( $T_6$ ) (TL) were stocked in cages at the best performing stocking density arrived at the first experiment ( $20$  nos/ $m^3$ ). The maximum Weight Gain ( $58.19 \pm 0.18$  g) were recorded in the lowest stocking size group ( $T_4$ ) and minimum ( $41.64 \pm 0.30$  g) were recorded in the bigger stocking size group ( $T_6$ ). The maximum Daily Weight Gain was  $0.97 \pm 0.00$  g and Specific

Growth Rate (SGR) was  $5.42 \pm 0.04$ , which were found in the lowest stocking size group (T<sub>4</sub>). In contrary, least Daily Weight Gain ( $0.70 \pm 0.01$  g) and poor Specific Growth Rate (SGR) ( $1.90 \pm 0.00$ ) were found in bigger stocking size group (T<sub>6</sub>).

The highest net biomass production ( $4.59 \pm 0.011$  kg) was recorded in cages where fishes of small stocking size were stocked (T<sub>4</sub>) and the least net biomass production ( $3.21 \pm 0.031$  kg) was recorded in cages where bigger stocking size fishes were stocked (T<sub>6</sub>). The highest biomass produced per unit area ( $1.20 \pm 0.003$  kg) was found in cage stocked with fishes of smaller stocking size (T<sub>4</sub>) and ( $1.15 \pm 0.021$  kg) fishes in T<sub>5</sub> group recorded the least biomass production per unit area. The highest survival ( $98.75 \pm 0.00$  %) was recorded in T<sub>4</sub> and the lowest survival ( $97.50 \pm 0.00$  %) was recorded in T<sub>6</sub>. This study showed that smaller the stocking size better the production per unit area.

The proximate composition of *P. hypophthalmus* flesh analysed at the end of experiment showed drastic variation. At the end of 1<sup>st</sup> experiment the highest protein content (15.14%) was recorded in the lowest stocking density group (T<sub>1</sub>) and the lowest values of protein content (10.5%) were recorded in the highest stocking density group (T<sub>3</sub>). The crude fat and fibre content were found decreased with increasing stocking density. After the 2<sup>nd</sup> experiment the highest protein content (15.76%) and lowest moisture content (79.97%) was found in T<sub>6</sub>. The maximum crude fat content (3.5%) was observed in T<sub>4</sub> and the least (3.0%) in T<sub>6</sub>.

The study revealed that the *P. hypophthalmus* showed better growth, survival and body composition in cages under the stocking density of 20 nos/m<sup>3</sup> with stocking size of 2".

## CONTENTS

Chapter No.	Title	Page No.
I	INTRODUCTION	1
II	REVEIW OF LITERATURE	8
2.1	Cage farming	8
2.2	Biology of <i>P. hypophthalmus</i>	8
2.3	Cage farming of <i>P. hypophthalmus</i>	9
2.4	Effect of stocking density on growth of fishes	10
2.5	Effect of stocking density on survival rate of fishes	13
2.6	Effect of stocking size on growth and survival of fishes	15
2.7	Effect of stocking density on meat quality	16
2.8	Water quality parameters	17
2.8.1	Temperature	18
2.8.2	Dissolved Oxygen (DO)	19
2.8.3	pH	19
2.8.4	Alkalinity	20
2.8.5	Hardness	21
2.8.6	Carbon dioxide (CO <sub>2</sub> )	21
2.8.7	Total ammonia nitrogen	22

<b>Chapter No.</b>	<b>Title</b>	<b>Page No.</b>
	2.8.8 Nitrite nitrogen	23
	2.8.9 Chemical Oxygen Demand	23
	2.8.10 Total Dissolved Solids	23
	2.8.11 Conductivity	24
<b>III</b>	<b>MATERIALS AND METHODS</b>	<b>25</b>
	3.1 Experiment fish	25
	3.2 Experiment design	25
	3.3 Stocking and maintenance	26
	3.4 Feeding of fishes	27
	3.5 Sampling and observations	27
	3.6 Assessment of growth parameters	28
	3.7 Physico – chemical parameters of water	29
	3.8 Proximate composition analysis for meat quality	29
	3.9 Harvesting	29
	3.10 Statistical analysis	29
<b>IV</b>	<b>RESULTS</b>	<b>30</b>
	4.1 Growth parameters of <i>P. hypophthalmus</i> in cages at different stocking densities	30
	4.1.1 Average body weight (g)	30

<b>Chapter No.</b>	<b>Title</b>	<b>Page No.</b>
4.1.2	Mean body weight gain (g)	30
4.1.3	Percentage Weight Gain (PWG)	30
4.1.4	Average Daily Weight Gain (DWG)	31
4.1.5	Specific Growth Rate (SGR)	31
4.1.6	Boimass production (kg)	31
4.1.7	Net biomass production (kg)	32
4.1.8	Biomass production per unit area	32
4.1.9	Food Conversion Ratio (FCR)	32
4.1.10	Food Conversion Efficiency (FCE)	32
4.1.11	Survival	33
4.2	Proximate composition of <i>P. hypophthalmus</i> carcass reared in cages at different stocking densities	39
4.3	Growth parameters of <i>P. hypophthalmus</i> in cages at different stocking sizes	41
4.3.1	Average body weight (g)	41
4.3.2	Mean Body Weight Gain (g)	41
4.3.3	Percentage Weight Gain (PWG)	41
4.3.4	Average Daily Weight Gain (DWG)	42
4.3.5	Specific Growth Rate (SGR)	42

<b>Chapter No.</b>	<b>Title</b>	<b>Page No.</b>
	4.3.6 Boimass production (kg)	42
	4.3.7 Net biomass production (kg)	42
	4.3.8 Biomass production per unit area	42
	4.3.9 Food Conversion Ratio (FCR)	43
	4.3.10 Food Conversion Efficiency (FCE)	43
	4.3.11 Survival	43
4.4	Proximate composition of <i>P. hypophthalmus</i> carcass reared in cages at different stocking sizes	49
4.5	Physico-chemical parameters of water during the rearing of <i>P. hypophthalmus</i> in cages	51
<b>V</b>	<b>DISCUSSION</b>	<b>55</b>
5.1	Growth of <i>P. hypophthalmus</i> reared in cages at different stocking densities	55
5.2	Proximate composition of <i>P. hypophthalmus</i> reared in cages at different stocking densities	57
5.3	Growth of <i>P. hypophthalmus</i> reared in cages at different stocking sizes	58
5.4	Proximate composition of <i>P. hypophthalmus</i> reared in cages at different stocking sizes	59
5.5	Physico-chemical parameters	60
<b>VI</b>	<b>SUMMARY AND CONCLUSION</b>	<b>63</b>
<b>VII</b>	<b>REFERENCES</b>	<b>67</b>

## LIST OF TABLES

Table No.	Title	Page No.
3.1	Details of experiment and codes of trial on stocking density of <i>P. hypophthalmus</i>	26
3.2	Details of experiment and experiment codes of trials on stocking size of <i>P. hypophthalmus</i>	26
3.3	Proximate composition of commercial pellet feed	27
4.1	Average Body Weight (g) of <i>P. hypophthalmus</i> during the rearing in cages under different stocking densities	34
4.2	Survival of <i>P. hypophthalmus</i> during the rearing in cages under different stocking densities	34
4.3	Estimated bio-growth parameters of <i>P. hypophthalmus</i> cultured in cages under different stocking densities	35
4.4	Estimated biomass production parameters and of <i>P. hypophthalmus</i> cultured in cages under different stocking densities	36
4.6	Average Body Weight (g) of <i>P. hypophthalmus</i> during the rearing in cages under different stocking sizes	44
4.7	Survival of <i>P. hypophthalmus</i> during the rearing in cage under different stocking sizes	44
4.8	Estimated bio-growth parameters of <i>P. hypophthalmus</i> cultured in cages under different stocking sizes	45

<b>Table No.</b>	<b>Title</b>	<b>Page No.</b>
4.9	Estimated biomass production parameters of <i>P. hypophthalmus</i> cultured in cages under different stocking sizes	46
4.10	Range values of water quality parameters in cages during the rearing of <i>P. hypophthalmus</i>	52
4.11	Mean $\pm$ SD values of water quality parameters in cages during the rearing of <i>P. hypophthalmus</i>	54

## LIST OF FIGURES

Figure No.	Title	Page No.
4.1	Growth pattern of <i>P. hypophthalmus</i> cultured under different stocking densities in cages	33
4.2	Daily weight gain (g) <i>P. hypophthalmus</i> cultured in cage at different stocking densities	37
4.3	Food Conversion Ratio of <i>P. hypophthalmus</i> cultured in cage at different stocking densities	37
4.4	Biomass production (kg) of <i>P. hypophthalmus</i> cultured in cages at different stocking densities	38
4.5	Survival of <i>P. hypophthalmus</i> during the culture period in cages at different stocking densities	38
4.6	Proximate composition of <i>P. hypophthalmus</i> muscle reared in cages at different stocking densities	40
4.7	Growth pattern of <i>P. hypophthalmus</i> cultured under different stocking sizes in cages	47
4.8	Daily Weight Gain (g) <i>P. hypophthalmus</i> cultured in cages at different stocking sizes	47
4.9	Food Conversion Ratio of <i>P. hypophthalmus</i> cultured in cages at different stocking sizes	48
4.10	Periodical biomass production (kg) of <i>P. hypophthalmus</i> cultured in cages at different stocking sizes	48

<b>Figure No.</b>	<b>Title</b>	<b>Page No.</b>
4.11	Percentage of survival of <i>P. hypophthalmus</i> during the culture period in cage at different stocking sizes	49
4.12	Proximate composition of <i>P. hypophthalmus</i> muscle reared in cage at different stocking sizes	50

## LIST OF PLATES

Plate No.	Title	Between The Pages
1	(a) Seeds of experiment fish	25 - 26
	(b) Acclimatization of <i>P. hypophthalmu</i>	25 - 26
2	(a) Initial length of <i>P. hypophthalmus</i> during 1 <sup>st</sup> experiment	25 - 26
	(b) Initial weight of <i>P. hypophthalmus</i> during 1 <sup>st</sup> experiment	25 - 26
3	(a) Total length (2")	25 - 26
	(b) Total length (4")	25 - 26
	(c) Total length (6")	25 - 26
4	(a) Tying of net in cages	26 - 27
	(b) Cage with top cover	26 - 27
	(c) Experiment setup	26 - 27
5	(a) Feeding in cages	27 - 28
	(b) Sampling of fishes	27 - 28
	(c) Cleaning of net cage	27 - 28
6	(a) Final harvested fishes	29 - 30
	(b) Final length of <i>P. hypophthalmus</i> after 90 days	29 - 30
	(c) Final weight of <i>P. hypophthalmus</i> after 90 days	29 - 30

## I. INTRODUCTION

“Hunger” is the major challenge faced by the mankind. Even after so many centuries, the situation continues to be travesty when fundamental human right to provide adequate food, freedom from hunger and malnutrition are reviewed. Therefore, it becomes the responsibility of every government to increase food production to feed the country’s growing population. It is more pertinent to countries like India, where the population growth surpasses the growth rate of food production. Among the various constituents of human food, protein is the major nutrient and animal protein is believed to be better than plant protein in nutritional perspectives. Fish is the best animal protein available because of its cheap cost and easy digestion. It also contains essential amino acids, poly unsaturated fatty acids and carbohydrate in proper proportion so as to be nutritive food for mankind.

Global fish production in 2018 was 179 million tonnes (FAO, 2020). Global capture fisheries contributed 96.4 million tonnes and the volume from aquaculture sector was 82.1 million tonnes (FAO, 2020). During 2001-2018, the annual growth rate of aquaculture production has been 5.3% (FAO, 2020). In India, aquaculture is an important economic activity and a flourishing sub-sector with varied resources and potential. Globally India is the second largest aquaculture fish producer which has contributed 6.3% of the global fish production (NFDB, 2018). Presently Indian fish production has been reported to be 12.61 million MT out of which capture fishery contribute 8.97 million MT and culture fishery contribute 3.6 million MT (DADF, 2018).

Fish consumption accounted for 17% of the global population’s intake of animal proteins, and 7% of all proteins intake (FAO, 2020). Globally fish provided

20% animal protein intake for approximately 3.3 billion people (FAO, 2020). People in developing countries have a higher contribution of fish protein in their diets than those in developed countries. Aquaculture is considered to be an impressive increase in supply of fish for human consumption.

The fishery sector contributed 7.28% to the gross value addition (GVA) of the agriculture sector and 1.24% to the national GVA (DADF, 2018). In the fisheries production in India, inland fisheries share was 71% in total fish production of the country. Total inland capture fisheries production in India during the year 2018 was around 1.70 million tonnes (FAO, 2020). There is a shift from exploitation to production within inland fisheries sector during last two and a half decades.

Freshwater aquaculture accounted for 34% in inland fisheries in mid 1980 which has increased up to 80% in 2017 (DADF, 2018) with the three Indian major carps viz., catla (*Catla catla*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*) provided a major share of 87% in the total production. Several carp culture methods such as recycled-wastewater culture, integrated agriculture aquaculture (IAA) and many short-term culture method have also been developed. However, freshwater aquaculture in India is largely dominated by pond-based systems.

Considering the accelerating and often conflicting cross-sectoral demands for water and land, there are limitations for growth in pond-based aquaculture in the country. In this regard, fish farming in enclosures such as cages installed in open water bodies offer scope for increasing production and helping the farmer to take up land-based fish farming ventures with agriculture and allied sectors.

In intensive fish farming fishes are reared under very high stocking density to obtain higher production to meet the expenses. In this regard, fishes are made

to depend on external feeds given to them and water exchange to maintain oxygen level. However, intensive farming can be done by installing cages in reservoir or large open water bodies to enhance aquaculture production. Besides helping in enhanced production per unit area, cage culture also offer numerous advantages as stated by (Halwart et al., 2007).

Cage farming has grown rapidly in the past 20 years and currently it is undergoing technical changes in response to reduce pressure from globalization and accelerating global demand for aquatic products (Halwart et al., 2007).

Cage culture of fishes was originated in Southeast Asia around 1800, particularly in the freshwater lakes and river systems of Cambodia. Fishes especially catfish (*Clarias sp.*) were commercially caught and held in cages until they reach market. Cage culture in India was initiated for culturing air breathing fishes in swamps. Major carps were farmed in running waters in Jamuna and Ganga at Allahabad, and farming of snake heads and tilapia in lakes, reservoirs and large water bodies of Karnataka. Later, the Central Institute of Fisheries Education conducted cage rearing of fingerlings and table sized fishes in the Powai, Govindsagar, Halali, Tandula and Dimbe reservoirs. Although Cage aquaculture is relatively new to the country's inland aquaculture it provided new opportunities for enhancing fish production from the reservoirs, lakes, floodplain wetlands and other open water bodies. This has helped in developing new skills among fish farmers and entrepreneurs to enhance their incomes.

Cage culture can be carried out in extensive, semi-intensive and intensive modes in selected water bodies. As an extensive method, cage culture does not require supplementary feed but rather the fishes are made to utilize phytoplankton and zooplankton available in the water bodies. This is suitable only

where the water productivity is relatively high and stable. Cage culture as a semi-intensive practice requires a low protein supplementary diet (<30%) and if feed exceeds 30% of protein content the practice can be considered as intensive cage culture system, where together with high protein feed, the stocking density also would be higher than normal.

Pangasiidae are economically important riverine catfishes that inhabit in freshwater from the Indian subcontinent to the Indonesian Archipelago (Gustiano et al., 2018). Total 19 species were recorded under the genera of *Pangasius*. Recently, seven new species were added to the genus of *Pangasius*. For aquaculture point of view the most important Pangasiidae species are *P. pangasius* (India), *P. hypophthalmus* (Thailand), and *P. djambal* (Indonesia, particularly Java) (Roberts and Vidthayano, 1991). They all are popular species for pond culture and cage culture.

Global *Pangasius* aquaculture production was 2.3 million metric tonnes in 2018 and 2.1 million metric tonnes in 2016 (FAO, 2020). In India, total production of *Pangasius* was 855,500 MT during the year of 2018 with 500,000 MT from Andhra Pradesh, followed by 150,000 MT from Bihar. In India, 42,900 ha area have been engaged in *Pangasius* farming of which 41,120 ha were earthen still water ponds and 1780 ha area were cage culture system during the year 2018. Andhra Pradesh had the major cultivated area of 24,000 ha followed by 8000 ha in Bihar and 6,400 ha in West Bengal (Mohan et al., 2019). Farming of *Pangasianodon* catfish began since 1960 but it geared up in 1996 after development of technology for seed production (Singh and Lakra, 2012).

*P. hypophthalmus* is one of the fast growing fishes in the world (Singh and Lakra, 2012). It is a ray-finned fish belonging to the order Siluriformes (Galagarza

et al., 2017). It is one of the major fish species in the Mekong river fishery and one of the largest and most important freshwater fish in the world. It is commonly known as striped (sutchi and iridescent shark) catfish (Chaturvedi et al., 2015). It is an air-breathing fish that can tolerate low dissolved oxygen (DO) content in the water and can be cultured in ponds, concrete tanks, fish cages or pens (Razzaque et al., 2003 and Vaishnav et al., 2017).

*P. hypophthalmus* is mainly cultured in Asian countries such as Bangladesh, Vietnam, Malaysia, Indonesia, Laos, Cambodia, China (Guimaraes et al., 2015), India and Myanmar (Rahman et al., 2006). It can replace cod and other expensive white fishes because of its more acceptability, affordable price, and white meat. It has been widely exported as chilled (pre-frozen), skinned and boneless frozen fillet (Karl et al., 2010 and Guimaraes et al., 2015). Sutchi catfish fillets have been used in more than 80 countries around the world including Netherlands, Germany, and United States, which demand mainly frozen fillets without skin and bone (Guimaraes et al., 2015). Therefore many countries and developing nation prefer intensive production of *P. hypophthalmus*.

In 1997, *P. hypophthalmus* was introduced in India through Bangladesh and culture was adopted by farmers in West Bengal. There has been much enthusiasm among fish breeders and farmers particularly in West Bengal, Andhra Pradesh and Chhattisgarh for its culture and breeding because of its remarkable growth rate (Singh and Lakra, 2012). Its culture practice is increasing more rapidly in Andhra Pradesh, Bihar, Uttar Pradesh, Orissa, Maharashtra, Chhattisgarh, Tamil Nadu, Karnataka, and Kerala.

*P. hypophthalmus* live in channels of large rivers, moving to floodplains and marshy areas during flooding in the rainy season. It is an omnivore fish,

primarily feeds on algae, zooplankton, crustaceans, and fishes. It migrates to longer distance (>300 km) for spawning from major rivers of Southeast Asia to spawning areas in northeastern Cambodia.

*P. hypophthalmus* is considered as the third most important freshwater aquaculture species because it grows fast, has versatile feeding habit (Rahman et al., 2006 and Kumar et al., 2017), highly tolerant of poor water quality and high market value (Makinen et al., 2013).

Growth and production of fish generally depends upon the daily feed consumption, quality of feed and feeding frequency. In most cultured species, among many factors stocking density and stocking size are considered important factors which influence the survival and growth, behavior, health, water quality, feeding and production (Rui et al., 2006). It can have either positive or negative effects on fish growth and this interaction seemed to be species-specific (Merino et al., 2007). Excessive stocking densities can increase the prevalence of physical injuries, stress, sensitivity to disease and alter swimming behaviour of fishes (Suarez et al., 2014). The optimization of stocking density and stocking size is important to develop a rearing technology of any species (Rahman et al., 2015). This has been emphasized and found true in the cage culture of hybrid tilapia by Alish (2019).

The quality of fish flesh is determined by nutritional value, sensory properties, muscular fiber structure and also by culture practices and environmental condition. The texture of fish flesh is affected by several factors, such as fish species, age, feeding management, fat content, muscle-lipid distribution, and handling stress before slaughtering (Suarez et al., 2014 and Refaey et al., 2018). Stocking density was also shown to contribute to the

proximate composition of fishes (Alish, 2019). During the culture period fishes are subjected to many stressors which results in reduction of muscular flesh quality, reduced consumption and causes great economic lose for farmer in aquaculture industry.

Therefore, the present study was planned to evaluate effect of stocking parameters on growth and survival of *P. hypophthalmus* in intensive cage culture system with the following objectives

1. To determine the influence of stocking density, stocking size and age of the seeds on the production of *P. hypophthalmus* (Sauvage, 1878) in the cage farming.
2. To observe the production parameters and their relationship with water quality in the intensive cage farming.
3. To investigate the effect of intensification in stocking on the survival of *P. hypophthalmus* in cages.
4. To study the influence of intensification on the meat quality of *P. hypophthalmus*.

## II. REVIEW OF LITERATURE

### 2.1 Cage farming

Cage culture of fish has been defined as the rearing of fish stocks, generally from juvenile to marketable size in a totally enclosed aquatic environment (Das et al., 2009). Globally 62 countries are engaged in cage aquaculture practices (Halwart et al., 2007). In this system of culture, fishes are confined in wire mesh net cage or bamboo splits-made cage which are supported or suspended in open and closed water bodies. Cage aquaculture has certain advantages over the other farming system according to Azimuddin et al. (1999). Use of existing water body, easy management of fishes and easy harvest are some of the advantages listed by them. By utilizing the viable alternative this technology offers landless farmers in resource-poor areas (Rahman et al., 2006).

In aquaculture enterprises, cage culture or any other intensive culture system, selection of species is important since all species are not suitable for every culture system. As FAO (2007) pointed out, commercial cage culture has been mainly restricted to the culture of high-value (in marketing terms) compound-feed-fed finfish species, carnivorous fish species (rainbow trout and snakehead) and an ever increasing proportion of omnivorous fish species (including Chinese carps, tilapia and catfish).

### 2.2 Biology of *P. hypophthalmus*

*P. hypophthalmus* is a riverine freshwater species that belongs to the Pangasiidae family under the order Siluriformes (Amin et al., 2005). It is native to Mekong river basin and it migrates long-distance of over a several hundred kilometres (potamodromous) between upstream and spawning habitats and downstream feeding and nursery habitats (Poulsen et al., 2004). It is a

benthopelagic fish species, typically living within the pH of 6.5-7.5 and temperature of 22-26 °C (Phen et al., 2005).

Body of *P. hypophthalmus* is elongated and laterally compressed, without any scale. Head and abdomen are flat, tail is constricted behind the adipose fin but a bit extended before the caudal peduncle (Gupta, 2016).

Eyes are relatively large. Two pairs of barbells, upper shorter than the lower. Fins are dark grey or black in colour. Young fish have black stripe along lateral line and another long black stripe below lateral line, large adults are uniformly grey but sometimes with greenish tint and sides silvery. Dark stripe on middle of anal fin, dark stripe in each caudal lobe, small gill rakers regularly interspersed with larger ones (Roberts and Vidthayanon 1991).

It grows up to 15.5 kg in weight and about 130 cm in length (Phen et al., 2005). Females take at least three years to reach sexual maturity in captivity while males often mature in their second year (Chaturved et al., 2015). A mature 10 kg female can spawn over one million eggs (FAO, 2020). *P. hypophthalmus* is a seasonal spawner and breeds once in a year in flooded river (Chaturvedi et al., 2015).

### **2.3 Cage farming of *P. hypophthalmus***

*P. hypophthalmus* is well accepted in commercial aquaculture system due to high-stress tolerance, disease resistance, consumer demand and its response to commercial feeds (Singh and Lakra, 2012 and Chowdhury et al., 2019). Pangasius is now cultured in several countries in the world like Thailand, Nepal, Pakistan, India, Bangladesh, Vietnam, Laos, Myanmar, Indonesia, and Cambodia (Vaishnav et al., 2017).

## 2.4 Effect of stocking density on the growth of fishes

Stocking density is one of the most important variables in aquaculture as it directly influences survival, growth, behavior, health, water quality, feeding and production (Razzaqu et al., 2003 and Mane et al., 2019). Increased stocking density resulted in stress which has led to higher energy requirements causing reduced growth and food utilization (Hengsawat et al., 1997). Hence optimum stocking densities need to be determined for each species and its production phases to enable efficient management and maximize production and profitability (Zhu et al., 2011 and Chattopadhyay et al., 2013).

In cage aquaculture, fish stocking density has great impact on growth, survival, health, water quality and production (Razzaqu et al., 2003 and Mane et al., 2019). Fishes could be stocked at a much higher density in cages when compared to other forms of fish culture (Azimuddin et al., 1999). Stocking density is one of the most important factors in determining the production of a fish in the culture system (El-Sayed, 2006). Rearing fish at inappropriate stocking densities may impair growth and cause reduction in immune competence due to factors such as social interactions and deterioration of water quality, which can affect both feed intake and conversion efficiency of the fish (Malik et al., 2014).

Chowdhury et al. (2019) studied the growth, yield and economic returns of striped catfish (*P. hypophthalmus*) at different stocking densities (19, 22 and 25 fish/m<sup>3</sup>) under floodplain cage culture system and found higher mean final weight (646.01 ± 4.37 g) in lower stocking density (19 fish/m<sup>3</sup>) and lower mean final weight (600.25 ± 8.02 g) in higher stocking density (25 fish/m<sup>3</sup>).

Vaishnav et al. (2017) evaluated the growth performance of *Pangasius* sp. cultured at different stocking densities (2600 fish/cage, 2800 fish/cage and 3000

fish/cage) in floating net cages in Mahi Bajaj Sagar Dam of Banswara (Rajasthan) for 60 days and found higher growth performance and percent increase in biomass at lower stocking density (2600 fish/cage). Islam et al. (2006) observed that stocking density positively influenced the yield and farm profitability in cage aquaculture of *P. sutchi*.

The optimum stocking density is the level where the maximum yield could be reached (Kjartansson et al., 1988). In cage culture, optimum stocking densities and carrying capacities varied with species, size of fish, size of cages, rate of water exchange, size of ponds and length of growing season (Rowland et al., 2006). The choice of stocking densities of fish depended in part on economic factors and also the market demands (Fattah and Aal, 2006). Increased stocking density reduced the mean size of fish (Jiwyam et al., 2011). Under stocking failed to make use of the available space and overstocking resulted in stress that led to higher energy requirements that caused low growth and feed utilization (Rahman et al., 2006).

The critical factor involved in designing an efficient cage aquaculture system was identifying the optimum stocking density for a species (Hengsawat, 1997). Rahman et al. (2017) reported that highest mean weight gain (14.96 g) of *Heteropneustes fossilis* was found in lower stocking density (100 fish/cage) compared to higher stocking density (300 fish/cage). The total final biomass of *P. sutchi* increased with increasing stocking density and survival rate of caged *P. sutchi* decreased from 98% to 94.8% with increased stocking densities from 100 to 150 fish/m<sup>3</sup> (Rahman et al., 2006).

Growth performance of *P. hypophthalmus* was recorded higher in cages (1026.87 g weight and 46.25 cm length) as compared to ponds (975.84 g and 45.06 cm) (Kumar et al., 2017). Allen (1974) found that mean fish weight, feed conversion efficiency and survival rate of *Ictalurus punctatus* declined as stocking density increased from 90 – 720 fish/m<sup>3</sup> but the net yield increased as stocking density increased up to 540 fish/m<sup>3</sup> which then declined at higher densities. Mane et al. (2019) reported that the survival rate of cage reared catla and rohu in higher stocking densities was lower and highest length gain and weight gain were obtained in the lower stocking densities which were due to the less competition for space and food among fishes.

Azimuddin et al. (1999) reported that the best individual growth of *P. sutchi* was obtained at a density of 40 fish/m<sup>3</sup> but the highest total production was obtained at a stocking density of 50 fish/m<sup>3</sup> in net cages where the fish was fed by 34% crude protein.

Datta et al. (2016) found that FCR of *P. pangasius* increased up to the stocking density of 25 fishes/m<sup>3</sup>, while it decreased at the stocking density of 30 fishes/m<sup>3</sup>. Osofero et al. (2009) stated an inverse relationship between survival rate and stocking density in *Oreochromis niloticus* and reported highest survival rate of 99.5% at stocking density of 100 juveniles/cage and lowest survival rate of 98.5% at the stocking density of 200 juveniles/cage. The specific growth rate, daily weight gain and weight gain were significantly higher at moderate stocking density of 7 nos/m<sup>2</sup> than those of 5 nos/m<sup>2</sup> and 10 nos/m<sup>2</sup> respectively in *Clarias gariepinus* (Oke et al., 2019).

Kwikiriza et al. (2016) evaluated the growth performance of the monosex Nile tilapia juvenile (*O. niloticus*) under different stocking densities and found a negative correlation between stocking density and growth rate. They also observed that the growth rate gradually decreased with increased stocking density and recorded the highest growth rate at a lower stocking density of 1000 nos/m<sup>3</sup> than that of 1250 nos/m<sup>3</sup> and 1500 nos/m<sup>3</sup>.

A number of studies addressed the effect of stocking density on *P. hypophthalmus* production (Azimuddin et al., 1999, Razzaque et al., 2003, Rahman et al., 2006 and Chowdhury et al., 2019). Most studies show reduced final weight with increased stocking density and maximum growth at low to intermediate stocking density (Razzaque et al., 2003, Islam et al., 2006, Rahman et al., 2017 and Chowdhury et al., 2019).

## **2.5 Effect of stocking density on survival rate of fishes**

The major problem observed during larval rearing of *P. hypophthalmus* is high mortality due to cannibalism (Subagja et al., 1999). This phenomenon is associated with large size variation, high population densities and limited food availability (Mukai et al., 2010).

The highest survival rate of *P. hypophthalmus* was found at a lower stocking density of 100 fry/tank and the lowest survival was recorded at a higher stocking density of 300 fry/tank (Malik et al., 2014). Rahman et al. (2006) stated that stocking densities did not affect the survival rate of *P. sutchi* in cage aquaculture. However, Rahman et al. (2017) found that survival rate of *H. fossilis* in cages decreased with increasing stocking densities and they observed a lower survival rate at 300 fish/cage when compared to 100 fish/cage and 200 fish/cage.

*Labeo bata* (Bata fish) when stocked in the nursery pond at 0.6, 0.8, 1.0 million/ha, the highest survival rate was obtained at lower stocking density of 0.6 million/ha and the lowest survival was observed at higher stocking density of 1.0 million/ha (Chakraborty and Mirza, 2007).

The effect of different larval stocking densities viz., 4, 8 and 12 nos/l resulted in size heterogeneity, cannibalism of *Lates calcarifer* this has been shown that the lowest survival and highest mortality was found at moderate density of 8 larvae/l, whereas the highest survival and lowest cannibalism was at lowest density of 4 larvae/l (Sukumaran et al., 2011). Osofero et al. (2009) found that there is no difference in survival rate (99.3%) of *O. niloticus* in cage but the highest survival was observed at stocking density of 150 juveniles/cage.

Suleiman and Solomon (2017) studied the effect of stocking density on the growth and survival of *C. gariepinus* grown in plastic tanks and found highest growth (25.8 g) and survival rate (100%) at stocking density of 10 fish/aquaria.

Effects of different stocking densities (90, 180, 350, 540 and 720 fish/m<sup>3</sup>) and water exchange (17.9 and 35.8 l/min inflow) on survival of channel catfish *I. punctatus* in circular tanks were evaluated by (Allen, 1974). He had shown that 100% survival rate was found at lower stocking density (90 fish/m<sup>3</sup>) whereas, lower survival (72.4%) was noticed at higher stocking density (540 fish/m<sup>3</sup>) but there was no difference in the survival rate with water exchange. Similarly Mane et al. (2019) evaluated the effect of stocking density (900, 1800, 2700 nos/cage) on growth performance, survival and production of *Catla catla* and *Labeo rohita* during nursery rearing in cages and the highest survival of 65.5% was found at lower stocking density (900 nos/cage).

Interactive effect of stocking density (10, 20 and 30 larvae/l) and different types of feed (Artemia nauplii, Zooplankton and Dry feed) on survival rate and cannibalism of *C. gariepinus* larvae resulted in the highest survival rate at lower density of 10 larvae/l and highest cannibalism rate at higher density of 30 larvae/l when they were fed with all three types of feed (Shourbela et al., 2016).

Slembrouck et al. (2009) stated that survival rate of *P. hypophthalmus* larvae depended only on the feeding level and not on stocking density. Azimuddin et al. (1999) found that survival rate of *P. hypophthalmus* in net cage ranged between 92-95%.

## **2.6 Effect of stocking size on growth and survival of fishes**

During production of fingerlings, the size of fry at stocking is an important criterion for high survival and growth apart from stocking density, suitable feed and water quality (Sahoo et al., 2004). The size of fish during stocking determined the economic viability of all types of production systems (Sahoo et al., 2004). Limbu et al. (2015) assessed the growth performance, percentage survival and yield of mixed sex Nile tilapia by culturing it with two different sizes of African sharptooth catfish (*Clarias gariepinus*) such as  $62.50 \pm 3.26$  g and  $40.00 \pm 2.68$  g and showed polyculture of tilapia with larger African sharptooth catfish grew higher than monoculture.

Sahoo et al. (2004) studied the effect of stocking sizes (0.06 g, 0.04 g and 0.02 g) on growth and survival of *C. batrachus* fry during fingerling hatchery production and found that the final weight were significantly higher in larger fish group (0.06 g) than that of smaller groups (0.02 g). They also reported that survival rate was significantly reduced (57%) while stocking 0.02 g fish compared to higher group (73%).

Akbulut et al. (2002) evaluated the effect of three stocking sizes (52.1 g, 77.6 g and 118.6 g) on the growth rate of rainbow trout, *Oncorhynchus mykiss*, reared in cages and observed that higher SGR (1.11%) was found at 52.1 g stocking size and higher final biomass (997.2 kg/cage) was found at 118.6 g stocking size.

## **2.7 Effect of stocking density on meat quality**

Proximate composition of fish is influenced mainly by species, catching season, environment, diet, age, sex and also the farming practices (Suarez et al., 2014). Muscular protein content increased and muscle fat content and muscle pH reduced with increasing stocking density (50, 150 and 300 fish/m<sup>3</sup>) of *I. punctatus* fingerlings in recirculatory system (Refaey et al., 2018).

Guimaraes et al. (2015) evaluated the chemical quality of frozen Vietnamese *P. hypophthalmus* fillets and found moisture, protein, lipid, and ash values between 83.83 and 85.59 g/100 g, 12.51 and 14.52 g/100 g, 1.09 and 1.65 g/100 g, and 0.76 and 2.38 g/100 g, respectively.

Cagiltay et al. (2015) analysed the proximate composition of *O. mykiss* at different stocking densities (5, 15, 25 kg fish/m<sup>3</sup>) and showed that higher moisture (74.1%) content was found in stocking density of 5 and 25 Kg/m<sup>3</sup>. Higher ash (1.81%), protein (20.22%), PUFA and amino acid were recorded at stocking density of 25 kg fish/m<sup>3</sup>.

*P. pangasius* when stocked in pond at different stocking densities (5000/ha, 8000/ha and 11000/ha) were found to have muscle composition almost similar in all stocking densities but lipid percentage of fish caught from open water was higher than that stocked in pond (Razzaque et al., 2003).

The channel catfish *I. punctatus* cultured under three different stocking

densities (50, 150 and 300 fish/m<sup>3</sup>) in recirculatory aquaculture system showed that the muscular protein content increased and fat content decreased with increasing stocking density (Refaey et al., 2018).

Battisti et al. (2020) evaluated the effect of stocking density (10, 20 and 30 g biomass/l) on growth, hematological and biochemical parameters and antioxidant status of silver catfish (*Rhamdia quelen*) cultured in a biofloc system and found highest fillet crude protein (19.21 ± 0.5 %) and lipid (9.25 ± 0.85%) in lower stocking density (10 g biomass/l) compared to other stocking densities.

Karl et al. (2010) studied the composition and quality attributes of conventionally and organically farmed *P. hypophthalmus* fillets and found that protein content of conventionally farmed fillets ranged between 13.3 to 15.7%, whereas organically produced fillets had significantly higher protein content of 17.0 to 17.4%. No difference in the fat content between farming methods was observed, which varied between 1.4 and 3.2%.

Crețu et al. (2014) studied the influence of different stocking densities (2.64 kg/m<sup>3</sup>, 5.16 kg/m<sup>3</sup>, 7.12 kg/m<sup>3</sup> and 9.42 kg/m<sup>3</sup>) on biochemical composition of Rainbow trout meat reared in a recirculating aquaculture system for 33 days and documented highest crude protein content (17.46±1.09%) in lower stocking density (2.64 kg/m<sup>3</sup>) whereas, highest lipid (3.58±0.03%) and moisture content (77.30±1.32%) was found in higher stocking density (9.42 kg/m<sup>3</sup>).

## **2.8 Water quality parameters**

Water quality is an integral part of cage aquaculture system. It plays a major role in fish health and any deterioration in water quality causes stress to fish and brings about diseases (Devi et al., 2017). Water quality, a major factor determining the production of fish, is dramatically influenced by the pond soil and

the pond management practices such as stocking density, fertilization strategy and supplemental feeding (Das et al., 2005). All living organisms have tolerable limits of water quality parameters in which they perform optimally. A sharp drop or an increase within these limits had adverse effects on their body functions (Bhatnagar and Devi, 2013). A good water condition is necessary for the survival and growth of fish since the entire life process of the fish wholly depend on the quality of its environment (Hossain et al., 2008 and Thirupathaiah et al., 2012).

*P. hypophthalmus* can tolerate wide fluctuation in water quality than most commonly farmed freshwater fish (Razzaque et al., 2003 and Nawang et al., 2019). The key water quality variables related to *P. hypophthalmus* culture in cages are temperature, dissolved oxygen (DO) and pH. However, other parameters such as ammonia, nitrates, nitrites, chemical oxygen demand (COD), alkalinity and hardness also have significant impacts within aquaculture ecosystems (Rahman et al., 2006 and Khan et al., 2018).

### **2.8.1 Temperature**

Water temperature is the most important abiotic factor which directly influences the fish growth performance, carcass composition and energy requirement (Ranjan et al., 2018). All biological and chemical processes in an aquaculture operation are influenced by temperature (Devi et al., 2017). Higher temperature increased the rate of bio-chemical activity of the micro biota, plant respiratory rate, and increased oxygen demand. It further caused decreased solubility of oxygen and also increased level of ammonia in water (Bhatnagar and Devi, 2013). It is one of the most important external factors which influenced fish production. *P. sutchi* showed highest growth rate at temperature that ranged from 21.1 to 32.2 °C (Rahman et al., 2006).

Chaturvedi et al. (2015) reported that optimum water temperature for breeding of *P. hypophthalmus* was 27.5 - 28.6°C. Temperature that ranged between 27.8 and 28.1 °C was suitable for cage culture of *O. niloticus* (Lira et al., 2012).

Sarkar et al. (2012) observed surface water temperature for pond culture of *P. hypophthalmus* to be in the range from 28.2 to 31.7°C. The growth rate of *P. pangasius* was higher in summer (32°C) and slower in winter (20°C) (Razzaque et al., 2003). Islam et al. (2019) observed that growth performance of *P. hypophthalmus* was better in the temperature ranged from 28 - 32°C.

### **2.8.2 Dissolved oxygen (DO)**

Dissolved oxygen affects the growth, survival, distribution, behaviour and physiology of aquatic organisms (Bhatnagar and Devi, 2013). DO concentration in water mainly depended upon temperature, dissolved salts, velocity of wind, pollution load, photosynthetic activity and respiration rate (Devi et al., 2017). Tropical fishes have more tolerance to low DO than temperate fishes. In general, warm water fishes such as catfish and tilapia required a DO concentration of 4 mg/l or greater for growth and survival. Kader et al. (2003) reported that the suitable range of DO for better growth and survival of *P. hypophthalmus* was 5.71-7.65 mg/l.

### **2.8.3 pH**

pH was reported to be a significant factor in the production of aquatic organism. pH between 7 to 8.5 was found ideal for biological productivity (Devi et al., 2017). Fishes became stressed in water with a pH that ranged from 4.0 to 6.5 and 9.0 to 11.0 and death was almost certain at a pH of less than 4.0 or greater than 11.0 (Bhatnagar and Devi, 2013).

*P. hypophthalmus* showed best growth rate at pH of 6.75-7.30 (Ngoc et al., 2016). Rahman et al. (2006) reported pH values from 7.0-8.0 for cage culture of *P. hypophthalmus*. The pH of water was greatly influenced by the concentration of carbon dioxide (CO<sub>2</sub>), an acidic substance. Phytoplankton and other aquatic vegetation remove CO<sub>2</sub> from the water during photosynthesis, so the pH of water body rises during the day and decreases during the night as it was reported by (Boyd and Pillai, 1985).

#### **2.8.4 Alkalinity**

Alkalinity is the ability of the water to resist changes in pH and is a measure of the total concentration of bases in pond water including carbonates, bicarbonates, hydroxides, phosphates and borates, dissolved calcium, magnesium, and other compounds in the water (Boyd et al., 2016). Wurts (2002) suggested that total alkalinity level for most aquaculture species was between 50 and 150 mg/L CaCO<sub>3</sub>, but not less than 20 mg/L CaCO<sub>3</sub>.

Boyd and Lichtkoppler (1979) mentioned that water with total alkalinity in the range of 20 to 150 mg/l contained required quantities of CO<sub>2</sub> to permit plankton production for fish culture. Ntengwe and Edema (2008) reported that alkalinity above 80 mg/L was found to be most favourable for pond aquaculture. Hossain et al. (2008) reported that the best alkalinity of 70-165 mg/l was found in perennial pond than that of non perennial pond (58-85 mg/l).

Wurts and Durborow (1992) stated that total alkalinity of 20 mg/L or more is necessary for good pond productivity. A desirable range of total alkalinity for fish culture is between 50 – 150 mg/L CaCO<sub>3</sub> (Wurts, 2002).

#### **2.8.5 Hardness**

It is the total concentration of divalent metal ions (primarily calcium and magnesium) expressed in mg/l of equivalent calcium carbonate (Boyd et al., 2016). Calcium and magnesium are essential in the biological processes of aquatic animals including bone and scale formation in fish. Aquatic animals can tolerate a broad range of calcium hardness concentrations.

According to Wurts (2002), desirable range of hardness for aquaculture was between 75 and 200 mg/L CaCO<sub>3</sub>. Boyd (1990) stated that desirable levels of total hardness and total alkalinity for fish culture generally fell within the range of 20 to 300 mg/L. Premchand and Kiranmai (2017) reported that total hardness of 90 to 110 mg/L was the best for culture of Indian Major Carps. Wurts and Durborow (1992) mentioned that the range of free calcium in culture water was 25 to 100 mg/L.

#### **2.8.6 Carbon dioxide (CO<sub>2</sub>)**

CO<sub>2</sub> exist in the water in the form of carbonates and bicarbonates. Carbon dioxide rarely causes direct toxicity to fish. However, high concentrations lower pond pH and limit the capacity of fish blood to carry oxygen by lowering blood pH at the gills (Wurts and Durborow, 1992). This had all extreme impact on the health of the fish (Hargreaves and Brunson, 1996).

According to Boyd and Lichtkoppler (1979) fish avoided free CO<sub>2</sub> levels as low as 5 mg/L. But catfish could tolerate 20 to 30 mg/L CO<sub>2</sub> if accumulation was slow and DO concentration was above 5 mg/L. In a reservoir or natural pond, CO<sub>2</sub> rarely exceeded 5 to 10 mg/L (Wurts and Durborow, 1992). Hossain et al. (2008) reported that CO<sub>2</sub> concentration was higher in non perennial pond (4.5-8.6 mg/L) compared to perennial pond (5.2-7.5 mg/L). High CO<sub>2</sub> concentrations were

always accompanied by low DO concentrations (high respiration) (Hargreaves and Brunson, 1996).

### **2.8.7 Total ammonia nitrogen**

Ammonia is the main nitrogenous waste produced by aquatic animals and is excreted through gill and kidney. In water, ammonia nitrogen occurs in two forms, un-ionized ammonia and ammonium ion (ionized ammonia) (Boyd and Pillai, 1985). Un-ionized ammonia is the toxic form and predominates when pH is high whereas, ammonium ion is relatively nontoxic and predominates when pH is low (Hargreaves and Tucker, 2004). The equilibrium between un-ionized ammonia ( $\text{NH}_3$ ) and ionized ammonia ( $\text{NH}_4^+$ ) is also affected by temperature (Boyd and Pillai, 1985). At any given pH, more toxic ammonia is present in warmer water than in cooler water (Hargreaves and Tucker, 2004). The tolerance of fish to ammonia varied with species, physiological and environmental conditions (Boyd and Pillai, 1985).

Jahan et al. (2014) fed *P. hypophthalmus* with supplementation of Bamboo charcoal (BC) for 91 days at 0%, 0.5%, 1% and 2% and showed that mean value of ammonia to be 1.5 mg/l, 0.67 mg/l, 0.25 mg/l, 0.4 mg/l respectively in pond water.

Excess ammonia could be eliminated from the culture system by improving feeds and feeding practices to increase the proportion of N recovered in fish and reduced the amount of  $\text{NH}_3$  excreted by fish. Efficient aeration and water circulation also could enhance nitrification and oxidation of organic nitrogen (Gross et al., 2000).

### **2.8.8 Nitrite nitrogen**

Nitrite is a by-product of oxidized  $\text{NH}_3$  or  $\text{NH}_4^+$ , an intermediary in the conversion of  $\text{NH}_3$  or  $\text{NH}_4^+$  into  $\text{NO}_3$  (Bhatnagar and Devi, 2013). When nitrite is absorbed by fish, it reacts with haemoglobin to form methemoglobin. Methemoglobin is not an effective oxygen carrier. Hence continued absorption of nitrite can lead to hypoxia and cyanosis (Boyd and Pillai, 1985).

### **2.8.9 Chemical Oxygen Demand**

Chemical oxygen demand (COD) is the amount of oxygen required to completely oxidize the organic matter in a water sample to  $\text{CO}_2$  and water (Boyd, 1973). Boyd (1973) reported COD in the range of 7.4 to 138.9 mg/l with an average of 43.4 mg/l. He also stated that oxygen utilization by living planktonic communities increased proportionally with increase in COD.

Queiroz and Boyd (1998) reported that COD level in bacterial inoculated pond was 21.7 mg/l than control pond (25.1 mg/l). Li and Li (2009) suggested that ponds having aquatic vegetation have lower COD than that of control pond.

### **2.8.10 Total Dissolved Solids**

Total dissolved solids are the solids present in the water in dissolved state (Devi et al., 2017). It consists of inorganic salts and dissolved materials. Total dissolved solids are the total amount of mobile charged ions, including minerals, salts or metal dissolved in a given volume of water expressed in mg/L. These ions are important in sustaining aquatic life. However, high concentrations can result in damage to organism's cell, reduce photosynthetic activity and increase the water temperature (Mitchell and Stapp, 1992).

Suspended solid can come from silt, decaying plant and animals, industrial waste, sewage and from organism living in water body (Schumann and Brinker, 2020). High concentrations had several negative effects, such as decreased the amount of light that could penetrate the water, thereby slowed photosynthetic processes which in turn lowered the production of DO, high absorption of heat from sunlight, thus increased the temperature which resulted in lower oxygen level, low visibility which affected the ability of fish to hunt for food, clog fish gills, prevented development of egg and larva (Scannell and Jacobs, 2001). It also served an indicator of higher concentration of bacteria, nutrients and pollutants in the water.

#### **2.8.11 Conductivity**

The conductivity is largely determined by ion levels in water, predominant ion being  $\text{Ca}^{2+}$  in the freshwater. These conductive ions come from dissolved salts and inorganic materials such as alkalis, chlorides, sulfides and carbonate compounds (Gautam et al., 2011). Conductivity is usually measured in micro or millisiemens per centimeter ( $\mu\text{S}/\text{cm}$  or  $\text{mS}/\text{cm}$ ). Nzeagwu et al. (2017) reported that optimum conductivity of 44.0 – 190.0  $\mu\text{S}/\text{cm}$  was good for pond culture of *C. gariepinus* and *T. zilli*. Makori et al. (2017) reported an optimum conductivity of 24.32 to 99.42  $\mu\text{S}/\text{cm}$  for tilapia culture.

### III. MATERIALS AND METHODS

The present research work was carried out at Thanjavur Centre for Sustainable Aquaculture (TCeSA), Thanjavur, Tamil Nadu to assess the effect of stocking density and stocking size on the growth and survival of *P. hypophthalmus* rearing in cage.

#### 3.1 Experiment fish

*P. hypophthalmus* seeds were procured from Patathari Fish Farm, Madurai, Tamil Nadu (Plate 1). Prior to acclimatization, the fishes were disinfected with 1% KMnO<sub>4</sub> solution and then acclimatized for 10 days with commercial diet in FRP tanks (Plate 1). The seeds were then graded according to their length and weight. Uniform size seeds were taken for experiment.

#### 3.2 Experiment design

In the present study, 2 sets of experiments were carried out. In the first experiment, seeds were stocked in the cages at three different stocking densities viz., 20/m<sup>3</sup>, 40/m<sup>3</sup> and 60/m<sup>3</sup>. The Average Body Weight (ABW) and Average Body Length (ABL) of the seeds stocked was 2.7±0.11 g and 6.9±0.06 cm respectively (Plate 2). The fishes were reared for a period of 90 days. The stocking density which yielded best result in terms of growth and survival was selected for the second experiment. The experiment set up and experiment codes used in the study are given in Table 3.1.

In the second experiment, the stocking density that gave the best result was chosen and seeds were stocked in the cages at three different stocking sizes viz., 2", 4" and 6" (Plate 3). The ABW of the seeds stocked was 2.35±0.05 g, 7.59±0.05 g and 19.59±0.10 g respectively. The fishes were reared for a period of 60 days. The stocking size which yielded the best result in terms of growth and

**Plate 1**



**(a) Seeds of experiment fish**



**(b) Acclimatization of *P. hypophthalmus***

## Plate 2



(a) Initial length of *P. hypophthalmus* during 1<sup>st</sup> experiment



(b) Initial weight of *P. hypophthalmus* during 1<sup>st</sup> experiment

### Plate 3



**(a) Total length (2")**



**(a) Total length (4")**



**(b) Total length (6")**

survival were recorded. The experiment set up and experiment codes used in the study are given in Table 3.2. Both the experiments had duplicate cage and arranged in a single cage unit.

**Table 3.1 Details of experiment and codes of trials on stocking density of *P. hypophthalmus***

S.No.	Stocking density (fishes/m <sup>3</sup> )	Stocking size (Inch)	Experiment code	Total number of fishes
1.	20	2	T1	80
2.	40	2	T2	160
3.	60	2	T3	240

**Table 3.2 Details of experiment and codes of trials on stocking size of *P. hypophthalmus***

S.No.	Stocking density (fishes/m <sup>3</sup> )	Stocking size (Inch)	Experiment code	Total number of fishes
1.	20	2	T4	80
2.	20	4	T5	80
3.	20	6	T6	80

### 3.3 Stocking and maintenance

Uniform size cages with uniform features were used for this study. The experiment consisted of 6 numbers of floating cage unit (Plate 4). The size of each cage was measuring 2 m X 2 m X 1.5 m. The cage unit was placed in an open water body (1 ha) located inside the premises of TCeSA. The water body had well organized inlet and outlet to maintain suitable water level in the pond.

## Plate 4



**(a) Tying of net in cages**



**(b) Cage with top cover**



**(c) Experiment setup**

Before starting the experiment, the cage net was cleaned with the help of brush and disinfected with  $\text{KMnO}_4$  (Plate 5). The net were tied into the cage before stocking the fish. The mesh size of outer net was 1 mm and inner net was 0.7 mm with top end closed to protect the fish from bird predation (Plate 4).

### 3.4 Feeding of fishes

Commercial pellet feed (M/S Growel Pvt. Ltd.) having a size of 2.5 mm was fed to the fishes twice a day viz., morning 10 am and evening 4 pm. The fishes were fed at the rate of 10% BW during the 1<sup>st</sup> month of rearing which was reduced to 5% BW of fish for the remaining culture period (Plate 5). The proximate composition of the commercial pellet feed is given in Table 3.3.

**Table 3.3 Proximate composition of commercial pellet feed**

Parameters	Values (%)
Crude protein (min.)	40
Crude fat (min.)	0.6
Crude fibre (max.)	3.0
Moisture (max.)	11.5

### 3.5 Sampling and observations

Sampling was done every fortnight and the growth parameters were recorded (Plate 5). Based on that the feeding rate was adjusted. During each sampling, 20 numbers of fishes were collected from each cage. The length and weight of the fishes were recorded by using scale and portable weighing balance respectively (Plate 6). The fishes were visually examined to determine the health condition. Prophylactic bath treatment with  $\text{KMnO}_4$  solution of 5 mg/L for 10 minutes was given to the fishes after every handling.

## Plate 5



**(a) Feeding in cages**



**(b) Sampling of fishes**



**(c) Cleaning of net cage**

### 3.6 Assessment of growth parameters

The growth parameters such as final body weight (g), final biomass (kg), survival (%), Weight Gain (g), Weight Gain Percentage (%), Daily Weight Gain (DWG) and Specific Growth Rate (SGR), feed given (g), Food Conversion Ratio (FCR), Food Conversion Efficiency (FCE), net biomass production (kg) and biomass production per unit area were estimated and recorded over the time of observation from the start of experiment. The growth pattern and trends were estimated based on the data collected.

1. **Mean weight gain (g)** = Mean final weight (g) - Mean initial weight (g)

2. **Weight gain percentage (%)** =  $\frac{W_f - W_i}{W_i} \times 100$

3. **Average daily weight gain (g) (ADG)** =  $\frac{\text{Final weight} - \text{Initial weight}}{\text{Days of culture}}$

4. **Total Biomass production (kg)** = Average final weight of fish X Total number of survivors

5. **Net biomass production (kg)** = Final biomass obtained – Initial biomass stocked

6. **Biomass production per unit area** =  $\frac{\text{Total net biomass produced}}{\text{Total area of culture system}}$

7. **Specific growth rate (SGR)** =  $\frac{\ln(W_f) - \ln(W_i)}{T} \times 100$

Where,

$W_i$  = Initial weight of fish (g)

$W_f$  = Final weight of fish (g)

T = Culture duration

## Plate 6



(a) Final harvested fishes



(b) Final length of *P. hypophthalmus* after 90 days



(c) Final weight of *P. hypophthalmus* after 90 days

$$8. \text{ Food Conversion Ratio (FCR)} = \frac{\text{Total feed (Kg)}}{\text{Net fish biomass produced}}$$

$$9. \text{ Food Conversion Efficiency (FCE)} = \frac{\text{Net biomass production}}{\text{Total feed given}} \times 100$$

$$10. \text{ Survival rate (\%)} = \frac{\text{Final harvested fish}}{\text{Initial stocked fish}} \times 100$$

### **3.7 Physico-chemical parameters of water**

During experiment, the water quality parameters such as temperature, pH, Electrical Conductivity (EC), Total Dissolved Solid (TDS) and DO were measured daily whereas, total alkalinity, total hardness, COD, total ammonia nitrogen and nitrite nitrogen were monitored once in a week during the study period. The parameters were estimated following the standard procedure (APHA, 1998).

### **3.8 Proximate composition analysis for meat quality**

The proximate composition of experimental fish flesh such as protein, fat, moisture and fibre content were estimated using standard method at TNJFU Referral Laboratory, Nagapattinam.

### **3.9 Harvesting**

At the end of experiment, the fishes were harvested from the cages by lifting the cage net. The total biomass of fish were weighed and recorded for each trial (Plate 6).

### **3.10 Statistical analysis**

The data obtained during experiment was statistically analyzed with One way ANOVA with SPSS 25 version and Duncan test.

## IV. RESULTS

### 4.1 Growth parameters of *P. hypophthalmus* in cages at different stocking densities

Estimated parameters which include Bio-growth, Bio-mass production and feed conversion during the culture of *P. hypophthalmus* under different stocking densities are presented in Table 4.3 and 4.4.

#### 4.1.1 Average Body Weight (g)

Average Body Weight (ABW) of *P. hypophthalmus* determined at different intervals during the experiment are presented in Table 4.1 and the growth curve was depicted in Fig. 4.1. The highest ABW ( $110.03 \pm 0.11$  g) was found to be with fishes of T<sub>1</sub> cage. The lowest ABW ( $95.01 \pm 0.23$  g) was observed in the highest stocking density T<sub>3</sub>. There were significant differences ( $P < 0.05$ ) among all the treatments.

#### 4.1.2 Mean Body Weight Gain (g)

The highest Mean Body Weight Gain ( $107.19 \pm 0.54$  g) was recorded in the lowest stocking density group T<sub>1</sub> followed by T<sub>2</sub> ( $97.56 \pm 0.01$  g) and the lowest mean body weight gain ( $92.39 \pm 0.23$  g) was recorded in the highest stocking density group T<sub>3</sub>. There were no significant differences ( $P > 0.05$ ) between T<sub>1</sub> and T<sub>2</sub> treatments, whereas both these treatments were significantly different ( $p < 0.05$ ) from T<sub>3</sub> group.

#### 4.1.3 Percentage Weight Gain (PWG)

The Weight Gain Percentage was maximum ( $3821.13 \pm 609.03$ ) for fishes in T<sub>1</sub> group where the stocking density was the least which was followed by T<sub>2</sub> group ( $3672.00 \pm 531.35$ ). The T<sub>3</sub> group registered the Lowest Weight Gain

Percentage ( $3519.45 \pm 18.37$ ). There were no significant differences ( $P > 0.05$ ) among the treatments.

#### **4.1.4 Average Daily Weight Gain (DWG)**

Average Daily Weight Gain (DWG) among three stocking densities was observed to be from  $1.00 \pm 0.01$  to  $1.08 \pm 0.00$  g. Highest daily weight gain ( $1.08 \pm 0.00$  g) was recorded at the lowest stocking density  $T_1$  and the lowest ( $1.00 \pm 0.01$  g) was recorded with  $T_3$  group where the stocking density was the highest. There were no significant differences ( $P > 0.05$ ) in the DWG between  $T_1$  and  $T_2$ , whereas the  $T_3$  was significantly different ( $P < 0.05$ ) from  $T_1$  and  $T_2$  (Fig. 4.2).

#### **4.1.5 Specific Growth Rate (SGR)**

Specific Growth Rate (SGR) of *P. hypophthalmus* was estimated at the end of experiment based on the collected weight data. The highest SGR ( $4.07 \pm 0.17$ ) was observed with the lowest stocking density group ( $T_1$ ) and the lowest SGR ( $3.98 \pm 0.01$ ) was observed with the highest stocking density group ( $T_3$ ). There were no significant differences ( $P > 0.05$ ) among the treatments.

#### **4.1.6 Biomass production (kg)**

Final biomass increased significantly as stocking density increased. Which are directly proportional to the biomass productions (kg) at different intervals are depicted in Fig. 4.4. There was a steady trend in the biomass increase as evidenced from the slope value ( $R^2$  value) which ranged from 0.9909 to 0.9953. Biomass production (kg) was higher ( $21.42 \pm 0.02$  kg) in the treatment with the highest density ( $T_3$ ) than that of  $T_2$  and  $T_1$  ( $15.34 \pm 0.06$  and  $8.58 \pm 0.01$  kg) respectively. There were significant differences ( $P < 0.05$ ) among all the treatments.

#### **4.1.7 Net biomass production (kg)**

The net biomass production also exhibited similar trends as that of total biomass production. The drastic changes are due to the differences in the initial biomass stocked. The final biomass harvested at the end of the experiment was the highest ( $21.42 \pm 0.02$  kg) in  $T_3$  group and the lowest ( $8.35 \pm 0.04$  kg) was with  $T_1$  group. The values were significantly different ( $P < 0.05$ ) between each other.

#### **4.1.8 Biomass production per unit area**

It can be seen in Table 4.4, that the biomass production per unit area at the end of experiment was the highest ( $5.36 \pm 0.00$  kg) for  $T_3$  group and the lowest ( $2.15 \pm 0.00$  kg) for  $T_1$  group. The values were significantly different ( $P < 0.05$ ) between each other. However, the mean body weight of the fishes showed negative trend with regard to stocking density (Table 4.1).

#### **4.1.9 Food Conversion Ratio (FCR)**

The mean values of Food Conversion Ratio observed were  $2.15 \pm 0.02$ ,  $2.25 \pm 0.00$  and  $2.24 \pm 0.04$  for the fishes in  $T_1$ ,  $T_2$  and  $T_3$ , respectively. The variation of FCR between the treatments was presented in Fig. 4.3. As there was higher biomass, the feed consumption was also increased (Table 4.4). However, the FCR did not show any marked difference.

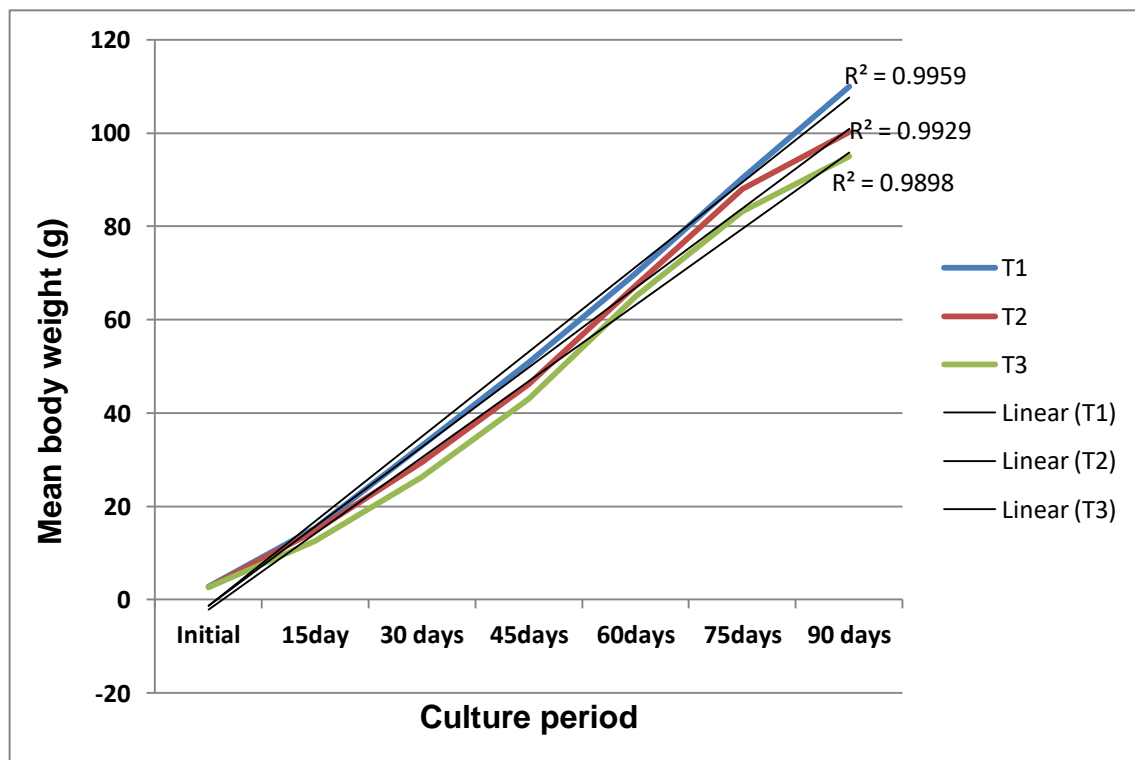
#### **4.1.10 Food Conversion Efficiency (FCE)**

Food Conversion Efficiency of *P. hypophthalmus* was calculated at the end of experiment and the highest ( $45.10 \pm 0.03$ ) was in the lowest stocking density ( $T_1$ ) group followed by  $T_2$  group ( $43.24 \pm 0.09$ ). The highest stocking density ( $T_3$ ) group had shown it as  $43.32 \pm 0.62$ . There were no significant difference ( $p > 0.05$ ) among the treatments.

#### 4.1.11 Survival

Observation on survival (%) at different intervals during the study period was presented in Table 4.2 and Fig. 4.5. At the end of experiment, the highest survival ( $97.5 \pm 0.00$  %) was recorded in the lowest stocking density group  $T_1$  followed by  $T_2$  group ( $95.6 \pm 0.00$  %) and the lowest ( $93.9 \pm 0.30$  %) was recorded in the highest stocking density group  $T_3$ . There were significant differences ( $P < 0.05$ ) in survival (%) between all the treatments.

**Fig 4.1. Growth pattern of *P. hypophthalmus* cultured under different stocking densities in cages**



**Table 4.1. Average Body Weight (g) (ABW) of *P. hypophthalmus* during the rearing in cages under different stocking densities**

Treatment	Average Body Weight (Mean ± SD) observed during the culture						
	Initial	15 <sup>th</sup> day	30 <sup>th</sup> day	45 <sup>th</sup> day	60 <sup>th</sup> day	75 <sup>th</sup> day	Final
<b>T1</b>	2.84±0.44 <sup>a</sup>	15.35±0.28 <sup>b</sup>	32.98±0.47 <sup>c</sup>	50.79±1.63 <sup>b</sup>	69.87±0.37 <sup>c</sup>	90.29±0.08 <sup>c</sup>	110±0.11 <sup>c</sup>
<b>T2</b>	2.69±0.39 <sup>a</sup>	14.71±0.10 <sup>ab</sup>	29.47±0.47 <sup>b</sup>	46.23±0.52 <sup>a</sup>	67.32±0.28 <sup>b</sup>	87.95±0.42 <sup>b</sup>	100.25±0.40 <sup>b</sup>
<b>T3</b>	2.63±0.01 <sup>a</sup>	12.59±0.95 <sup>b</sup>	26.24±0.78 <sup>a</sup>	42.95±0.42 <sup>a</sup>	64.94±0.65 <sup>a</sup>	83.26±0.56 <sup>a</sup>	95.01±0.23 <sup>a</sup>

Values with different superscripts within column differ significantly (P<0.05)

**Table 4.2. Survival of *P. hypophthalmus* during the rearing in cages under different stocking densities**

Treatment	Periodical observation of percentage of survival (Mean ± SD) during the culture						
	Initial	15 <sup>th</sup> day	30 <sup>th</sup> day	45 <sup>th</sup> day	60 <sup>th</sup> day	75 <sup>th</sup> day	Final
<b>T1</b>	100	98.75±0.00 <sup>a</sup>	97.50±0.00 <sup>a</sup>	97.50±0.00 <sup>b</sup>	97.50±0.00 <sup>c</sup>	97.50±0.00 <sup>c</sup>	97.50±0.00 <sup>c</sup>
<b>T2</b>	100	98.75±0.00 <sup>a</sup>	97.50±0.00 <sup>a</sup>	96.88±0.00 <sup>b</sup>	96.25±0.00 <sup>b</sup>	95.63±0.00 <sup>b</sup>	95.63±0.00 <sup>b</sup>
<b>T3</b>	100	98.54±0.30 <sup>a</sup>	97.29±0.30 <sup>a</sup>	96.04±0.30 <sup>a</sup>	95.21±0.30 <sup>a</sup>	94.38±0.29 <sup>a</sup>	93.96±0.30 <sup>a</sup>

Values with different superscripts within column differ significantly (P<0.05)

**Table 4.3. Estimated bio-growth parameters of *P. hypophthalmus* cultured in cages under different stocking densities**

Treatment	Parameters (Mean ± SD)							
	Stocking density (no/m <sup>3</sup> )	Initial BW (g)	Final BW (g)	Weight Gain (g)	Weight Gain (%)	DWG (g)	SGR	Survival (%)
T <sub>1</sub>	20	2.84±0.45 <sup>a</sup>	110.03±0.11 <sup>c</sup>	107.19±0.54 <sup>c</sup>	3821.13±609.03 <sup>a</sup>	1.08±0.00 <sup>b</sup>	4.07±0.17 <sup>a</sup>	97.50±0.00 <sup>c</sup>
T <sub>2</sub>	40	2.69±0.39 <sup>a</sup>	100.25±0.40 <sup>b</sup>	97.56±0.01 <sup>b</sup>	3672.00±531.35 <sup>a</sup>	1.05±0.01 <sup>b</sup>	4.03±0.16 <sup>a</sup>	95.63±0.00 <sup>b</sup>
T <sub>3</sub>	60	2.63±0.01 <sup>a</sup>	95.01±0.23 <sup>a</sup>	92.39±0.23 <sup>a</sup>	3519.45±18.37 <sup>a</sup>	1.00±0.01 <sup>a</sup>	3.98±0.01 <sup>a</sup>	93.96±0.30 <sup>a</sup>

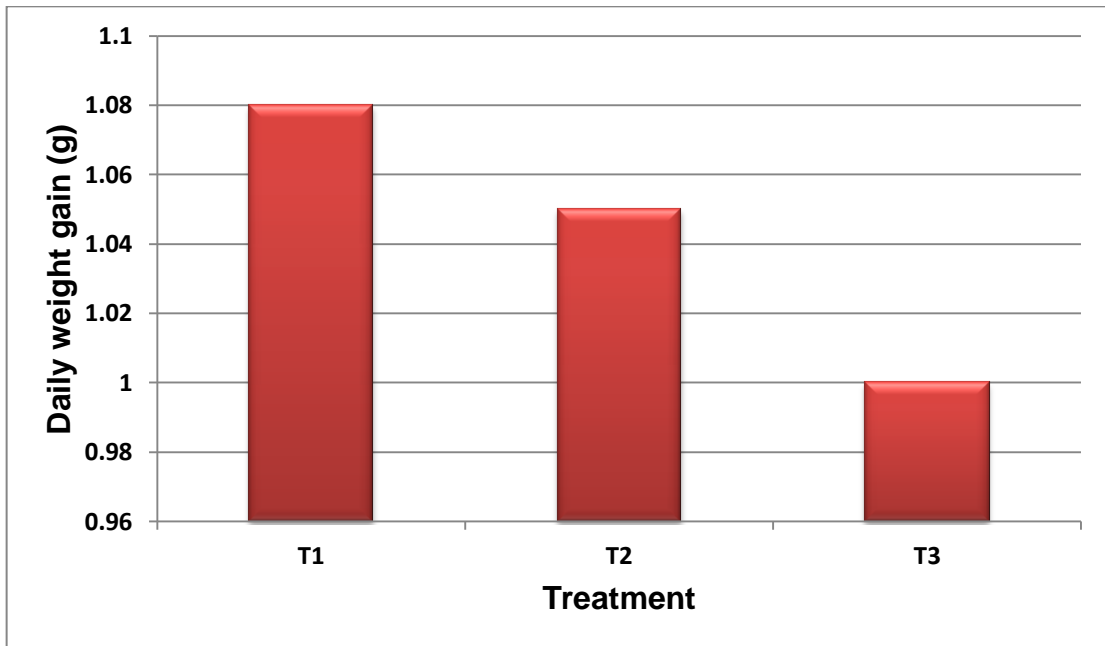
Values with different superscripts within column differ significantly (P<0.05)

**Table 4.4. Estimated biomass production parameters of *P. hypophthalmus* cultured in cages under different stocking densities**

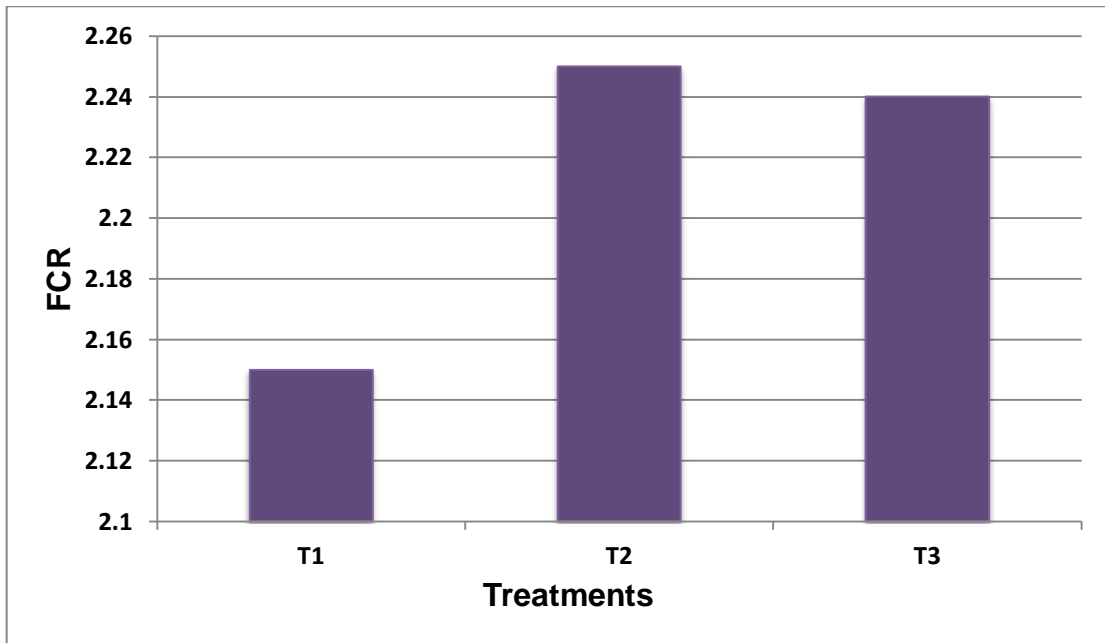
Treatment	Parameters (Mean ± SD)							
	Initial mean Biomass (kg)	Final Mean Biomass (kg)	Net Biomass Produced (kg)	Biomass production/m <sup>3</sup>	Total Feed Given (kg)	FCR	FCE	Survival (%)
T <sub>1</sub>	0.23±0.04 <sup>a</sup>	8.58±0.01 <sup>a</sup>	8.35±0.04 <sup>a</sup>	2.15±0.00 <sup>a</sup>	15.90	2.15±0.02 <sup>a</sup>	45.10±0.03 <sup>a</sup>	97.50±0.00 <sup>c</sup>
T <sub>2</sub>	0.43±0.06 <sup>b</sup>	15.34±0.06 <sup>b</sup>	14.91±0.00 <sup>b</sup>	3.83±0.02 <sup>b</sup>	34.50	2.25±0.00 <sup>a</sup>	43.24±0.09 <sup>a</sup>	95.63±0.00 <sup>b</sup>
T <sub>3</sub>	0.63±0.00 <sup>c</sup>	21.42±0.02 <sup>c</sup>	21.42±0.02 <sup>c</sup>	5.36±0.00 <sup>c</sup>	48.00	2.24±0.04 <sup>a</sup>	43.32±0.62 <sup>a</sup>	93.96±0.30 <sup>a</sup>

Values with different superscripts within column differ significantly (P<0.05)

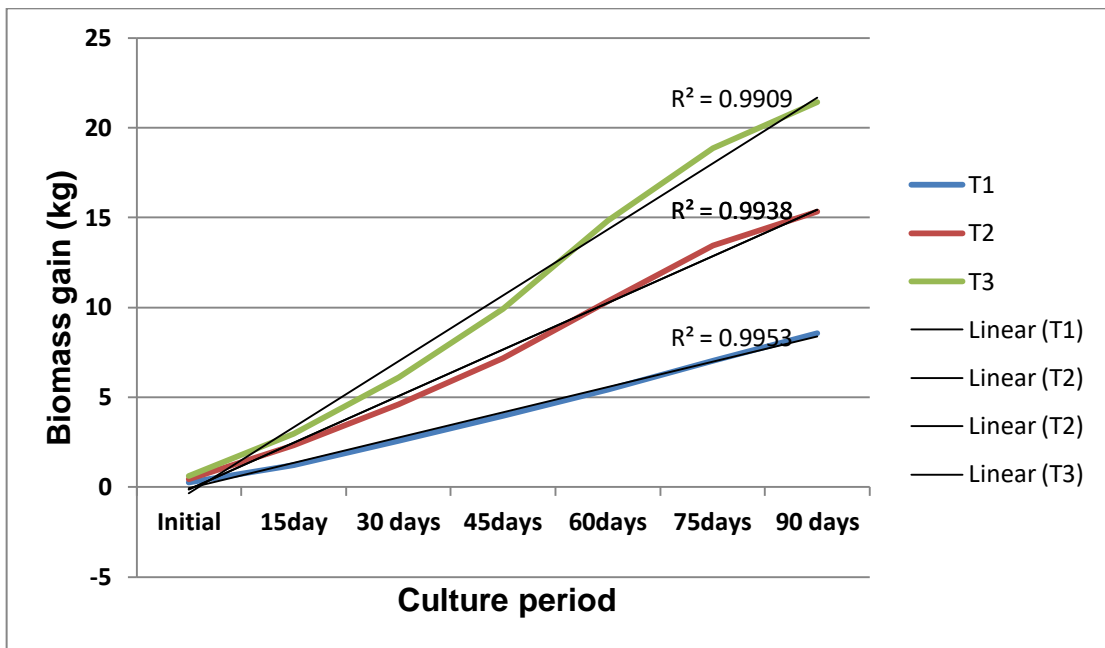
**Fig 4.2. Daily Weight Gain (g) of *P. hypophthalmus* cultured in cages at different stocking densities**



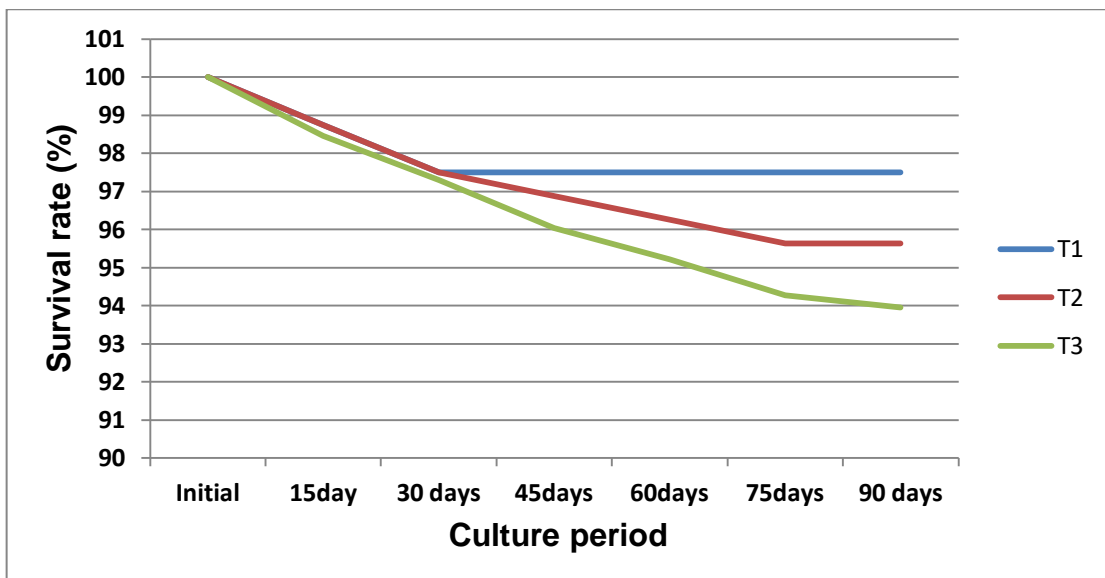
**Fig 4.3. Food Conversion Ratio of *P. hypophthalmus* cultured in cages at different stocking densities**



**Fig 4.4. Biomass production (kg) pattern of *P. hypophthalmus* cultured in cages at different stocking densities**



**Fig 4.5. Survival of *P. hypophthalmus* during the culture period in cages at different stocking densities**



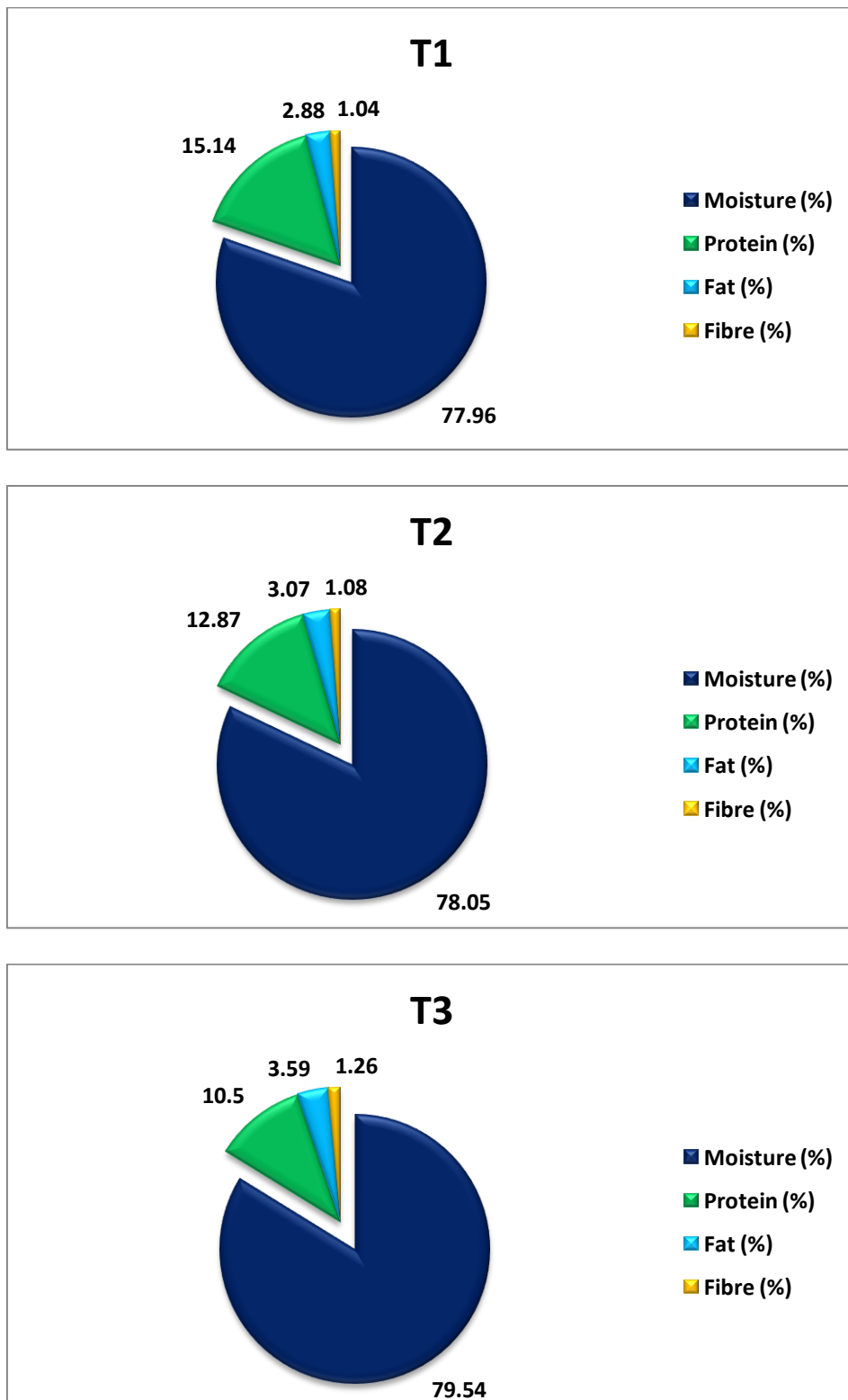
#### **4.2 Proximate composition of *P. hypophthalmus* carcass reared in cages at different stocking densities**

The results of proximate composition of *P.hypophthalmus* flesh at the end of experiment are depicted in Fig 4.6.

There is huge variation observed in the protein content of the fishes cultured at different stocking densities. Higher protein percentage (15.14%) was recorded in the lowest stocking density group T<sub>1</sub> followed by T<sub>2</sub> group (12.87%) and the least of all (10.5%) was noted in the lowest T<sub>3</sub> group.

The crude fat values of fish muscles were 3.59% in T<sub>3</sub> followed by 3.07% and 2.88% in T<sub>2</sub> and T<sub>1</sub>, respectively. Similarly there was huge variation in moisture percentage, which was 77.96%, 78.05% and 79.54% in T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub>, respectively which followed the order of stocking densities. The crude fibre content was maximum (1.26%) in T<sub>3</sub> group followed by T<sub>2</sub> (1.08%) and 1.04% in T<sub>1</sub> group of fishes. However, significant difference could be noticed between treatments only for crude protein and fat between T<sub>3</sub> and T<sub>1</sub>.

Fig 4.6. Proximate composition of *P. hypophthalmus* muscle reared in cages at different stocking densities



### **4.3 Growth parameters of *P. hypophthalmus* in cages at different stocking sizes**

Bio-growth parameters, Bio-mass production and feed conversion parameters were estimated for the culture of *P. hypophthalmus* under different stocking sizes and are presented in Table 4.8 and 4.9.

#### **4.3.1 Average Body Weight (g)**

Average Body Weight (ABW) of *P. hypophthalmus* recorded at during the experiment are presented in Table 4.6 and the growth curve was depicted in Fig. 4.7. The highest ABW ( $61.23 \pm 0.40$  g) was with fishes of T<sub>6</sub> cage. The lowest ABW ( $58.67 \pm 0.53$  g) was found in the medium stocking size group (T<sub>5</sub>). T<sub>4</sub> significantly different ( $P < 0.05$ ) from T<sub>5</sub> and T<sub>6</sub> whereas, these two treatments do not significantly different ( $P > 0.05$ ) with each other.

#### **4.3.2 Mean Body Weight Gain (g)**

The highest Mean Body Weight Gain ( $58.19 \pm 0.18$  g) was recorded in the smaller stocking size group T<sub>4</sub> followed by T<sub>5</sub> ( $51.08 \pm 0.48$  g) and the lowest Mean Body Weight Gain ( $41.64 \pm 0.30$  g) was recorded in the larger stocking size group T<sub>6</sub>. There were significant differences ( $P < 0.05$ ) among all the treatments.

#### **4.3.3 Percentage Weight Gain (PWG)**

The weight gain percentage was maximum ( $2482.09 \pm 60.23$ ) in T<sub>4</sub> group where the stocking size was the least. The T<sub>6</sub> group registered the lowest weight gain percentage ( $212.56 \pm 0.44$ ). There were significant differences ( $P < 0.05$ ) among the treatments.

#### **4.3.4 Average Daily Weight Gain (DWG)**

Average Daily Weight Gain (DWG) among three stocking sizes was observed to be from  $0.70\pm 0.01$  g to  $0.97\pm 0.00$ g. Highest DWG ( $0.97\pm 0.00$  g) was recorded at smaller stocking size group ( $T_4$ ) and the lowest ( $0.70\pm 0.01$  g) was recorded with  $T_6$  group where the stocking size was the largest. There were significant differences ( $P<0.05$ ) among all the treatments (Fig. 4.8).

#### **4.3.5 Specific Growth Rate (SGR)**

The highest SGR ( $5.42\pm 0.04$ ) was observed with the smallest stocking size group ( $T_4$ ) and the lowest SGR ( $1.90\pm 0.00$ ) was observed with the biggest stocking size group ( $T_6$ ). There were significant differences ( $P<0.05$ ) among all the treatments.

#### **4.3.6 Biomass production (kg)**

The biomass production (kg) at different intervals is depicted in Fig. 4.10. The mean biomass production (kg) was higher ( $4.7\pm 10.61$  kg) in the treatment with the smaller stocking size ( $T_4$ ) than that of  $T_5$  and  $T_6$  ( $4.6\pm 83.11$  and  $4.7\pm 30.89$  kg), respectively. There were no significant differences ( $P>0.05$ ) among all the treatments.

#### **4.3.7 Net biomass production (kg)**

The final net biomass harvested at the end of the experiment was maximum ( $4.59\pm 0.011$  kg) in smaller stocking size group ( $T_4$ ) and it was minimum ( $3.21\pm 0.031$  kg) in larger stocking size group ( $T_6$ ). The values were significantly different ( $P<0.05$ ) between each other.

#### **4.3.8 Biomass production per unit area**

Table 4.9, gives the details of biomass production per unit area, which was highest ( $1.20 \pm 0.003$  kg) at the end of experiment for the lowest stocking size ( $T_4$ ) and lowest ( $1.15 \pm 0.021$  kg) for the medium stocking size ( $T_5$ ). The values were not significantly different ( $P > 0.05$ ) with each other.

#### **4.3.9 Food Conversion Ratio (FCR)**

The mean values of Food Conversion Ratio observed were  $1.14 \pm 0.0085$ ,  $1.37 \pm 0.0106$  and  $1.74 \pm 0.0007$  in  $T_4$ ,  $T_5$  and  $T_6$  respectively. Which showed a steady increase as the stocking sizes increased. The variation of FCR between the treatments are presented in Fig. 4.9. There were significantly different ( $P < 0.05$ ) among all the treatments.

#### **4.3.10 Food Conversion Efficiency (FCE)**

Food Conversion Efficiency of *P. hypophthalmus* was the highest ( $84.64 \pm 0.57$  %) in smaller stocking size ( $T_4$ ) group followed by ( $63.55 \pm 0.62$  %) in  $T_5$  group. The highest stocking size ( $T_6$ ) group had shown it as  $38.55 \pm 0.02$  %. All the treatments were significantly different ( $P < 0.05$ ) with each other.

#### **4.3.11 Survival**

Observation on survival (%) at different intervals during the study period was presented in Table 4.7 and Fig. 4.11. Highest survival (%) was recorded in the  $T_4$  ( $98.75 \pm 0.00$  %) followed by  $T_5$  group ( $98.13 \pm 0.88$  %) and the lowest was recorded in the  $T_6$  ( $97.50 \pm 0.00$  %). However, there were no significant difference ( $P > 0.05$ ) of survival (%) among all the treatments.

**Table 4.6. Average Body Weight (g) of *P. hypophthalmus* during the rearing in cages under different stocking sizes**

Treatment	Average body weight (Mean $\pm$ SD) observed during the culture				
	Initial	15 <sup>th</sup> day	30 <sup>th</sup> day	45 <sup>th</sup> day	60 <sup>th</sup> day
<b>T4</b>	2.35 $\pm$ 0.05 <sup>a</sup>	14.85 $\pm$ 0.35 <sup>a</sup>	29.20 $\pm$ 0.21 <sup>a</sup>	45.20 $\pm$ 0.40 <sup>a</sup>	60.54 $\pm$ 0.13 <sup>a</sup>
<b>T5</b>	7.59 $\pm$ 0.05 <sup>b</sup>	18.53 $\pm$ 0.11 <sup>b</sup>	33.40 $\pm$ 0.12 <sup>b</sup>	47.22 $\pm$ 0.45 <sup>b</sup>	58.67 $\pm$ 0.53 <sup>b</sup>
<b>T6</b>	19.59 $\pm$ 0.10 <sup>c</sup>	29.21 $\pm$ 0.11 <sup>c</sup>	41.20 $\pm$ 0.49 <sup>c</sup>	51.78 $\pm$ 0.25 <sup>c</sup>	61.23 $\pm$ 0.40 <sup>b</sup>

Values with different superscripts within column differ significantly (p<0.05)

**Table 4.7. Survival of *P. hypophthalmus* during the rearing in cages under different stocking sizes**

Treatment	Periodical observation of percentage of survival (Mean $\pm$ SD) during the culture				
	Initial	15 <sup>th</sup> day	30 <sup>th</sup> day	45 <sup>th</sup> day	60 <sup>th</sup> day
<b>T4</b>	80	98.75 $\pm$ 0.00 <sup>a</sup>	98.75 $\pm$ 0.00 <sup>a</sup>	98.75 $\pm$ 0.00 <sup>a</sup>	98.75 $\pm$ 0.00 <sup>a</sup>
<b>T5</b>	80	98.13 $\pm$ 0.88 <sup>a</sup>	98.13 $\pm$ 0.88 <sup>a</sup>	98.13 $\pm$ 0.88 <sup>a</sup>	98.13 $\pm$ 0.88 <sup>a</sup>
<b>T6</b>	80	97.50 $\pm$ 0.00 <sup>a</sup>	97.50 $\pm$ 0.00 <sup>a</sup>	97.50 $\pm$ 0.00 <sup>a</sup>	97.50 $\pm$ 0.00 <sup>a</sup>

**Table 4.8. Estimated bio-growth parameters of *P. hypophthalmus* cultured in cages under different stocking sizes**

Treatment	Parameters (Mean ± SD)							
	Stocking density (no/m <sup>3</sup> )	Initial BW (g)	Final BW (g)	Weight Gain (g)	Weight Gain (%)	DWG (g)	SGR	Survival (%)
<b>T4</b>	80	2.35±0.05 <sup>a</sup>	60.54±0.13 <sup>a</sup>	58.19±0.18 <sup>c</sup>	2482.09±60.23 <sup>c</sup>	0.97±0.00 <sup>c</sup>	5.42±0.04 <sup>c</sup>	98.75±0.00 <sup>a</sup>
<b>T5</b>	80	7.59±0.05 <sup>b</sup>	58.67±0.53 <sup>b</sup>	51.08±0.48 <sup>b</sup>	673.43±1.94 <sup>b</sup>	0.86±0.01 <sup>b</sup>	3.41±0.00 <sup>b</sup>	98.13±0.88 <sup>a</sup>
<b>T6</b>	80	19.59±0.10 <sup>c</sup>	61.23±0.40 <sup>b</sup>	41.64±0.30 <sup>a</sup>	212.56±0.44 <sup>a</sup>	0.70±0.01 <sup>a</sup>	1.90±0.00 <sup>a</sup>	97.50±0.00 <sup>a</sup>

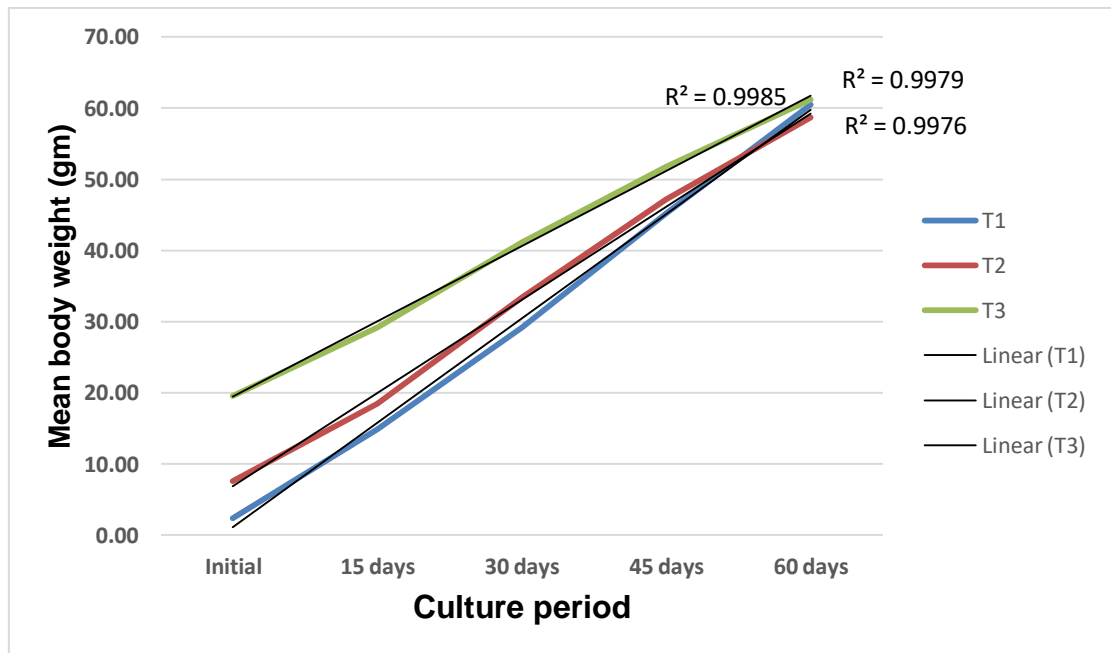
**Values with different superscripts within column differ significantly (p<0.05)**

**Table 4.9. Estimated biomass production parameters of *P. hypophthalmus* cultured in cages at different stocking sizes**

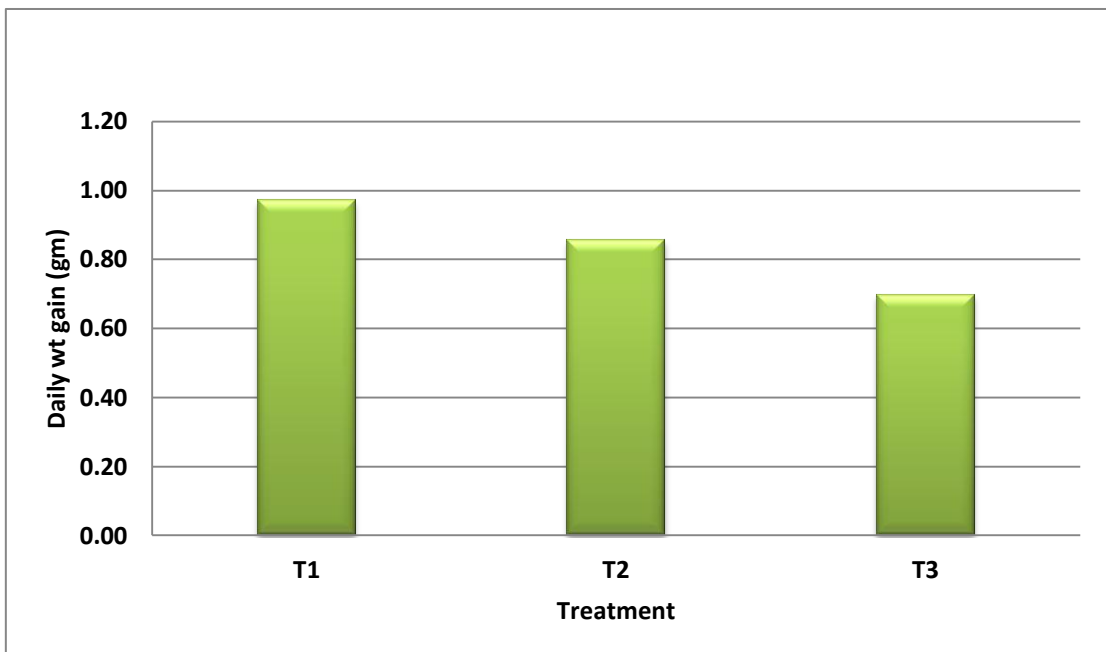
Treatment	Parameters (Mean ± SD)							
	Initial mean Biomass (kg)	Final Mean Biomass (kg)	Net Biomass Produced (kg)	Biomass production/m <sup>3</sup>	Total Feed Given (kg)	FCR	FCE (%)	Survival (%)
<b>T4</b>	0.19±0.004 <sup>a</sup>	4.782±10.61 <sup>a</sup>	4.59±0.011 <sup>c</sup>	1.20±0.003 <sup>a</sup>	5.43±0.054 <sup>a</sup>	1.14±0.0085 <sup>a</sup>	84.64±0.57 <sup>c</sup>	98.75±0.00 <sup>a</sup>
<b>T5</b>	0.61±0.004 <sup>b</sup>	4.605±83.11 <sup>a</sup>	4.00±0.083 <sup>b</sup>	1.15±0.021 <sup>a</sup>	6.29±0.063 <sup>b</sup>	1.37±0.0106 <sup>b</sup>	63.55±0.62 <sup>b</sup>	98.13±0.88 <sup>a</sup>
<b>T6</b>	1.57±0.008 <sup>c</sup>	4.776±30.89 <sup>a</sup>	3.21±0.031 <sup>a</sup>	1.19±0.008 <sup>a</sup>	8.32±0.056 <sup>c</sup>	1.74±0.0007 <sup>c</sup>	38.55±0.02 <sup>a</sup>	97.50±0.00 <sup>a</sup>

Values with different superscripts within column differ significantly (p<0.05)

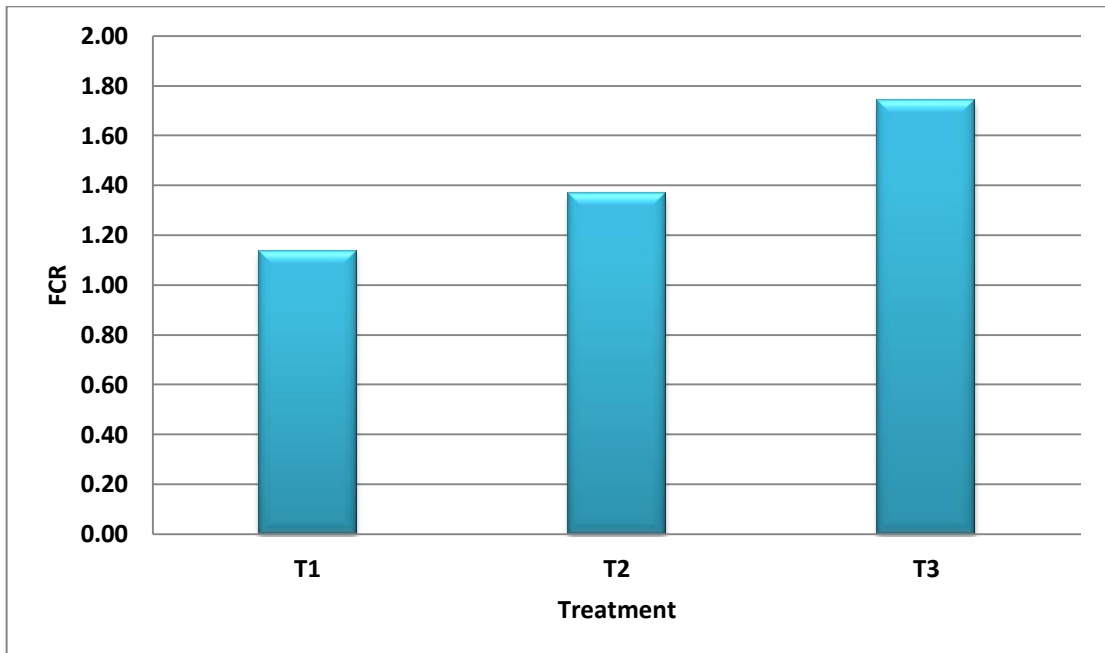
**Fig 4.7. Growth pattern of *P. hypophthalmus* cultured under different stocking sizes in cages**



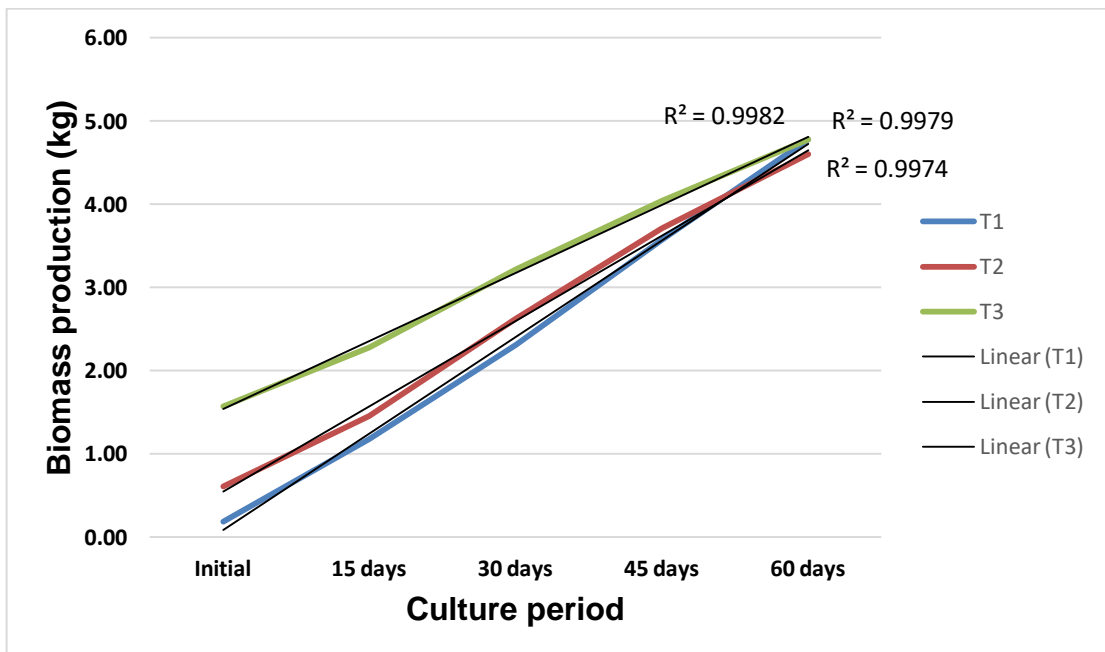
**Fig 4.8. Daily Weight Gain (g) of *P. hypophthalmus* cultured in cages at different stocking sizes**



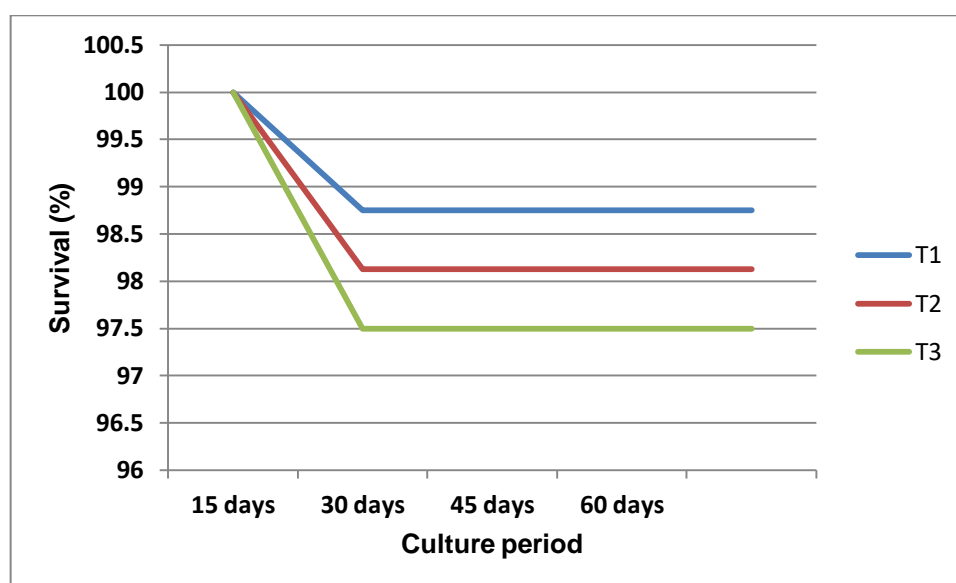
**Fig 4.9. Food Conversion Ratio of *P. hypophthalmus* cultured in cages at different stocking sizes**



**Fig 4.10. Periodical biomass production (kg) of *P. hypophthalmus* cultured in cages at different stocking sizes**



**Fig 4.11. Percentage of survival of *P. hypophthalmus* during the culture period in cages at different stocking sizes**



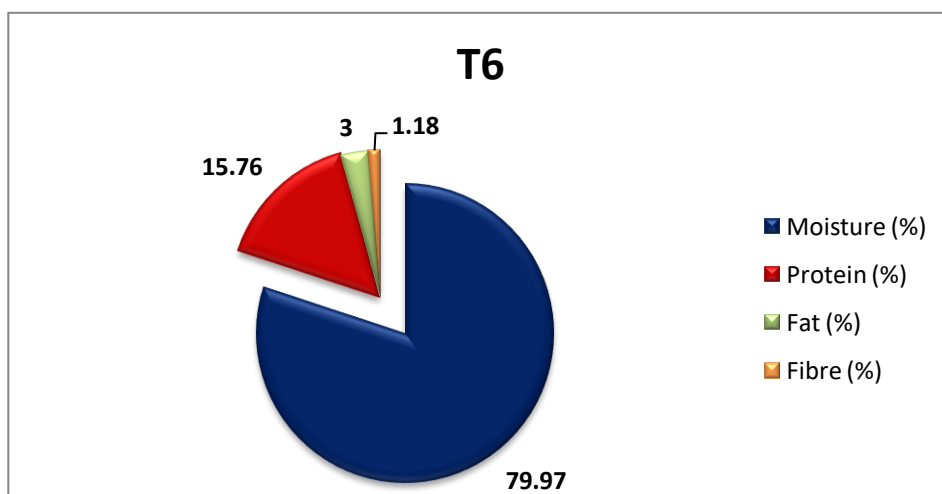
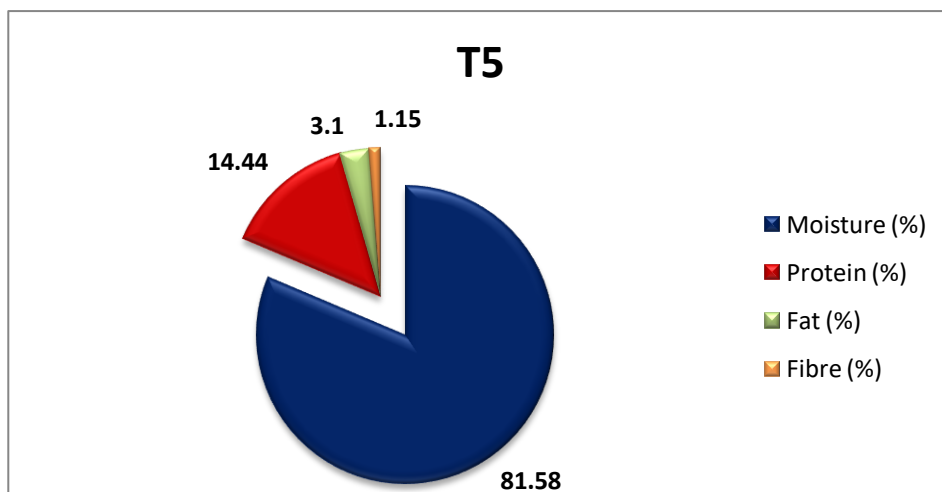
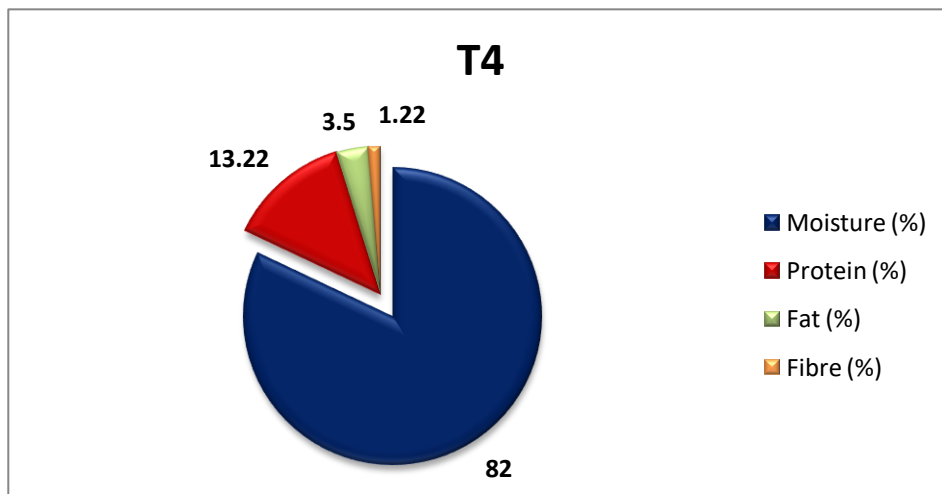
#### **4.4. Proximate composition of *P. hypophthalmus* carcass reared in cages at different stocking sizes**

The proximate composition of *P. hypophthalmus* flesh were analysed and depicted in Fig 4.12.

Highest protein content (15.76%) was estimated in a larger size group (T<sub>6</sub>) followed by (14.14 %) in T<sub>5</sub> and the lowest (13.22%) was estimated in T<sub>4</sub> group. The moisture content in flesh was recorded to be from 82.00 to 79.97%. Highest percentage of moisture content (82.00%) was recorded at T<sub>4</sub> group and the least (79.97%) was recorded at T<sub>6</sub> group.

The maximum crude fat content (3.5%) in fish flesh was observed in T<sub>4</sub> followed by (3.1%) in T<sub>5</sub> and the minimum (3.0%) was observed in T<sub>6</sub>. There was no huge difference of fibre content in fish flesh and estimated in the range of 1.22 to 1.18%.

**Fig 4.12. Proximate composition of *P. hypophthalmus* muscle reared in cages at different stocking sizes**



#### **4.5 Physico-chemical parameters of water during the rearing of *P. hypophthalmus* in cages**

The range values of physico-chemical parameters such as temperature (°C), dissolved oxygen (mg/l), pH, total hardness (mg/l), total alkalinity (mg/l), ammonia nitrogen (mg/l), nitrite nitrogen (mg/l), chemical oxygen demand (mg/l), electrical conductivity ( $\mu$ Siemens/cm) and total dissolved solids (ppm) are given in Table 4.10 and final Mean $\pm$ SD presented in Table 4.11. The water temperature of the different treatments ranged between 25 to 31 °C throughout the experimental period which is the normal temperature range in the tropical place. The dissolved oxygen (DO) level of all the experimental cages was recorded in the range of 4.4 to 7.0 mg/l. The pH values of all the cages was recorded in the range from 7.5 to 8.5. The average value of CO<sub>2</sub> was found to be in the range of 1.83 to 3.31 mg/l.

The value of total alkalinity in experimental cages ranged from 84 to 136 mg/l. Similarly, the total hardness was found in the range of 148 to 192 mg/l in all the cages. The chemical oxygen demand (COD) was ranged from 12.8 to 35.2 mg/l. Ammonia-N was recorded within the range values of 0.022 to 0.055 mg/l in cage site. Nitrite-N values varied from 0.009 to 0.036 mg/l among all the treatments. The value of EC was ranged from 420 to 693  $\mu$ Siemens/cm. Total Dissolve Solids was found to be in the range of 258 to 398 ppm.

**Table 4.10. Range values of water quality parameters in cages during the rearing of *P. hypophthalmus***

<b>Week</b>	<b>pH</b>	<b>Temp (°C)</b>	<b>DO mg/l</b>	<b>Alkalinity (mg/l)</b>	<b>Hardness (mg/l)</b>	<b>COD (mg/l)</b>	<b>Ammonia (mg/l)</b>	<b>Nitrite (mg/l)</b>	<b>Conductivity (µSiemens/c m)</b>	<b>TDS (ppm)</b>
<b>1<sup>st</sup> week</b>	8.0 - 8.1	27.2 – 27.9	4.8 - 6.0	80 - 96	156 - 176	16 - 28.8	0.022 - 0.033	0.01 - 0.017	440 - 586	268 - 286
<b>2<sup>nd</sup> week</b>	7.9 - 8.3	28.2 - 28.7	4.4 - 6.0	80 - 92	184 - 192	16 - 25.6	0.027 - 0.035	0.012 - 0.013	562 - 639	315 - 380
<b>3<sup>rd</sup> week</b>	8.1 - 8.5	28.0 – 28.9	4.4 - 5.6	84 - 100	180 - 192	19.2 – 25.6	0.027 - 0.035	0.012 - 0.020	673 - 681	325 - 340
<b>4<sup>th</sup> week</b>	7.5 - 8.2	28.6 - 29.0	4.4 - 6.0	84 - 100	172 - 192	19.2 - 28.8	0.031 - 0.045	0.014 - 0.045	542 - 581	340 - 370
<b>5<sup>th</sup> week</b>	7.8 - 8.2	28.9 - 29.6	4.8 - 6.4	88 - 96	172 - 192	19.2 - 28.8	0.036 - 0.046	0.017 - 0.045	689 - 699	349 - 355
<b>6<sup>th</sup> week</b>	7.6 - 8.0	29.3 – 29.9	4.8 - 6.4	84 - 96	160 - 176	19.2 – 25.6	0.039 - 0.046	0.017 - 0.027	633 - 652	275 - 332
<b>7<sup>th</sup> week</b>	7.8 - 8.5	29.7 - 30.2	4.8 - 7.6	80 - 88	176 - 192	19.2 – 35.2	0.039 - 0.052	0.019 - 0.029	549 - 582	320 - 337
<b>8<sup>th</sup> week</b>	7.8 - 8.5	29.9 - 30.6	4.8 - 7.6	84 - 96	160 - 188	28.8 - 38.4	0.041 - 0.052	0.02 - 0.029	644 - 675	303 - 338
<b>9<sup>th</sup> week</b>	7.8 - 8.2	30.3 - 30.6	4.4 - 6.4	84 - 96	148 - 160	19.2 – 35.2	0.045 - 0.055	0.022 - 0.033	665 - 671	319 - 328
<b>10<sup>th</sup> week</b>	8.1 - 8.4	30.5 – 30.9	4.4 - 6.4	84 - 96	148 - 168	22.4 - 38.4	0.048 - 0.058	0.022 - 0.036	655 - 686	395 - 398
<b>11<sup>th</sup> week</b>	7.9 - 8.2	26.5 – 27.5	4.6 - 5.6	116 - 130	148 - 160	12.8 – 22.4	0.025 - 0.032	0.009 - 0.015	539 - 651	350 - 397
<b>12<sup>th</sup> week</b>	8.1 - 8.5	26.0 – 26.5	5.4 - 6.4	104 - 112	154 - 164	16.0 – 28.8	0.028 - 0.030	0.01 - 0.015	530 - 555	339 - 361

<b>13<sup>th</sup> week</b>	7.5 - 8.1	25.0 – 26.0	6.2 - 7.0	114 - 120	150 - 160	12.8 - 22.4	0.029 - 0.039	0.018 - 0.02	392 - 428	247 - 297
<b>14<sup>th</sup> week</b>	7.8 - 8.1	25.0 – 25.5	6.0 - 6.8	104 - 112	146 - 178	16.0 – 25.6	0.039 - 0.045	0.013 - 0.018	438 - 445	278 - 297
<b>15<sup>th</sup> week</b>	7.5 - 8.4	25.0 – 25.5	5.2 - 6.4	120 - 130	152 - 164	19.2 - 28.8	0.035 - 0.042	0.015 - 0.019	467 - 469	258 - 283
<b>16<sup>th</sup> week</b>	7.9 - 8.2	25.5 – 26.0	5.2 - 6.4	108 - 118	148 - 160	12.8 – 25.6	0.039 - 0.045	0.019 - 0.025	445 - 455	268 - 273
<b>17<sup>th</sup> week</b>	8.1 - 8.4	26.0 – 26.5	5.2 - 6.4	104 - 112	164 - 174	16.0 – 25.6	0.041 - 0.045	0.019 - 0.024	464 - 469	258 - 272
<b>18<sup>th</sup> week</b>	7.9- 8.4	26.5 – 27.0	5.2 - 6.8	100 - 110	180 - 192	12.8 - 22.4	0.042 - 0.047	0.022 - 0.025	487 - 493	275 - 279
<b>19<sup>th</sup> week</b>	7.6 - 7.9	27.0 – 27.5	6.0 - 6.6	112 - 126	146 - 178	16.0 – 25.6	0.041 - 0.045	0.022 - 0.035	481 - 487	293 - 297
<b>20<sup>th</sup> week</b>	7.9 - 8.0	27.0 – 27.5	5.6 - 6.2	106 - 116	152 - 168	19.2 – 28.8	0.042 - 0.048	0.023 - 0.027	475 - 478	272 - 278

**Table 4.11. Mean±SD values of water quality parameters in cages during the rearing of *P. hypophthalmus***

<b>Parameters</b>	<b>Mean±SD</b>
Temperature (°C)	27.90±1.67
pH	8.04±0.08
Dissolved Oxygen (mg/l)	5.7±0.36
Carbon Dioxide (mg/l)	2.3±0.45
Total Alkalinity (mg/l)	101.6± 13.75
Total Hardness (mg/l)	166.98±6.28
Chemical Oxygen Demand (mg/l)	23.06±4.47
Total Ammonia – N (mg/l)	0.039±0.002
Nitrite – N (mg/l)	0.020±0.002
Conductivity (µSiemens/cm)	555.9±79.7
TDS (ppm)	317±26.3

## V. DISCUSSION

### 5.1 Growth of *P. hypophthalmus* reared in cages at different stocking densities

The present study showed clear difference among the treatments when *P. hypophthalmus* were reared in cages at different stocking densities. At lower stocking density (20 nos/m<sup>3</sup>) the fishes grew superior than that of 40 nos/m<sup>3</sup> and 60 nos/m<sup>3</sup>. This is confirmed by the R<sup>2</sup> value or slope value (0.9959) of the growth curve of T<sub>1</sub> which was higher than that of T<sub>2</sub> and T<sub>3</sub>. Similar results were reported by Razzaque et al. (2003), Rahman et al. (2006), Narejo et al. (2005), Kumar et al. (2017), Rahman et al. (2017) and Chowdhury et al. (2019), who recorded higher growth at lower stocking density they tried.

Stocking density significantly affected the percentage weight gain, weight gain and daily weight gain of *P. hypophthalmus*. The highest weight gain and percentage weight gains that were recorded in lower stocking density (T<sub>1</sub>) due to might be the sufficient space for movement and sufficient food availability. The result of the current studies well agreed with the results reported for the cage culture of *P. sutchi* (Azimuddin et al., 1999 and Rahman et al., 2006), cage culture of striped catfish (*Pangasianodon hypophthalmus*) (Chowdhury et al., 2019), tank culture of *Clarias gariepinus* (Suleiman and Solomon, 2017) and culture of *Heteropneustes fossilis* in cemented cistern (Narejo et al., 2005).

Results from this study fall in line with the reports from other researchers. Osofero et al. (2009) found that the highest daily weight gain of *O. niloticus* was in lower stocking density (50 nos/cage) and lowest daily weight gain was in higher stocking density (200 nos/cage) they tried. Similarly Hengsawat et al.

(1997) reported higher daily weight gain in lower stocking density for *C. gariepinus*.

The highest SGR observed in lower stocking density in the present study which is consistent with similar findings reported for *Pangasius* spp. by Azimuddin et al. (1999), Datta et al. (2016), Chowdhury et al. (2019) and Vaishnav et al. (2017).

Survival rate is reported to be inversely related to stocking density which is found from in the present research. High fish density, coupled with insufficient food supply, stimulated food competition and cannibalism when cultured of sharptooth catfish. Although there was a difference in the survival rate, (Baras and Jobling, 2002), In the present study there was no significant difference in survival rate of *P. hypophthalmus* among the treatments.

Chowdhury et al. (2019) already concluded that survival rate of *Pangasianodon hypophthalmus* for cage culture was the highest in lower stocking density. Similarly Allen (1974) observed that survival rate of Channel catfish was higher in lower stocking density. Jamabo and Keremah, (2009) also found that highest survival for *C. gariepinus* fingerlings in lower stocking density. Hengsawat et al. (1997) reported mortality for African catfish in cages affected by higher stocking density. These are found agreeable in the present cage farming trial.

High stocking density is believed to cause several changes in energy metabolism that would lead to deviation of energy to face the stress resulting a drop in food conversion efficiency. In the present study, the fish held in high stocking density would not have taken feed properly due to overcrowding resulting in lower FCE (Refaey et al., 2018).

High food conversion ratio that was observed during this study which ranged from 2.15 to 2.24 was found to be better when compared to other reports. Razzaque et al. (2003) observed FCR for *Pangasius pangasius* between 7.06 and 7.72. However, Chowdhury et al. (2019) and Datta et al. (2016) observed FCR for *Pangasius* spp. between 1.3 and 1.4 and 1.8 to 1.9.

The relationship between stocking density and biomass production obtained in the present study was in close agreement with many reports published on this factor (Hengsawat et al., 1997, Razzaque et al., 2003, Islam et al., 2006, Rahman et al., 2017 and Chowdhury et al., 2019). Hengsawat et al. (1997) achieved highest biomass at highest stocking density for African catfish culture in cage. Similarly Islam et al. (2006) observed the highest biomass production in higher stocking density for cage culture of *P. sutchi*. It is also general rationale that the higher the density higher would be the biomass.

The present study agree with the study of Alish (2019) who reported the bio - growth and biomass production of Hybrid tilapia (Red strain) in freshwater cage was higher in the least stocking density (20 nos/m<sup>3</sup>) as compared to other densities (30 and 40 nos/m<sup>3</sup>).

## **5.2 Proximate composition of *P. hypophthalmus* reared in cages at different stocking densities**

In the present investigation, there was notable impact of the stocking density on protein and moisture content. Increasing stocking density caused negative effect on body composition, causing decreased protein content in *Ictalurus punctatus* (Refaey et al., 2018), *Clarias gariepinus* (Toko et al., 2007).

Cagiltay et al. (2015) reported that highest protein content of *Oncorhynchus mykiss* was found in intermediate stocking density. In present study highest protein content was observed in the least stocking density group, which is agreement with the above reports. Similarly increased moisture content that was found in lower stocking density is also in line with the finding of Toko et al. (2007), Cagiltay et al. (2015) and Refaey et al. (2017). However, Wang et al. (2012) reported that the highest protein content was found in cage reared longsnout catfish compared to the pond reared and wild caught longsnout catfish.

Since the present study did not have any control to compare the protein content of the pond reared *P. hypophthalmus*. This fact could not be continued. However, further research can be done in this line to compare the effect of stocking density on the proximate composition based on the culture system.

The present findings revealed significant increase in muscle lipid content with increasing stocking density. Cagiltay et al. (2015) observed that lipid content of flesh in *O. mykiss* increased up to 15 kg/m<sup>3</sup> after that it was decreased. But Toko et al. (2007) reported highest lipid content in *C. gariepinus* and *H. longifilis* in lower stocking density. Therefore, the impact of stocking density on the lipid content remains inconclusive.

### **5.3 Growth of *P. hypophthalmus* reared in cages at different stocking sizes**

In the present study, it was observed that growth and biomass production of *P. hypophthalmus* was significantly influenced by the initial stocking size. The smaller size (2" TL) showed higher weight gain, higher food conversion efficiency, higher biomass production and higher survival compared to larger size (4" and 6" TL) of *P. hypophthalmus*. This is in line with the findings of Akbulut et al. (2002)

who reported that *O. mykiss* showed higher growth performance and survival in smaller initial stocking size (52.1 g) compared to other stocking sizes (77.6 g and 118.6). Similarly Limbu et al. (2015) reported that higher Daily Weight Gain (DWG) and Specific Growth Rate (SGR) of *O. niloticus* recorded when the *O. niloticus* was cultured with smaller size *C. gariepinus*.

Szczepkowski et al. (2012) observed that highest final body weight, mean weight gain and highest final biomass were within smaller stocking size (1.5 g) of juvenile perch (*Esox lucius L.*) as compared to other stocking sizes (7.0 and 18.5 g) when they cultured in earthen pond. Therefore, it could be confirmed that the smaller size fishes could perform better than bigger size fishes, were cultured at equal density.

#### **5.4 Proximate composition of *P. hypophthalmus* reared in cages at different stocking sizes**

From the present study the proximate composition of *P. hypophthalmus* flesh had shown variation among the different sizes. The present study showed that the protein content decreased with increasing moisture content of flesh as showed in Fig. 4.12. This is in agreement with the Breck (2014) who reported that the amount of water per unit protein decreasing in larger fish. Similarly Naeem and Ishtiaq (2011) observed that body weight of *Mystus bleekeri* positively correlate with protein and organic contents (wet and dry weight).

Naeem and Salam (2010) reported that protein and fat content was positively increased with body weight increment and moisture content was decreased with body weight in *Aristichthys nobilis*.

The present study was coincide with Alish (2019) who observed that the higher protein and fat content was found in the larger size of Hybrid tilapia (Red strain) when they grown in cage system.

### **5.5 Physico - chemical parameters**

Physico – chemical parameters recorded during the experimental period were within the suitable range, indicating that experimental condition suitable for growth of *P. hypophthalmus* (Boyd and Pillai, 1985, Bhatnagar and Devi, 2013 and Devi et al., 2017).

*P. hypophthalmus* being eurythermal can adapt to wide range of temperature fluctuation. Islam et al. (2019) already reported that *P. hypophthalmus* can grow at optimum level when the temperature ranged from 28 to 32 °C. Bhatnagar and Devi, (2013) also reported that the tolerable range of temperature for fish culture 20 to 30 °C.

Normally pH range of 6.5 to 9 is said to be favourable for fish growth (Boyd and Pillai 1985). Wurts and Durborow (1992) said that desirable pH range for pond water was 7.0 to 8.0. Rahman et al. (2006) reported that optimum pH range for *P. sutchi* was 7.0 to 8.0. However, the pH recorded in the present experiment was alkaline (7.5 to 8.5) which was not found to be adverse for fish culture and comparable to pervious findings also.

Dissolved oxygen is said to be the most critical water quality parameter in tropical fish culture that exerts direct effect on food consumption and metabolisms. In present study dissolved oxygen was found within the range of 4.4 to 7.0 mg/l. Islam et al. (2019) recorded dissolved oxygen ranges of 5.8 to 6.8 mg/l at temperature of 24 °C which was decreased up to 3.2 to 3.4 mg/l in 36 °C during the culture of *P. hypophthalmus*.

Boyd and Pillai (1985) suggested that dissolved oxygen level should be more than 5.0 mg/l for better growth and survival of fishes. Santhosh and Singh (2007) reported that catfish and other air-breathing fishes can survive in low oxygen concentration of 4 mg/l. In the present study the dissolved oxygen level was well maintained and therefore, it did not pose any threat.

Wurts (2002) said that desirable range of total alkalinity was 50 to 150 mg/l but it should not be less than 20 mg/l. Bhatnagar and Devi (2013) suggested that alkalinity between 50 to 200 mg/l is ideal in an aquaculture pond. This factor in the present study was optimal.

Boyd and Pillai (1985) suggested that desirable range of total hardness of 20 to 300 mg/l was suitable for fish culture. Wurts (2002) reported that total hardness level of 75 to 200 mg/l was desirable for aquaculture system. In present study total hardness level found within the range of 148 to 192 mg/l which is in agreement with above findings.

When dissolved oxygen concentrations are low, the presence of carbon dioxide concentration is normally high in fish pond. Respiration by fishes and microscopic plants and animals are the main source of carbon dioxide in fish pond. Wurts and Durborow (1992) suggested that catfish can tolerate 20 to 30 mg/l CO<sub>2</sub> if the dissolved oxygen concentration was more than 5 mg/l. Bhatnagar and Devi (2013) reported that 5.0 to 8.0 mg/l CO<sub>2</sub> was desirable for fish culture. During the present study carbon dioxide content was recorded in acceptable range (1.8 to 3.3 mg/l) and values agree with the previous reports.

The total ammonia nitrogen recorded in all the treatments during the experiment was within a range of 0.022 to 0.055 mg/l but the highest concentration of ammonia nitrogen was found in higher stocking group (T<sub>3</sub>). This

might be due to the accumulation of feed and decomposition of organic matter.

According to Boyd and Pillai (1985) channel catfish showed reduced growth when the ammonia concentration as low as 0.06 mg/l. Bhatnagar and Devi (2013) suggested the acceptable range of ammonia concentration (0 to 0.05 mg/l) for aquaculture production.

In the present study, nitrite nitrogen value was in the range between 0.009 to 0.036 mg/l. The value increased as the stocking density increase which could be attributed to the higher amount of excreta and uneaten feed. Bhatnagar and Devi (2013) reported that 0.02 to 2 mg/l of nitrite as the safe level for fish culture. Boyd and Pillai (1985) stated that nitrite concentrations above 1 mg/l in pond water are usually undesirable for aquaculture.

In the present experiment the Chemical Oxygen Demand (COD) was found in the range which was reported well within the range by Queiroz and Boyd (1998). They reported that COD increased with increasing production period of channel catfish and found 25.1 mg/l COD in control pond and 21.7 mg/l in bacterial inoculated pond.

Conductivity of water depends on its ionic concentration ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{HCO}_3^-$ ,  $\text{CO}_3^-$ ,  $\text{NO}_3^-$  and  $\text{PO}_4^-$ ), temperature and on variations of dissolved solids. Mustapha, (2017) reported conductivity between 348 to 428  $\mu\text{S}/\text{cm}$  in earthen pond. During the present study the conductivity level was found between 420 to 693  $\mu\text{Siemens}/\text{cm}$ , which was well within the optimum level.

## VI. SUMMARY AND CUNCLUSION

*P. hypophthalmus* is one of the fast-growing fish presently cultured in freshwaters. It is the third most important freshwater aquaculture species because of its market demand and fast-growing nature, accepting feeds, highly tolerant to poor water quality. It is an air-breathing fish that has been reported to tolerate low dissolved oxygen (DO) situations in the water and can be cultured in ponds, concrete tanks, fish cages or pens.

Growth and production of any species generally depend upon the pond environment, availability of feed in right quality and quantity. In most culture species, among many factors, stocking density and stocking size are considered as important which influence survival and growth, behavior, health, water quality, feeding and production. In the present study, the effect of different stocking densities and stocking sizes on growth and survival of *P. hypophthalmus* in intensive cage culture system was investigated.

The present research work was conducted at Thanjavur Centre for Sustainable Aquaculture (TCeSA), Thanjavur of TNJFU. *P. hypophthalmus* seeds were procured from Madurai and acclimatized before stocking. In the first set of experiment, *P. hypophthalmus* seeds of 2.7 g ABW were stocked in three different stocking densities (20, 40 and 60 nos/m<sup>3</sup>, code number as T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub>, respectively) and grown for a period of 90 days. Commercial pellet feed was given twice a day and sampling was done in every fortnight. Periodically bio growth parameters such as length, weight, survival, total feed given, etc. were recorded along with water quality parameters.

The highest final mean body weight ( $110.03 \pm 0.11$  g) and Weight Gain ( $107.19 \pm 0.54$  g) were observed in the lowest stocking density group (20 nos/m<sup>3</sup>) and the lowest values ( $95.01 \pm 0.23$  g and  $97.56 \pm 0.01$  g, respectively) were observed in the highest stocking density group (T<sub>3</sub>). The values were statistically significant when analysed using One way ANOVA ( $P < 0.05$ ). The Daily Weight Gain (g) and Specific Growth Rate also followed the same trend as per the body weight gain. Better Food Conversion Ratio (FCR) ( $2.15 \pm 0.02$ ) was observed in the lowest stocking density group (T<sub>1</sub>). From the present study it was revealed that survival rate of fishes decreased with increasing stocking density as the better survival was with T<sub>1</sub> only ( $97.50 \pm 0.00$  %).

After harvesting of all the fishes from cages, it was estimated that total biomass production increased with increasing stocking density (T<sub>3</sub> had  $21.42 \pm 0.02$  kg). It also confirmed that per unit area maximum biomass production was recorded in T<sub>3</sub> group. The proximate composition of flesh was analysed at the close of the trial and it was found that protein content of flesh decreased with increasing stocking densities whereas, crude fat, moisture and fibre content increased with increasing stocking densities. The highest protein content (15.14%) was observed in the least stocking density group (T<sub>1</sub>). The crude fat content (3.59%) found to be high in the highest stocking density group (T<sub>3</sub>).

In the present study best stocking density (20 nos/m<sup>3</sup>) from 1<sup>st</sup> experiment was chosen for 2<sup>nd</sup> phase of experiment to investigate the effect of stocking sizes on growth and survival of *P. hypophthalmus*, same method of farming was carried out in the same cages.

At the end of 2<sup>nd</sup> experiment, the maximum Weight Gain ( $58.19 \pm 0.18$  g) was recorded in the smallest stocking size group ( $T_4$ ) and minimum ( $41.64 \pm 0.30$ ) was recorded in larger stocking size group ( $T_6$ ). The values were statistically significant ( $p > 0.005$ ). The highest Daily Weight Gain ( $0.97 \pm 0.00$  g) and Specific Growth Rate (SGR) ( $5.42 \pm 0.04$ ) was obtained in the smallest stocking size group ( $T_4$ ) and the least daily weight gain ( $0.70 \pm 0.01$  g) and Specific Growth Rate (SGR) ( $1.90 \pm 0.00$ ) was obtained in the biggest stocking size group ( $T_6$ ).

The total biomass production was decline with rising of stocking size. The highest net biomass production ( $4.59 \pm 0.011$  kg) was obtained in the ( $T_4$ ) group and the lowest ( $3.21 \pm 0.031$  kg) was obtained in the ( $T_6$ ) group. The maximum biomass produced per unit area ( $1.20 \pm 0.003$  kg) was found in smaller stocking size ( $T_4$ ) and minimum ( $1.15 \pm 0.021$  kg) in  $T_5$  group. In this experiment, it was found that survival rate of fishes falling off with increasing stocking sizes and the highest survival ( $98.75 \pm 0.00$  %) was recorded in ( $T_4$ ) group and the lowest survival ( $97.50 \pm 0.00$  %) was recorded in ( $T_6$ ) group.

The body composition of flesh was estimated at the end of the trial and it was observed that higher protein content (15.76 %) was found in ( $T_6$ ) group. The crude fat content of flesh decreased with increasing fish size. The higher percentage (3.5 %) of fat was found in  $T_4$  group and the lowest (3.0 %) in  $T_6$  group. The moisture content was found to be in the range of 82.0 to 79.97 %.

The physico – chemical parameters such as temperature, pH, DO, CO<sub>2</sub>, COD, total alkalinity, total hardness total ammonia nitrogen, nitrite nitrogen, conductivity and TDS were monitored throughout the experiment period.

The temperature was found to be in the range of 25 to 31 °C and pH was 7.5 to 8.5. The dissolved oxygen concentration in cages was in the range of 4.4 to 7.0 mg/l, CO<sub>2</sub> was 1.83 to 3.31 mg/l and COD was 12.8 to 35.2 mg/l. Total alkalinity was recorded as 84 to 136 mg/l and total hardness was 148 to 192 mg/l. Total ammonia nitrogen was observed in cages which varied from 0.022 to 0.055 mg/l and nitrite concentration from 0.009 to 0.036 mg/l. All the values were in suitable range for culture of *P. hypophthalmus*.

The present study revealed that the lowest stocking density (20 nos/m<sup>3</sup>) and smaller initial stocking size (2" TL) showed better performance in term of growth and survival.

## VII. REFERENCES

- Akbulut, B., Şahin, T., Aksungur, N., Aksungur, M., 2002. Effect of initial size on growth rate of rainbow trout, *Oncorhynchus mykiss*, reared in cages on the Turkish Black Sea Coast. *Tur. J. Fish. Aquat. Sci.* 2(2), 133-136.
- Ali, M. Z., Hossain, M. A., Mazid, M. A., 2005. Effect of mixed feeding schedules with varying dietary protein levels on the growth of sutchi catfish, *Pangasius hypophthalmus* (Sauvage) with silver carp, *Hypophthalmichthys molitrix* (Valenciennes) in pond. *Aquat. Res.* 36(7), 627 – 634.
- Alish Bebbarma, 2019. Evaluation of stocking parameters influencing the growth of Hybrid Tilapia (Red strain) under intensive cage farming. M.F.Sc. Thesis submitted to Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Nagapattinam. 121p.
- Allen, K. O., 1974. Effects of stocking density and water exchange rate on growth and survival of channel catfish *Ictalurus punctatus* (Rafinesque) in circular tanks. *Aquaculture.* 4, 29-39.
- Amin, A. R., 2005. The Impacts of Compensatory Growth on Food Intake, Growth Rate and Efficiency of Feed Utilization in Thai Pangas (*Pangasius hypophthalmus*) Bangladesh. *Pak. J. Biol. Sci.* 8(5), 766-770.
- APHA, 1998. Standard methods for the estimation of water and waste waters, 20<sup>th</sup> edn, American Public Health Association, New York. 157 – 169.
- Azimuddin, K. M., Hossain, M. A., Wahab, M. A., Noor, J., 1999. Effect of stocking density on the growth of Thai pangas, *Pangasius sutchi* (Fowler) in net cage fed on formulated diet. *Bang. J. Fish. Res.* 3(2), 173 -180.
- Baras, E., Jobling, M., 2002. Dynamics of intracohort cannibalism in cultured fish. *Aquat Res.* 33(7), 461-479.

- Battisti, E. K., Rabaioli, A., Uczay, J., Sutili, F. J., Lazzari, R., 2020. Effect of stocking density on growth, hematological and biochemical parameters and antioxidant status of silver catfish (*Rhamdia quelen*) cultured in a biofloc system. *Aquaculture*. 524, 735213.
- Bhatnagar, A., Devi, P., 2013. Water quality guidelines for the management of pond fish culture. *Int. J. Environ. Sci.* 3(6), 1980.
- Boyd, C. E., 1973. The chemical oxygen demand of waters and biological materials from ponds. *Transactions of the American fisheries society*. 102(3), 606-611.
- Boyd, C. E., 1990. Water quality in ponds for aquaculture. Alabama Agricultural Experiment Station Birmingham Publishing, Auburn University, USA, 482.
- Boyd, C. E., Lichtkoppler, F., 1979. Water Quality Management in Pond Fish Culture Research and Development Series No 22. Auburn (US), Auburn University, Agricultural Experiment Station.
- Boyd, C. E., Pillai, V. K., 1985. Water quality management in aquaculture. *CMFRI special Publication*. 22, 1-44.
- Boyd, C. E., Tucker, C. S., Somridhivej, B., 2016. Alkalinity and hardness: critical but elusive concepts in aquaculture. *J. World Aquac. Soc.* 47(1), 6-41.
- Breck, J. E., 2014. Body composition in fishes: body size matters. *Aquaculture*. 433, 40-49.
- Çagiltay, F., Erkan, N., Ulusoy, Ş., Selcuk, A., Ozden, O., 2015. Effects of stock density on texture-colour quality and chemical composition of rainbow trout (*Oncorhynchus mykiss*). *Iran. J. Fish. Sci.* 14(3), 687 - 698.
- Chakraborty, B. K., Mirza, M. J. A., 2007. Effect of stocking density on survival and growth of endangered bata, *Labeo bata* (Hamilton–Buchanan) in nursery

ponds. *Aquaculture*. 265(1-4), 156-162.

Chattopadhyay, D. N., Mohapatra, B. C., Adhikari, S., Pani, K. C., Jena, J. K., and Eknath, A. E., 2013. Effects of stocking density of *Labeo rohita* on survival, growth and production in cages. *Aquac. Int.* 21(1), 19 - 29.

Chaturvedi, C. S., Lakra, W. S., Singh, R. K., Pandey, A. K., 2015. Successful induced breeding and larval rearing of *Pangasianodon hypophthalmus* under Controlled conditions of Raipur (Chhattisgarh). *J. BMC.* 106 – 112.

Chowdhury, M. A., Roy, N. C., & Chowdhury, A., 2020. Growth, yield and economic returns of striped catfish (*Pangasianodon hypophthalmus*) at different stocking densities under floodplain cage culture system. *Egypt. J. Aquat. Res.* 46(1), 91-95.

Coulibaly, A., Ouattara, I. N., Kone, T., Ndouba, V., Snoeks, J., Bi, G. G., Kouamélan, E. P., 2007. First results of floating cage culture of the African catfish *Heterobranchus longifilis* Valenciennes, 1840: Effect of stocking density on survival and growth rates. *Aquaculture*. 263(1-4), 61-67.

Cretu, M., Victor, C., Lorena, D., Mihai, P. S., 2014. The influence of different stocking densities on biochemical composition of rainbow trout meat reared in a recirculating aquaculture system. *J. Anim. Sci. Biotechnol.* 47(1), 200-204.

DADF, 2020. Annual Report 2018 - 19, Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture, Government of India.

Das, P. C., Ayyappan, S., Jena, J., 2005. Comparative changes in water quality and role of pond soil after application of different levels of organic and inorganic inputs. *Aquac. Res.* 36(8), 785-798.

- Datta, S. N., Dhawan, A., Kumar, S., Singh, A., Parida, P., 2017. Standardization of stocking density for maximizing biomass production of *Pangasius pangasius* in pond cage aquaculture. *J. Environ. Biol.* 38(2), 237.
- Devi, P. A., Padmavathy, P., Aanand, S., Aruljothi, K., 2017. Review on water quality parameters in freshwater cage fish culture. *Int. J. Appl. Res.* 3(5), 114-120.
- Diana, M. J., Wahl, D. H., 2009. Growth and survival of four sizes of stocked largemouth bass. *N. Am. J. Fish.* 29(6), 1653-1663.
- El-Sayed, A. F. M., 2002. Effects of stocking density and feeding levels on growth and feed efficiency of Nile tilapia (*Oreochromis niloticus* L.) fry. *Aquac. Res.* 33(8), 621-626.
- FAO. 2020. The State of World Fisheries and Aquaculture. Sustainability in action. Rome. 199p.
- Galagarza, O. A., Kuhn, D. D., Smith, S. A., Hrubec, T. C., 2017. Hematologic and plasma chemistry RIs for cultured Striped catfish (*Pangasius hypophthalmus*) in recirculating aquaculture systems. *Vet. Clin. Pathol.* 46(3), 457-465.
- Gautam, S. P., Reeta, K., Suniti, P., Basu, D. D., Kamyotra, J. S., 2011. Guide manual: Water and wastewater analysis. *Central Pollution Control Board, Ministry of Environment & Forests, Government of India.*
- Gross, A., Boyd, C. E., Wood, C. W., 2000. Nitrogen transformations and balance in channel catfish ponds. *Aquacult. Eng.* 24(1), 1-14.
- Guimaraes, C. F. M., Mársico, E. T., Monteiro, M. L. G., Lemos, M., Mano, S. B., Conte Junior, C. A., 2016. The chemical quality of frozen Vietnamese *Pangasius hypophthalmus* fillets. *Food Sci. Nutr.* 4(3), 398-408.

- Gustiano, R., Prakoso, V. A., Ath-thar, M. H. F., 2018. Asian catfish Genus *Pangasius*, Diagnosis and distribution. *Indones. Fish. Res. J.* 24(2), 99-115.
- Hargreaves, J. A., & Brunson, M., 1996. Carbon dioxide in fish ponds Starkville, Mississippi: Southern Regional Aquaculture Center. 1- 6.
- Hargreaves, J. A., Tucker, C. S., 2004. Managing ammonia in fish ponds (Vol. 4603). Stoneville, MS: Southern Regional Aquaculture Center.
- Hengsawat, K., Ward, F. J., Jaruratjamorn, P., 1997. The effect of stocking density on yield, growth and mortality of African catfish (*Clarias gariepinus* Burchell 1822) cultured in cages. *Aquaculture*. 152(1-4), 67-76.
- Ibrahim, A. H. M., Ahmed, Z. F., Ohtomi, J., El-Kady, M. A., Fulanda, B., 2008. Comparison studies on water quality and plankton production between perennial and non-perennial ponds in Bangladesh. *J. Fish. Aquat. Sci.* 3(3), 176-183.
- Islam, M. A., Uddin, M. H., Uddin, M. J., Shahjahan, M., 2019. Temperature changes influenced the growth performance and physiological functions of Thai pangas *Pangasianodon hypophthalmus*. *Aquac. Rep.* 13, 100179.
- Islam, M. S., Rahman, M. M., Tanaka, M., 2006. Stocking density positively influences the yield and farm profitability in cage aquaculture of sutchi catfish, *Pangasius sutchi*. *J. Appl. Ichthyol.* 22(5), 441-445.
- Jahan, R., Quaiyum, M. A., Jahan, N., Akhter, T., Islam, M. S., 2014. Dietary added bamboo charcoal can evoke *Pangasianodon* growth and can reduce ammonia from culture medium. *Int. J. Fish. Aquat.* 6(7), 87-93.
- Jamabo, N. A., Keremah, R. I., 2009. Effects of stocking density on the growth and survival of the fingerlings of *Clarias gariepinus* (Burchell, 1822). *Int. J. Fish. Aquac.* 4(4), 55-57.

- Jiwyam, W., 2011. The effect of stocking density on yield, growth, and survival of Asian river catfish (*Pangasius bocourti* Sauvage, 1880) cultured in cages. *Aquac. Int.* 19(5), 987-997.
- Kader, M. A., Hossain, M. A., Hossain, M. D., 2003. A comparative study on the effect of commercial fish feeds on the growth of Thai pangas, *Pangasius hypophthalmus*. *Ban. J. Fish. Res.* 7(1), 53-58.
- Karl, H., Lehmann, I., Rehbein, H., Schubring, R., 2010. Composition and quality attributes of conventionally and organically farmed *Pangasius* fillets (*Pangasius hypophthalmus*) on the German market. *Int. J. Food Sci. Technol.* 45(1), 56-66.
- Khan, N., Atique, U., Ashraf, M., Mustafa, A., Mughal, M. S., Rasool, F., Iqbal, K. J., 2018. Effect of various protein feeds on the growth, body composition, hematology and endogenous enzymes of catfish (*Pangasius hypophthalmus*). *Pak. J. Zool. Suppl. Ser.* 13, 112-119.
- Kjartansson, H., Fivelstad, S., Thomassen, J. M., Smith, M. J., 1988. Effects of different stocking densities on physiological parameters and growth of adult Atlantic salmon (*Salmo salar* L.) reared in circular tanks. *Aquaculture.* 73(1-4), 261-274.
- Kumar, M., Dube, K., Tiwari, V. K., Reddy, A. K., Chaturvedi, C. S., 2017. Comparative Performance of *Pangasianodon hypophthalmus* (Sauvage, 1878) Culture in Cages and Ponds. *Int. J. Curr. Microbiol. App. Sci.* 6(10), 1679-1688.
- Kwikiriza, G., Barekye, A., Muhereze, R., Makuma, K. A., Tibihika, P. D., 2016. Growth performance of monosex Nile tilapia (*Oreochromis niloticus*) juveniles at different stocking densities in cages at Lake Bunyonyi in South

Western Highland Agro-Ecological Zones (SWHAEZs). *Int. J. Fish. Aquat. Stud.* 4(6), 42-48.

Li, W., Li, Z., 2009. In situ nutrient removal from aquaculture wastewater by aquatic vegetable *Ipomoea aquatica* on floating beds. *Water Sci. Technol.* 59(10), 1937-1943.

Limbu, S. M., Shoko, A. P., Lamtane, H. A., Shirima, E. D., Kische-Machumu, M. A., Mgana, H. F., Mgaya, Y. D., 2015. Effect of initial stocking size of the predatory African sharptooth catfish (*Clarias gariepinus*) on recruits, growth performance, survival and yield of mixed-sex Nile tilapia (*Oreochromis niloticus*) in concrete tank culture system. *Int. Aquat. Res.* 7(1), 63-73.

Mäkinen, T., Weyl, O. L., Van der Walt, K. A., Swartz, E. R., 2013. First record of an introduction of the giant pangasius, *Pangasius sanitwongsei* Smith 1931, into an African river. *Afr. Zool.* 48(2), 388-391.

Malik, A., Kalhor, H., Shah, S. A., Kalhor, I. B., 2014. The effect of different stocking densities on growth, production and survival rate of pangas (*Pangasius hypophthalmus*) fish in cemented tanks at fish hatchery Chilya Thatta, Sindh-Pakistan. *Int. J. Interdiscip. Multidiscip. Stud.* 1(10), 129-136.

Mane, A. M., Dube, K., Varghese, T., Chavan, B. R., Kamble, M. T., 2019. Effects of Stocking Density on Growth Performance, Survival and Production of *Catla catla* and *Labeo rohita* During Nursery Rearing in Cages. *Proc. Natl. Acad. Sci. India, Sect. B Biol. Sci.* 89(1), 275-281.

Merino, G. E., Piedrahita, R. H., Conklin, D. E., 2007. The effect of fish stocking density on the growth of California halibut (*Paralichthys californicus*) juveniles. *Aquaculture.* 265(1-4), 176-186.

- Mitchell, M. K., Stapp, W. B., 1992. Field Manual for Water Quality Monitoring: An environmental education program for schools. Dexter, MI: Thomson-Shore. 272.
- Mohan, A. B. C., Gopala, R. K., Ravi, B. G., 2019. Recent trends in Pangasius (*Pangasianodon hypophthalmus*) farming, production and marketing in India. Asian Pacific Aquaculture (APA 2019), held during 19 – 21 June 2019 at Chennai.
- Mukai, Y., Tuzan, A. D., Lim, L. S., Yahaya, S., 2010. Feeding behavior under dark condition in larvae of sutchi catfish *Pangasianodon hypophthalmus*. *Fish. Sci.* 76(3), 457-461.
- Mustapha, M. K., 2017. Comparative assessment of the water quality of four types of aquaculture ponds under different culture systems. *Adv. Res. life Sci.* 1(1), 104-110.
- Naeem, M., Ishtiaq, A., 2011. Proximate composition of *Mystus bleekeri* in relation to body size and condition factor from Nala Daik, Sialkot, Pakistan. *Afr. J. Biotechnol.* 10(52), 10765-10773.
- Naeem, M., Salam, A., 2010. Proximate composition of fresh water bighead carp, *Aristichthys nobilis*, in relation to body size and condition factor from Islamabad, Pakistan. *Afr. J. Biotechnol.* 9(50), 8687-8692.
- Narejo, N. T., Salam, M. A., Sabur, M. A., Rahmatullah, S. M., 2005. Effect of stocking density on growth and survival of indigenous catfish, *Heteropneustes fossilis* (Bloch) reared in cemented cistern fed on formulated feed. *Pak. J. Zool.* 37(4), 49.
- Ntengwe, F. W., Edema, M. O., 2008. Physico-chemical and microbiological characteristics of water for fish production using small ponds. *Phys.*

*Chem. Earth.* 33(8-13), 701-707.

- Nzeagwu, A.C., Anyanwu, E.D., Avoaja, D.A., 2017. Dynamics of water quality in tropical earthen fish ponds. *Nig. J. Fish. Aqua.* 14, 1289 – 1295.
- Oke, V., Goosen, N. J., 2019. The effect of stocking density on profitability of African catfish (*Clarias gariepinus*) culture in extensive pond systems, *Aquaculture.* 507, 385 – 392.
- Orban, E., Navigato, T., Di Lena, G., Masci, M., Casini, I., Gambelli, L., Caproni, R., 2008. New trends in the seafood market. Sutchi catfish (*Pangasius hypophthalmus*) fillets from Vietnam: Nutritional quality and safety aspects. *Food Chem.* 110(2), 383-389.
- Osofero, S. A., Otubusin, S. O., Daramola, J. A., 2009. Effect of stocking density on tilapia (*Oreochromis niloticus* Linnaeus 1757) growth and survival in, bamboo–net cages trial. *Afr. J. Biotechnol.* 8(7), 13322 – 1325.
- Phen, C., Thang, T. B., Baran, E., Vann, L. S., 2005. Biological reviews of important Cambodian fish species, based on FishBase 2004. *World Fish Center. Phnom. Penh.* 103 – 110.
- Policar, T., Stejskal, V., Kristan, J., Podhorec, P., Svinger, V., Blaha, M., 2013. The effect of fish size and stocking density on the weaning success of pond cultured pikeperch *Sander lucioperca* L. juveniles. *Aquac. Int.* 21(4), 869-882.
- Poulsen, A. F., Hortle, K. G., Valbo-Jorgensen, J., Chan, S., Chhuon, C. K., Viravong, S., Tran, B. Q., 2004. Distribution and ecology of some important riverine fish species of the Mekong River Basin. *MRC technical paper.* 10, 116.

- Premchand, K., Ushakiranmai, G., 2017. Impact Of Physico-Chemical Parameters On Growth Of Indian Major Carps Cultured In Different Ponds At Krishna District, Andhra Pradesh, India. *Int. J. Inno. Res. Creat. Tech.* 2 (4), 169 – 173.
- Queiroz, J. F., Boyd, C. E., 1998. Effects of a bacterial inoculum in channel catfish ponds. *J. World Aquac. Soc.* 29(1), 67-73.
- Rahman, M. A., Habib, K. A., Hossain, M. A., Azad, S. O., Rayhan, M. Z., 2017. Impacts of stocking density and economic returns on the cage culture of stinging catfish, *Heteropneustes fossilis*. *Int. J. Fish. Aquat. Std.* 5(4), 198 – 201.
- Rahman, M. M., Islam, M. S., Halder, G. C., Tanaka, M., 2006. Cage culture of sutchi catfish, *Pangasius sutchi* (Fowler 1937): effects of stocking density on growth, survival, yield and farm profitability. *Aquac Res.* 37(1), 33 - 39.
- Ranjan, A., Jain, K. K., Srivastava, P. P., Muralidhar, P. A., 2018. Dietary energy requirement of *Pangasianodon hypophthalmus* (Sauvage, 1878) juveniles reared at two temperatures. *Turk. J. Fish. Aquat Sci.* 18(1), 101-108.
- Razzaque, M. A., Mazid, M. A., Islam, M. N., Kamal, M., Hossain, M. A., Mansur, M. A., 2003. Influence of stocking density on the culture potential of freshwater catfish *Pangasius pangasius* in pond. *Bang. J. Fish. Res.* 7(2), 123-130.
- Refaey, M. M., Li, D., Tian, X., Zhang, Z., Zhang, X., Li, L., Tang, R., 2018. High stocking density alters growth performance, blood biochemistry, intestinal histology and muscle quality of channel catfish *Ictalurus punctatus*. *Aquaculture.* 492, 73 – 81.

- Roberts, T. R., Vidthayanon, C., 1991. Systematic revision of the Asian catfish family Pangasiidae, with biological observations and descriptions of three new species. *Proc. Acad. Nat. Sci. Philadelphia*. 97-143.
- Rowland, S. J., Mifsud, C., Nixon, M., Boyd, P., 2006. Effects of stocking density on the performance of the Australian freshwater silver perch (*Bidyanus bidyanus*) in cages. *Aquaculture*. 253(1- 4), 301 - 308.
- Rui, L., Youjoun, O., Xiaowei, G., 2006. A review: influence of stocking density on fish welfare mortality, growth, feeding and stress response. *South China Fish. Sci.* 2, 76-80.
- Sahoo, S. K., Giri, S. S., Sahoo, A. K., 2004. Effect of stocking size of *Clarias batrachus* fry on growth and survival during fingerling hatchery production. *Asian Fish Sci.* 17, 229-233.
- Santhosh, B., Singh, N. P., 2007. Guidelines for water quality management for fish culture in Tripura. *ICAR Research Complex for NEH Region, Tripura Center, Publication*. 29(10).
- Sarkar, M. R. U., Khan, S., Haque, M. M., Haq, M. S., 2006. Evaluation of growth and water quality in pangasiid catfish (*Pangasius hypophthalmus*) monoculture and polyculture with silver carp (*Hypophthalmichthys molitrix*). *J. Bang. Agril. Univ.* 4(452-2018-3921), 339-346.
- Sawant, R., Chavan, N., 2013. Water quality status of Mahagaon reservoir from Gadhinglaj tahsil from Maharashtra. *Int. J. Environ. Sci. Technol.* 2(6), 1196-1204.
- Sayeed, M. A. B., Hossain, G. S., Mistry, S. K., Huq, K. A., 2008. Growth performance of thai pangus (*Pangasius hypophthalmus*) in polyculture system using different supplementary feeds. *Univ. J. Zool. Rajshahi. Univ.*

27, 59-62.

- Scannell, P. W., Jacobs, L. L., 2001. Effects of total dissolved solids on aquatic organisms: Tech Report No. 01 – 06., *Alaska: Alaska Department of Fish and Game Restoration*. 62p.
- Schumann, M., Brinker, A., 2020. Understanding and managing suspended solids in intensive salmonid aquaculture: a review. *Aquaculture*. 12(4), 2109-2139.
- Shaker, I., Abdel-Aal, M., 2006. Growth performance of fish reared under different densities in semi-intensive and extensive earthen ponds. *Egypt. J. Aquat. Biol. Fish.* 10(4), 109-127.
- Shourbela, R. M., Waleed, N., Abd El-Rahman, S. H., 2016. Interactive effects of stocking density and feed type on growth, survival and cannibalism among African catfish (*Clarias gariepinus* Burchell 1822). *J. Anim. Feed Res.* 6, 73 – 82.
- Singh, A. K., Lakra, W. S., 2012. Culture of *Pangasianodon hypophthalmus* into India: impacts and present scenario. *Pak. J. Biol. Sci.* 15(1), 19.
- Slembrouck, J., Baras, E., Subagja, J., Hung, L. T., Legendre, M., 2009. Survival, growth and food conversion of cultured larvae of *Pangasianodon hypophthalmus*, depending on feeding level, prey density and fish density. *Aquaculture*. 294(1-2), 52-59.
- Suarez, M. D., García-Gallego, M., Trenzado, C. E., Guil-Guerrero, J. L., Furné, M., Domezain, A., Sanz, A., 2014. Influence of dietary lipids and culture density on rainbow trout (*Oncorhynchus mykiss*) flesh composition and quality parameter. *Aquacult. Eng.* 63, 16-24.
- Subagja, J., Slembrouck, J., Legendre, M., 1999. Larval rearing of an Asian catfish *Pangasius hypophthalmus* (Siluroidei, Pangasiidae): Analysis of precocious

mortality and proposition of appropriate treatments. *Aquat. Living Resour.* 12(1), 37-44.

Suleiman, M. A., Solomon, R. J., 2017. Effect of stocking on the growth and survival of *Clarias gariepinus* grown in plastic tanks. *Direct Res. J. Vet. Med. Anim. Sci.* 2(3), 82-92.

Szczepkowski, M., Zakęs, Z., Kapusta, A., Szczepkowska, B., Hopko, M., Jarmołowicz, S., Wunderlich, K., 2012. Growth and survival in earthen ponds of different sizes of juvenile pike reared in recirculating aquaculture systems. *Fish. & Aquat. Life.* 20(4), 267-274.

Tacon, A. G., Halwart, M., 2007. Cage aquaculture: a global overview. *FAO Fisheries Technical Paper.* 498, 3.

Thirupathaiah, M., Samatha, C. H., Sammaiah, C., 2012. Analysis of water quality using physico-chemical parameters in lower manair reservoir of Karimnagar district, Andhra Pradesh. *Int. J. Environ. Sci.* 3(1), 172-180.

Toko, I., Fiogbe, E. D., Koukpode, B., Kestemont, P., 2007. Rearing of African catfish (*Clarias gariepinus*) and vundu catfish (*Heterobranchus longifilis*) in traditional fish ponds (whedos): Effect of stocking density on growth, production and body composition. *Aquaculture.* 262(1), 65-72.

Tossavi, C. E., Djissou, A. S. M., Issa, N., 2017. Effects of stocking density on growth, survival and feed utilization of Silver catfish *Schilbe intermedius* (Rüppel, 1832) fingerlings reared in circular concrete tanks. *Int. J. Fish. Aquat. Std.* 5(1), 162 – 166.

Tucker, L., Boyd, C. E., McCoy, E. W., 1979. Effects of feeding rate on water quality, production of channel catfish, and economic returns. *Trans. Am. Fish. Soc.* 108(4), 389-396.

- Usandi, B., Saini, V. P., Ojha, M. L., Jain, H. K., 2019. Effect of larval rearing density on growth and survival of koi carp, *Cyprinus carpio*. *J. Entomol. Zool. Std.* 7(2), 548 - 553.
- Vaishnav, M., Sharma, S. K., Sharma, B. K., Ojha, M., 2017. Growth performance of *Pangasius* Sp. cultured at different stocking density in floating net cages in Mahi Bajaj Sagar Dam of Banswara (Rajasthan). *J. Entomol. Zool. Std.* 5(5), 649-652.
- Vu, N. U., Huynh, T. G., Truong, Q. P., Morales, J., Nguyen, T. P., 2016. Assessment of water quality in catfish (*Pangasianodon hypophthalmus*) production systems in the Mekong delta. *Can Tho Univ. J. Sci.* 3, 71-78.
- Wang, F., Ma, X., Wang, W., Liu, J., 2012. Comparison of proximate composition, amino acid and fatty acid profiles in wild, pond-and cage-cultured long snout catfish (*Leiocassis longirostris*). *Int. J. Food Sci. Technol.* 47(8), 1772-1776.
- Wurts, W. A., 2002. Alkalinity and hardness in production ponds. *World aquaculture-baton rouge.* 33(1), 16-17.
- Wurts, W. A., Durborow, R. M., 1992. Interactions of pH, carbon dioxide, alkalinity and hardness in fish ponds. *SRAC.* 464, 1 – 3.
- Zakes, Z., 1999. The effect of body size and water temperature on the results of intensive rearing of pike-perch, *Stizostedion lucioperca* (L.) fry under controlled conditions. *Fish. Aquat. Life.* 7(1), 187-199.
- Zhu, Y. J., Yang, D. G., Chen, J. W., Yi, J. F., Liu, W. C., Zhao, J. H., 2011. An evaluation of stocking density in the cage culture efficiency of Amur sturgeon *Acipenser schrenckii*. *J. Appl. Ichthyol.* 27(2), 545-549.