Influence of maternal size, offspring feeding and their interaction on the hatchery outcomes of an Indian major carp, Rohu (*Labeo rohita*)

Soma Kundu
Student ID: MS-190611

Fisheries and Marine Resource Technology Discipline
Khulna University, Khulna
Bangladesh

December, 2019

Influence of maternal size, offspring feeding and their interaction on the hatchery outcomes of an Indian major carp, Rohu (*Labeo rohita*)

A Thesis

By

Soma Kundu

Student ID: MS 190611

Session: 2019-2020

A thesis submitted to the Fisheries and Marine Resource Technology Discipline in partial fulfillment of the requirements for the degree of Masters of Science (MSc) in Fish Genetics & Biotechnology

December, 2019

Influence of maternal size, offspring feeding and their interaction on the hatchery outcomes of an Indian major carp, Rohu (*Labeo rohita*)

Approved as to style and content by

Professor Dr. Muhammad Abdur Rouf
Head
Fisheries and Marine Resource Technology Discipline
Khulna University
Khulna, Bangladesh

December, 2019

Declaration

Influence of maternal size, offspring feeding and their interaction on the hatchery outcomes of an Indian major carp, Rohu (*Labeo rohita*)

The results presented in the thesis with the above mentioned title are entirely of the candidate's own investigations and no part of the results has been accepted for any degree nor is it concurrently submitted for any degree.

Soma 16.02.20

(Signature of the candidate)
Soma Kundu
Student ID: Ms-190611
Session: 2019-2020

(Signature of the supervisor)
Md. Shahin Parvez
Assistant Professor
Fisheries and Marine Resource Technology Discipline
Khulna University, Khulna, Bangladesh

December, 2019

DEDICATED

TO

MY BELOVED PARENTS

Acknowledgement

At first, all my admiration goes to the supreme creator and ruler of the universe, the Almighty Allah for his great mercy to keep me alive and enables me to pursue my education in 'Fisheries and Marine Resource Technology Discipline' as well as to complete my work for the degree of 'Master of Science' in "Fish Genetics & Biotechnology".

I would like to express my sincere gratitude and profound appreciation to my honorable supervisor **Md. Shahin Parvez**, Assistant Professor, Fisheries and Marine Resource Technology Discipline, Khulna University. I again owe a significant thanks to honorable teacher **Dr. Md. Moshiur Rahman**, Professor, Fisheries and Marine Resource Technology Discipline, Khulna University for his continuous guidance, valuable suggestions and sustained support throughout the survey work.

I would like to express my profound gratitude to Professor **Dr. Muhammad Abdur Rouf**, Head, Fisheries and Marine Resource Technology Discipline, Khulna University for his valuable suggestions and providence of all necessary facilities.

I recall with warm appreciation and great indebtedness or the support, guidance and suggestion extended to me by all of my respected teachers in Fisheries and Marine Resource Technology Discipline, Khulna University.

Finally, I would like to express my very profound gratitude to my parents for providing me with unfailing support and continuous encouragement throughout my study. I would also like to thank my friends. This accomplishment would not have been possible without them.

Abstract Broodstocks' size and larval feeding are very crucial in quantitative and qualitative production of gametes and offspring in any fish breeding system. Therefore, this study was carried out to investigate the influence of maternal size, offspring feeding strategy and their interaction on spawning performance and offspring fitness using a highly commercially important aquaculture species, an Indian major carp (*Labeo rohita*). The entire study was comprised of two experiments, such as 1) maternal size effect and 2) maternal size, offspring feeding and their interactive effects. During the study, females were divided into two size groups ('large' and 'small'), while offspring were randomly assigned into two feeding strategies ('everyday' and 'every other day'). The results revealed that larger mothers produced significantly higher amount of eggs with enhanced hatching and reduced deformation rate, and larger sized offspring than the smaller mothers. The offspring feeding strategy disclosed that everyday fed offspring had higher survival and better size than those fed every other day. The study did not find any significant effect of maternal size on egg number and size, and offspring survival, while interaction between maternal size and offspring feeding showed no significant effect on any offspring trait which confirmed that very strong effects of maternal condition and offspring feed deprivation were not compromised with any change. The overall findings of this study suggest that maternal size and regular offspring feeding must be considered to produce high quantity and good quality of gametes and offspring for sustainable production of this valuable species.

Keywords Broodstock size · Gamete quality · Larvae production · Offspring fitness

Table of Contents

Chapter	Title	Page no.
Chapter-1	**Introduction**	**1-3**
	1.1 Background of the study	1
	1.2 Objective	3
Chapter-2	**Literature Review**	**4-10**
	2.1 General Introduction	4
	2.2 Parental influence on offspring	4
	2.3 Maternal influence on offspring	5
	2.4 About the model species (Rohu)	6
	2.4.1 General Information	6
	2.4.2 Classification	7
	2.4.3 Morphology	7
	2.4.4 Habitat & Ecology	7
	2.4.5 Breeding	8
	2.5 Previous studies on Rohu (*Labeo rohita*)	8
	2.6 Research gap	9
	2.7 Present study	10
Chapter-3	**Materials and Methods**	**11-19**
	3.1 Broodstock selection and rearing	11
	3.2 Artificial propagation and fertilization	12
	3.3 Measurements of parental phenotypic traits	13
	3.4 Experimental procedure	14
	3.5 Offspring rearing and traits measurement	16
	3.6 Statistical analyses	18
Chapter-4	**Results**	**20-23**
	4.1 Experiment-1: maternal size effect	20
	4.2 Experiment-2: maternal size-by-offspring feeding effects	22
Chapter-5	**Discussion**	**24-28**
	5.1 Maternal size effect	24
	5.2 Offspring feeding effect	26
	5.3 Maternal size-by-offspring feeding effects	27

Chapter-6	Conclusion……………………………………………………………	29
Chapter-7	Reference……………………………………………………………	30-44
Chapter- 8	Appendix……………………………………………………………	45

List of Tables

No.	Title	Page No.
1	Variation among different reproductive traits of *Labeo rohita* due to the difference in maternal body size. Significant values are denoted as Italic and bold.	21

List of Figures

No	Title	Page No.
1	Pictures of Rohu (*Lebeo rohita*)	7
2	Experimental design 1	11
3	Experimental design 2	12
4	Administering the recommended dose of PG	13
5	Measuring standard length from the digital photograph using *ImageJ*	14
6	Measuring body area from the digital photograph using *ImageJ*	14
7	Egg stripping	15
8	Sperm stripping	15
9	Egg measurement	15
10	Sperm measurement	15
11	Addition of sperm and egg	16
12	Mixing	16
13	Placement in incubation jar	16
14	Hatchlings counting	17
15	Stocking in glass aquarium	18
16	Length measurement	18
17	Body area measurement	18
18	Maternal body size effects on offspring	22
19	Offspring feeding strategy effects on offspring	23
20	Maternal size effect	25
21	Maternal size-by-offspring feeding effects	28

Chapter-1

1.0 Introduction

1.1 Background of the study

Body size-dependent reproductive tactics are well known in many fishes which allocate reproductive energy to enhance direct (e.g. eggs, milt, fertilization, hatching, etc.) and indirect (e.g. offspring fitness) spawning benefits (Duarte and Alcaraz 1989; Johnson et al. 2011; Hixon et al. 2014; Barneche et al. 2018). Studies reported that larger females consistently produced more, bigger and good quality eggs (Mehault et al. 2010; Wang et al. 2012; McBride et al. 2015) which had greater success of fertilization and hatching than smaller females (Johnston et al. 2007; Hagmayer et al. 2018). Evidence also demonstrated that larger females not only produced good quality eggs but also allocated their reproductive energy to obtain indirect benefits by producing good quality offspring (Sogard et al. 2008; Rollinson and Rowe 2016; Barneche et al. 2018). Recent studies revealed that females could transfer molecular resources (e.g. nutrients, non-genetic information, etc.) via eggs to increase the fitness of their offspring (Giesing et al. 2011; Morrison et al. 2017). But these direct and indirect outcomes are not so straightforward which depend on many factors such as parental conditions, their nutrition, husbandry, spawning strategy, etc. (Bobe and Labbé 2010; Migaud et al. 2013; Newman et al. 2016; Ljungström et al. 2019) as well as offspring rearing strategies and environment (Rahman et al. 2013; Thompson and Volpedo 2018; Vega-Trejo et al. 2018).

Among many factors, offspring feeding strategy is a crucial one which can affect their survival, behavior, growth and other fitness traits (Devigili et al. 2012; Garrido et al. 2015; Politis et al. 2018). Moreover, studies suggested that larval feeding accounted for the maximum cost in any aquaculture production system (Coyle et al. 2004; Sarker et al. 2013). Therefore, researchers get huge interests about how to minimize feeding cost adopting different strategies such as substituting live feeds (Cahu and Infante 2001), formulating low-cost feeds (Jomori et al. 2005), intermittent feeding (Thongprajukaew and Rodjaroen 2017), etc. Studies found that these feeding strategies could significantly reduce the overall production costs (Lee 2003; Kolkovski 2013).

Although several studies showed that maternal condition and offspring feeding strategy could influence the spawning benefits in different fishes, only a limited number of them explored these effects on commercially important aquaculture species (e.g. Mehault et al. 2010; Yengkokpam et al. 2013; Falica et al. 2017). Moreover, a very few evidence is available yet about the interactive effect of maternal size and offspring feeding on fish offspring fitness (Vijendravarma et al. 2010; Vega-Trejo et al. 2018). These have attracted scientists to explore the effects of maternal size and offspring feeding strategy on commercial fish hatchery production, and also to know whether offspring of larger females reared with low amount of feed will have better fitness or at least similar performance to the offspring of smaller females providing higher amount of diet. To find out the answers, the present study was conducted by dividing the females into two size groups, while their offspring were further sub-divided into two feeding groups which were fed either everyday or every alternative day. This study was carried out with a highly commercially important aquaculture species, an Indian major carp (*Labeo rohita*).

L. rohita is the most popular freshwater aquaculture species in the Indian sub-continent which produced more than 1,842 and 1,962 million tons during 2016 and 2017, respectively and this production accounted for approximately 3% of total global aquaculture finfish production (FAO 2019). They are largely produced through different culture systems such as polyculture with other carps (Pradhan et al. 2019; Das et al. 2019), mixed culture with other fishes (Wahab et al. 2011, 2019) and prawns (Hossain and Islam 2006; Jana et al. 2019), integrated culture with rice (Dey et al. 2019) and livestock (Kestemont 1995), etc. Since they are highly demanding species, their production requires a huge number of larvae. Unfortunately, the natural sources are unable to provide these vast amount of larvae and therefore, hundreds of carp hatcheries have been established in this region to fulfill the demand (Rahman 2008; Khatun et al. 2017). In these hatcheries, the usage of broodstocks varies based on their availability and market demands. For example, some hatcheries do not have their own broodstock ponds which depend on natural or other sources, while many hatcheries do not have or maintain size and age selective broodstock facilities. Thus, hatcheries use randomly different sized broodstocks to fulfill the market demands which produce various qualities of eggs and offspring. This is a great problem in this big aquaculture industry which is a puzzle to them. On the other hand, many hatcheries try to feed their larvae as less as possible or irregularly to minimize the production cost which is another big issue in this aquaculture system. Therefore, this study was conducted to provide information that broodstocks particularly maternal size is a prerequisite to obtain greater production benefits. Moreover, the study showed that not only the maternal size but also the offspring feeding strategy and their interactions are very essential to produce good quality larvae for the sustainable production of this species.

1.2 Objectives of the study

The major aims of this study were:

- To investigate maternal size effect on spawning performance and offspring fitness using a highly commercially important aquaculture species, an Indian major carp (*Labeo rohita*).
- To explore maternal size, offspring feeding and their interactive effects on Rohu (*L. rohita*)

Chapter-2

2.0 Literature Review

2.1 General Introduction

The term 'literature' refers to 'the knowledge (theoretical and practical) of a particular topic' and 'review' means 'the organization of knowledge'. Literature review is an indispensable part of research as it helps researchers to be familiar with the work by building a link between what have been studied on the selected topic and what is going to be studied. It forms the foundation and recapitulates ticklish points upon which all future work will be built.

Some studies have already been driven to pursue how several parental phenotypic traits and feeding regime are correlated with their fertilization success and offspring fitness in different animals. The present study has been planned to explore whether the influence of maternal size, offspring feeding strategy and their interaction on spawning performance and offspring fitness using a highly commercially important aquaculture species, an Indian major carp (*Labeo rohita*). This section of thesis work will give an essence and the approximate review of former research pertinent to the present study.

2.2 Parental influence on offspring

Investigating parental effects on offspring fitness-related traits has been an ongoing interest for evolutionary ecologists (Falica and Higgs 2013), with parental effects driven by both genetic influences (e.g. Johnsen et al. 2000; Klemme et al. 2008), and non-genetic environmental influences (e.g. Freeman-Gallant 1998; Gruebler and Naef-Daenzer 2010). 'Parental effects' comprise both maternal (Dam) effects and paternal (Sire) effects. Parental influences include all trans-generational processes that affect offspring (phenotype & fitness) without alteration of the primary structure of DNA (Youngson and Whitelaw 2008; Bonduriansky and Day 2009; Jablonka and Raz 2009; Kangassalo et al. 2015).

In fishes, the roles of dam and sire influences have been studied in many phenotypic traits in offspring including embryo survival (e.g. Wedekind et al. 2008; Rodriguez-Munoz and Tregenza 2009; Kekalainen et al. 2010), growth (e.g. Bang et al. 2006; Wang 2006; Pitcher and Neff 2007; Evans et al. 2010; Janhunen et al. 2011), disease resistance (e.g. Balfry et al. 1997), embryonic viability (Janhunen et al. 2010), swimming performance (Falica and Higgs 2013), parental body size impacts on offspring (Iyengar and Eisner 1999, Davis and Landolt 2012; Xu and Wang 2013), anti-predator behaviour (e.g. Evans et al. 2004, Huuskonen et al. 2009), and larval spinal deformity (e.g. Evans and Neff 2009). All of these studies noticed significant parental influences on various aspects of offspring traits regarding different factors that may have different effects at different life stages in the species of interest. However, it is important to recognize 'parental effects' as it provides an important source of variation among offspring, and contribute to the effects of environmental changes on the resulting phenotypes (Janhunen et al. 2010).

2.3 Maternal influence on offspring

Though maternal, paternal, and parental interactions all contribute to the variation in developing larvae (Butts and Litvak 2007), maternal effects are generally considered to be more important than paternal effects, as females usually invest more care and resources in the production of offspring (e.g. Tallamy 1984; Mousseau and Fox 1998; Bonduriansky and Day 2009; Kangassalo et al. 2015). Female effects on offspring traits can be divided into genetic and nongenetic (maternal environment) effects (Huuskonen et al. 2009). The pronounced maternal effects on early life processes, including the viability itself, are unambiguous, since all the essential constituents for sustaining embryonic development are provisioned together with yolk (Heath and Blouw 1998; Heath et al. 1999; Berg et al. 2001; Kamler 2005; Janhunen et al. 2010). In particular, mothers have the ability to modulate egg size and resource content, and this egg size is regarded as a key feature in fish early history (Kangassalo et al. 2015). Egg size may be expressed as egg diameter, egg volume, wet weight, dry weight, energy content per egg or else the content of a key substance (e.g. carbon, nitrogen, protein) per egg. This factors particularly affect the traits expressed in early ontogeny, such as embryonic and larval viability, and development rate (Mousseau and Fox 1998; Fox and Czesak 2000; Bonduriansky and Head 2007). This maternal effect could also serve as a potential adaptive pathway in the course of evolutionary processes (McAdam et al. 2002; Janhunen et al. 2010).

Maternal effects on progeny traits are often documented (Berg et al. 2001; Trippel et al. 2005; McCormick 2006), given the importance of the maternal genetic and female-mediated provisioning of nutrients and other compounds (e.g. hormones) to the eggs (Brooks et al. 1997; Berg et al. 2001; Nadeau 2009) as well as on progeny. Some studies have been conducted to see the maternal effects on offspring traits which revealed that maternal effects on offspring size may translate into variation in offspring fitness particularly under unfavourable conditions in fish (Reviewed in: Hutchings 1991; Einum and Fleming 1999; Einum 2003, Janhunen et al. 2010). Few other studies have found a positive correlation between female size and egg diameter (Wright and Shoesmit 1988; Murry et al. 2008), and female size and survival of larvae (Arlinghaus et al. 2010). A common feature of many large fish species is that larger and older mother produce higher and bigger offspring with higher viability than small individuals (Chambers and Leggett 1996; Einum and Fleming 1999; Birkeland and Dayton 2005; Johnston et al. 2007). Bigger larvae, having more available food item, less potential predators and better swimming performance, are strongly related to better survival (Perez and Munch 2010; Kotakorpi et al. 2013).

Falica et al. (2017) also found that maternal genetic effects play an important role in larval length and survival, and that these effects decrease with age, possibly due to environmental variation masking genetic effects. Berejikian et al. (2011) reviewed the positive correlation between female body size and offspring size that suggests a potential maternal genetic effect on offspring growth rate. According to Janhunen et al. (2010), maternal effects (e.g. female investment into their offspring via the egg characteristics) are often strong at early life-history stages but generally decline with increasing offspring age (Fox et al. 2003). Nonetheless, the relative influence of maternal identity in affecting offspring fitness can vary by species, populations or by a range of environmental conditions.

2.4 About the model species (Rohu)

2.4.1 General Information

Labeo rohita, known as rohu, is the highly esteemed Indian major carp which belongs to the family Cyprinidae and contributes about 35% in the aquaculture production of India (Mir et al. 2017). It is considered as one of the most important primary fish species for freshwater aquaculture in Asian sub-continent, due to its delicious flesh quality, great economic value, easy culture techniques, rapid growth rate, resistance and better disease (Abidi and Khan 2011; Saha et al. 2015). The higher demand of Rohu requires higher production. So the production capacity of this fish is expected to increase with the increase in the research efforts.

Figure 1: Pictures of Rohu (*L. rohita)* (Source: Wikipidia, 2017)

2.4.2 Classification

Phylum- Chordata

Class- Oesteichthyes

Order- Cypriniformes

Family- Cyprinidae

Genus- Labeo

Species – *L. rohita*

2.4.3 Morphology

Rohu has elongated body shape with a short caudal peduncle. Body color is back brownish, silvery on sides and beneath. Dorsal and abdominal profiles are convex. It has fairly depressed snout, projected beyond jaw, thick & fringed lips. Inside of both lips is covered by a cartilaginous part. A pair of short maxillary barbells is present. It exhibit complete lateral line & moderate scale pattern. The description is reviewed from (Talwar and Jhingran 1991; Zakia 2010; Sarma et al. 2017).

2.4.4 Habitat & Ecology

Rohu is the natural inhabitant of freshwater sections of the rivers and thrives well in all fresh (Sarma et al. 2017). They are naturally distributed in the rivers of Bangladesh, India, Pakistan and Myanmar (Talwar and Jhingran 1991; Ullah et al. 2015).

The species is an omnivore and prefer different types of food at different life stages. At their early stage of life, it eats mainly zooplankton, but as it grows, it eats more and more phytoplankton, and as a juvenile or adult, it is an herbivorous column feeder, eating mainly phytoplankton and submerged vegetation.

2.4.5 Breeding

Rohu reaches sexual maturity between two and five years of age. The spawning season of rohu generally coincides with the southwest monsoon extending from April to September. Spawn may be collected from rivers and reared in tanks and lakes (Sarma et al. 2017). The fecundity of Rohu varies from 226,000 to 2,794,000, depending upon the length and weight of the fish and weight of the ovary. The spawn of this fish is collected from rivers during monsoon and reared in tanks and lakes.

Rohu is a eurythermal species and does not thrive at temperatures below 14 °C. It is a fast growing species and attains about 35-45cm total length and 700-800g in one year under normal culture conditions.

2.5 Previous studies on Rohu (*Labeo rohita*)

From the aquaculture perspective, carps are the most important fisheries products. Indian major carps, rohu (*Labeo rohita*), catla (*Catla catla*) and mrigal (*Cirrhinus mrigala*) are the prime carp species cultivated in inland freshwater aquaculture system in Bangladesh and other Asian countries constituting about 87% of the total fresh water production. Among them Rohu is regarded as highly delicious and most popular fish with many other good attributes that make it an outstanding species for aquaculture (Abidi and Khan 2010; Musharraf and Khan 2019b). Although several researches have been conducted by researchers regarding parental influence, genetic variability, diet effects, sperm competition etc. on carp, very few have considered maternal genetic & offspring feeding impacts specifically.

Studies include passive transfer of maternal antibodies and their existence in eggs, larvae and fry of Indian major carp, *Labeo rohita* (Ham.) (Swain et al. 2006), Offspring fitness and fecundity of an Indian major carp, *Labeo rohita* (Ham.) in relation to egg size (Sehgal and Toor 1991), Parentage analysis using molecular marker in Indian major carp (*Labeo rohita*) (Sahoo et al. 2017), Evaluation of intraspecific genetic variation and relatedness among populations of Indian major carp, Rohu (*L. rohita*) through randomly amplified polymorphic DNA analysis (Islam and

Alam 2004), Effect of long term administration of dietary β-glucan on immunity, growth and survival of *L. rohita* fingerlings (Misra et al. 2006), Dietary zinc requirement of fingerling Indian major carp, *L. rohita* (Hamilton) (Musharraf and Khan 2019a), Dietary iron requirement of fingerling Indian major carp, *L. rohita* (Hamilton) on growth and body composition (Musharraf and Khan 2019b) etc.

2.6 Research gap

From the previously reviewed literatures, it is clear that maternal effects, feeding effects & their interaction play vital roles in selective advanced aquaculture system. Offspring survival rate, fitness, growth, quality, culture cost benefits, and overall production success depend on the proper modulation of these two important factors. Many studies have been conducted at different time on different species to observe these effects particularly.

Many studies have been carried out considering the size effects and consequence of parents as well as larvae and reported that larger body size has many benefits, such as increased reproductive success, ability to evade predators and increased competitive ability and social status (Mehault et al. 2010; Vallin and Nissling 2000; McLennan et al. 2016).

Few studies reviewed maternal impacts. For example, Kamler (2005) reviewed 'Parent–egg–progeny' relationships in teleost fishes and found that the key pathway in the 'parent–egg–progeny' relationship are the positive relations between female size, egg size and larval size, the later resulting in variability of larval resistance to starvation and predation. Both, paternal and maternal factors contribute to total viability, operating at different time and in different ways. Kangassalo et al. (2015) studied the intra- and trans-generational effects of larval diet on immune susceptibility in the greater wax moth, (*Galleria mellonella*) and fount that maternal nutrition affects immune function in insects while paternal effects are not as important as maternal effects in influencing immune function.

Some other studies consider feeding impacts growth, fitness, immunity and other traits of fish larvae (Shan et al. 2008; Takeuchi 2014; Ali et al. 2016; Musharraf and Khan 2019a; Musharraf and Khan 2019b). Besides the others species many studies chose Rohu (*L. rohita*) to observe various impacts like, evolution of genetic variation (Islam and Alam 2004), diet impacts (Misra et al. 2006; Musharraf and Khan 2019a; Musharraf and Khan 2019b), maternal-egg impacts (Sehgal and Toor 1991). Unfortunately, none of these studies verify maternal impacts and offspring diet impacts on offspring survival and fitness considering an important carp species, Rohu. Therefore, the present study will be carried out to assess the interactive effects of maternal size and offspring feeding strategy on a popular carp species, Rohu (*L. rohita*).

2.7 Present study

From the previous discussion, it is clear that parental genetic and feeding regime have significant effects on offspring fitness. But specifically in carp species, very little findings have been identified, demonstrating maternal impacts on interaction with dietary modulation. The present study has generated an interest to investigate the 1) maternal size effect and 2) maternal size, offspring feeding and their interactive effects, using Rohu (*L. rohita*), one of the most important Indian major carp.

Chapter-3

3.0 Materials & Methods

3.1 Broodstock selection and rearing

The sexually mature *L. rohita* were reared in broodstock ponds of a commercial carp hatchery (the South Bay Pvt. Ltd. Hatchery, Khulna, Bangladesh) which maintained the breeding protocols to avoid inbreeding problems. The entire study was carried out with two separate experiments- (1) Experiment-1: maternal size effects and (2) Experiment-2: maternal size, offspring feeding and their interactive effects (hereafter called 'maternal size-by-offspring feeding'). In experiment-1, 20 large sized females (weight range: 1.51-2.53kg and mean±SE: 1.87±0.07kg) and 20 small sized females (weight range: 0.53-1.43kg and mean±SE: 0.97±0.07kg) were sorted out, while six males (weight range: 1.80-3.50kg and mean±SE: 2.31±0.11kg) were selected as 'common males' to fertilize the eggs of both female groups (Experimental design 1 in Fig. 2).

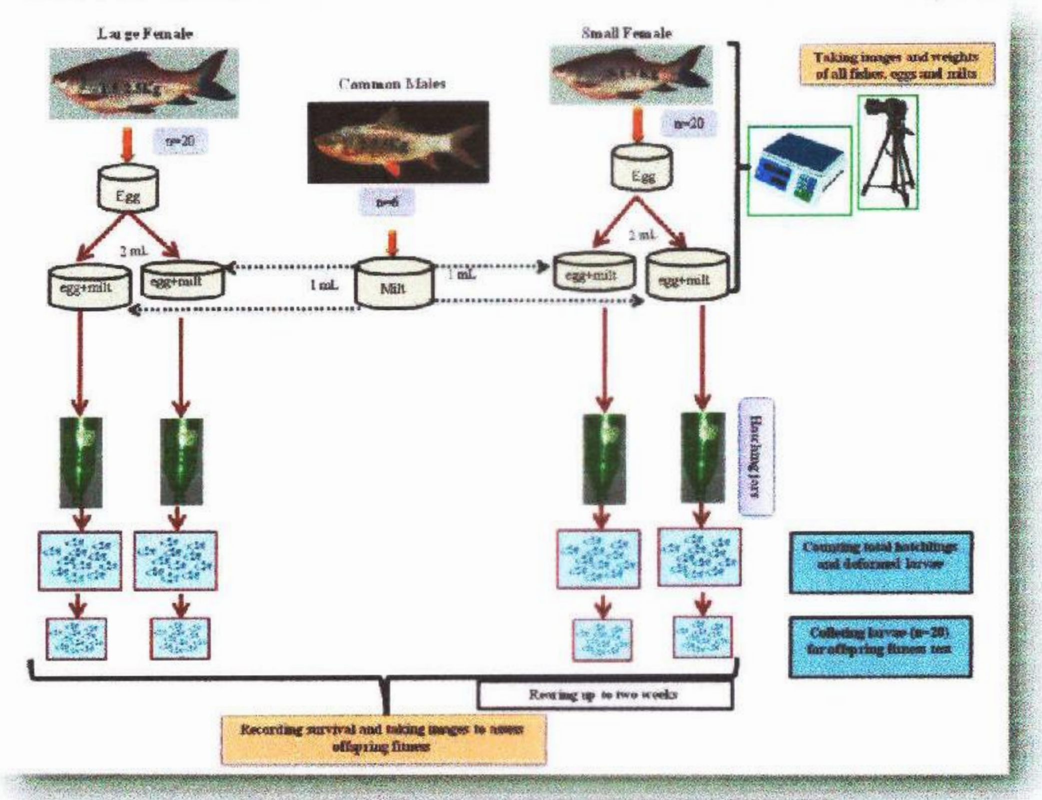

Figure 2: Experimental design 1

In experiment-2, 16 large sized females (weight range: 2.01-2.50kg and mean±SE: 2.23±0.04kg) and 16 small sized females (weight range: 0.80-1.40kg and mean±SE: 1.10±0.05kg) were selected, whereas only four males (weight range: 2.20-2.80kg and mean±SE: 2.40±0.06kg) were selected as 'common males' to fertilize the eggs of both female groups (Experimental design 2 in Fig. 3 and the detailed protocol is given below). The age of all females ranged from 1.5 to 2.5 years, while common males were 2.0-3.0 years old. Finally, these selected males and females were kept experiment-wise separately in large tanks (5000L) up to two days under the same conditions (i.e. feed, water, etc.) before the fertilization process.

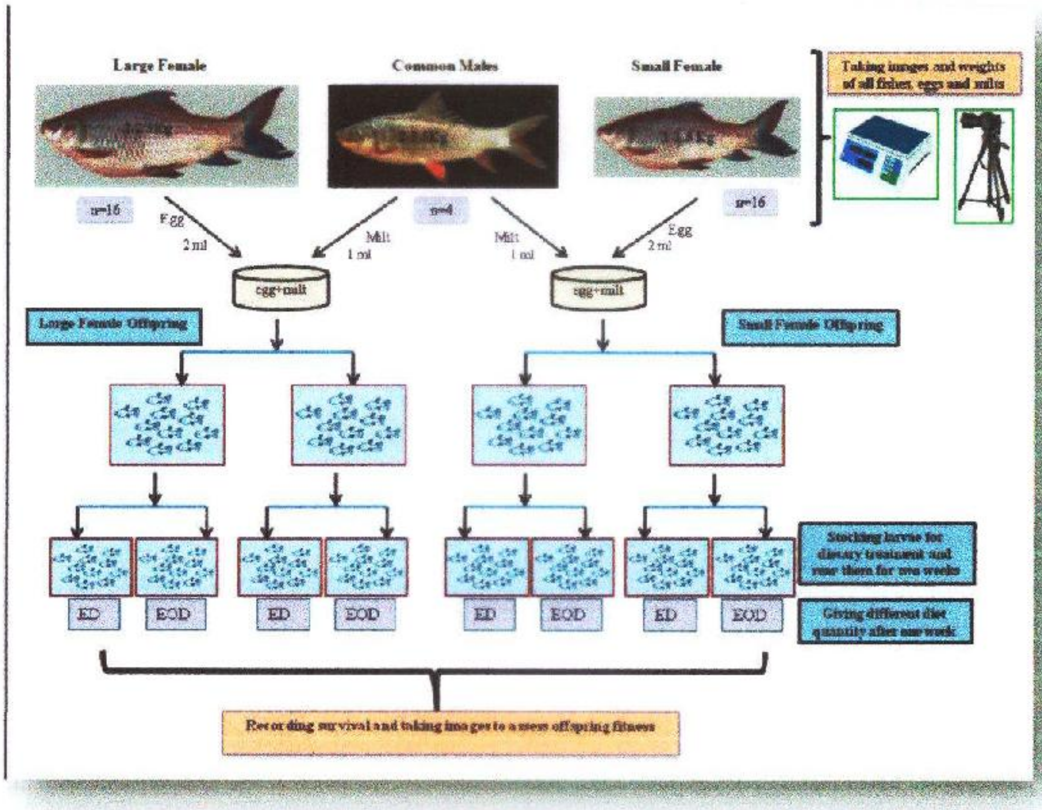

Figure 3: Experimental design 2

3.2 Artificial propagation and fertilization

The artificial propagation technique ('hypophysation') was applied at the base of pectoral fin by using the recommended doses of pituitary glands (PG) (Fig. 4) for induced spawning of Indian major carp (Jhingran and Pullin 1985; Sarder 2007). In brief, females were administered two times at the rate of 1 mg PG/kg body weight for first time and approximately after 6 hours, the second dose was injected at the rate of 6.0 mg PG/kg body weight. The experimental males were administered only a single dose when the females were injected their second dose at the rate of 1 mg PG/kg body weight. Then they could become ready for artificial spawning after another 6 hours.

Figure 4: Administering the recommended dose of PG

3.3 Measurements of parental phenotypic traits

After collecting sperm and eggs from each male and female, individual's photograph along with their ID was taken with a digital camera (Canon DS126621). Then standard length (distance in cm from tip of the snout to the posterior end of the last vertebra) (Fig. 5) and body area (area covered from tip of the snout to the last mark of caudal peduncle in cm2) (Fig. 6) were measured from the digital photographs taken of each fish, using *ImageJ* software (http://rsbweb.nih.gov/ij/). Meanwhile, weight of individual fish was recorded using a digital balance.

Figure 5: Measuring standard length from the digital photograph using *ImageJ*

Figure 6: Measuring body area from the digital photograph using *ImageJ*

3.4 Experimental procedure

The ejected gametes were collected by hand stripping in clean and dry bowls (Fig. 7 & Fig. 8), and immediately weights of total milt and eggs were measured in digital weight machine (Fig. 9 & Fig. 10) and recorded. Then they were stirred well to have random samples from which exactly 1 mL of milt was collected from a common male's pooled milt with individual new syringe and mixed with 2 mL of eggs (collected with a marked new syringe) of individual female (Fig. 11). Thus, eggs from two to four females from each group were mixed with the milt of a common male. The milt was properly mixed with the eggs by adding water and continuous stirring with a clean chicken's feather (Fig. 12). Then the fertilized egg masses were transferred to previously labeled plastic containers (2 L), (Fig. 13) fitted with continuous aerated water flow and kept for incubation up to 36-40 hours at ambient temperature (28-30°C) until the maximum hatching occurred. Meanwhile, the average total number of eggs per 1 mL were counted, while images of 20 eggs were captured under a microscope (LABOMED, Lx 400) mounted with camera to measure the diameter and area of eggs latter using the *ImageJ* software v-1.46 (https://imagej.nih.gov/ij/download.html). During this spawning trail, there were two replications of each female. The whole study was carried out during the first natural spawning cycle to ensure maximum quantity and good quality of gametes (Kucharczyk et al. 2008; Chattopadhyay 2016). Moreover, all collected samples were quickly checked to ensure good quality through visual inspection (Chatakondi 2012; Cogliati et al. 2018).

Figure 7: Egg stripping

Figure 8: Sperm stripping

Figure 9: Egg measurement

Figure 10: Sperm measurement

Figure 11: Addition of sperm and egg

Figure 12: Mixing

Figure 13: Placement in incubation jar

3.5 Offspring rearing and traits measurement

After confirmation of the maximum hatching, the total content of each incubator (i.e. alive and dead hatchlings, unfertilized eggs, etc.) was transported to the 'Wet laboratory' (6 km distance) of the Fisheries and Marine Resource Technology Discipline of Khulna University, Bangladesh. The transportation was done very carefully using the plastic bags filled with the required amount of water and aeration which were carried to the destination by the auto-rickshaws to avoid any travel stress to the offspring. The total number of alive hatchlings in each incubator was counted and reared them maternal family-wise up to three days to start gradually exogenous feeding.

After three days of rearing, the total number of alive and deformed hatchlings was counted and recorded (Fig. 14).

Figure 14: Hatchlings counting

Then 30 good looking offspring (visually had no deformation and active swimmers) were sorted and stocked family-wise in a glass aquarium (50cm×29cm×30cm) (Fig. 15) up to two weeks for the assessment of offspring fitness. In experiment-2, offspring were further randomly assigned to two feeding treatment groups for two weeks, such as 1) everyday feeding (hereafter called 'ED') and 2) every other day feeding (hereafter called 'EOD'). Thus, the design of experiment-2 was able to test not only the effect of offspring feeding level (i.e. 'ED' and 'EOD') but also their interaction with maternal size group (i.e. 'large' and 'small'). During the study, water quality parameters (e.g. dissolved oxygen, temperature and pH) were monitored daily. All offspring were fed *ad libitum* up to the apparent satiation level twice in both feeding groups at 09.00 and 17.00 hours (Khan et al. 2004; Mohapatra et al. 2012). At the end of experiment, offspring number was counted to determine their survival rate and then photograph of each anaesthetized (ice bathed) offspring was taken using a digital camera (Canon DS126621) to measure total length and body area with the *ImageJ* software (Fig. 16 & Fig. 17). The study was conducted up to this larval stage as most of the farmers prefer either three days old hatchling for fingerling business purpose or one/two-week old offspring for production purpose (personal communication).

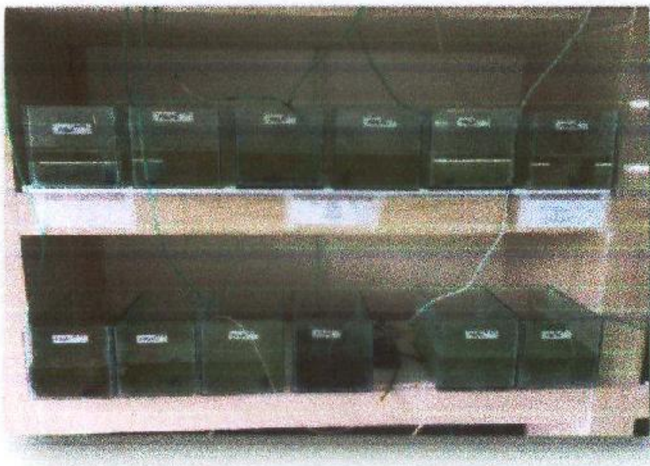

Figure 15: Stocking in glass aquarium

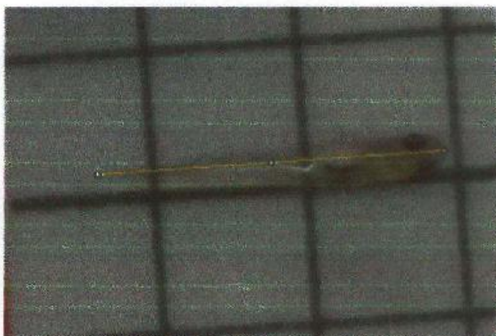

Figure 16: Length measurement

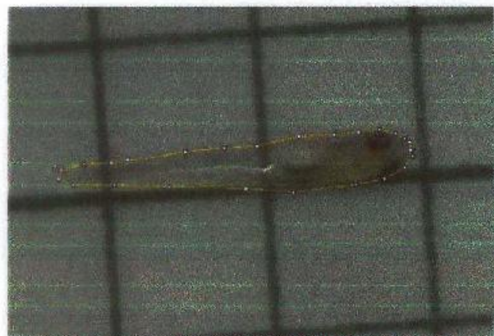

Figure 17: Body area measurement

3.6 Statistical analyses

All analyses were performed using 'R' version 3.5.2 (R Development Core Team 2018). The descriptive statistics (means, SD, SEs, etc.) were calculated using the 'psych' package. The Shapiro-Wilk test of normality and the Levene's tests for homogeneity of variance were done with the 'onewaytests' package.

The univariate analysis of variance (ANOVA) model was performed using the 'car' package to find out any variation in traits, whereas the default Kruskal-Wallis (K-W) test was applied to those traits which were not normally distributed by any transformation but homogenous. The generalized linear model (GLM) with 'quasi-poisson' family option was applied using 'pscl' package for the 'percentage data' (hatching, deformation and survival rates) which did not comply with the assumptions of any parametric model. The 'quasi-poisson' regression is not only flexible with data assumptions but also allows for over-dispersion in the dependent variable (Mangiafico 2016). To avoid pitfalls of significance testing (the *P*-value) and also to quantify the magnitude of effects, the effect size was calculated (Cohen 1988) based on the appropriate statistical significance tests. Thus, Cohen's effect size (*d*) was estimated for ANOVA model (Lakens 2013), Epsilon square (ε^2) was calculated for K-W test (Levine and Hullett 2002) and coefficient of determination (r^2) was estimated for GLM (Nakagawa et al. 2017). The correlations among variables were tested and plotted using "Performance Analytics" package to explore any trade-offs. Finally, all graphs were made using 'ggplot2' package.

Chapter-4

4.0 Results

4.1 Experiment-1: maternal size effect

The initial analysis revealed no variation in body weight (K-W: $\chi^2=0$ and $P=1$) and average milt weight (K-W: $\chi^2=0$ and $P=1$) of the common males used in this experiment which also confirmed no effect of common male on any measured trait. On the other hand, females' body weight (ANOVA: $F_{1,38}=86.63$ and $P<0.001$) and standard length (ANOVA: $F_{1,38}=29.58$ and $P<0.001$) were significantly different between two groups. Thus, it was confirmed that the maternal body size might have some effects on reproductive outputs during the hatchery production.

The analyses revealed that the average egg weight, hatching rate, offspring total length and body area were significantly higher, while hatchling deformation rate was significantly lower in larger females than the smaller females (Table 1). The findings also showed no significant variations in number, diameter and area of eggs, and survival rate of offspring (Table 1).

Table 1 Variation among different reproductive traits of *Labeo rohita* due to the difference in maternal body size. Significant values are denoted as Italic and bold.

Response traits	Maternal size group (mean±SE)		Stat-value	*P*	Effect size	Statistical model
	Large	Small				
Average egg weight (g)	222.57±26.25	152.63±14.27	5.48	***0.02***	$d = 0.74$	ANOVA
Average egg number/g	344.20±16.92	337.25±18.97	0.09	0.75	$d = 0.09$	ANOVA
Average egg diameter (mm)	1.01±0.01	0.99±0.01	0.76	0.38	$d = 0.27$	ANOVA
Average egg area (mm^2)	0.80±0.02	0.80±0.04	0.002	0.96	$d = 0.01$	ANOVA
Hatching rate (%)	76.97±2.73	65.91±4.04	4.98	***0.02***	$r^2 = 0.12$	GLM
Hatchling deformation rate (%)	4.02±0.78	7.51±1.49	4.81	***0.02***	$r^2 = 0.11$	GLM
Offspring survival rate (%)	29.33±1.56	26.42±0.9	2.70	0.10	$r^2 = 0.06$	GLM
Offspring total length (mm)	11.25±0.20	10.37±0.11	10.63	***0.001***	$\varepsilon^2 = 0.27$	K-W
Offspring body area (mm^2)	16.79±0.38	15.34±0.25	10.07	***0.001***	$d = 1.00$	ANOVA

4.2 Experiment-2: maternal size-by-offspring feeding effects

Like experiment-1, the initial analysis confirmed no variation in body weight (K-W: χ^2=0.49 and P=0.92) and average milt weight (K-W: χ^2=0.05 and P=0.99) of the common males used in this experiment and thereby ensured no effect of common male on any measured offspring fitness. Logically, the females selected as the larger group had significantly higher body weight (K-W: χ^2=23.55 and P<0.001) than smaller sized group which gave a notion about the possible effect of maternal body size on some offspring traits.

The findings revealed that the offspring survival rate was not significantly influenced by maternal body size (GLM: χ^2=0.88, P=0.35 and Fig. 18a) and maternal size-by-offspring feeding (GLM: χ^2=0.001 and P=0.97), while the feeding trial showed that ED reared offspring had significantly higher survival rate than those of EOD group (GLM: χ^2=8.56, P=0.003, r^2=0.21 and Fig. 19a).

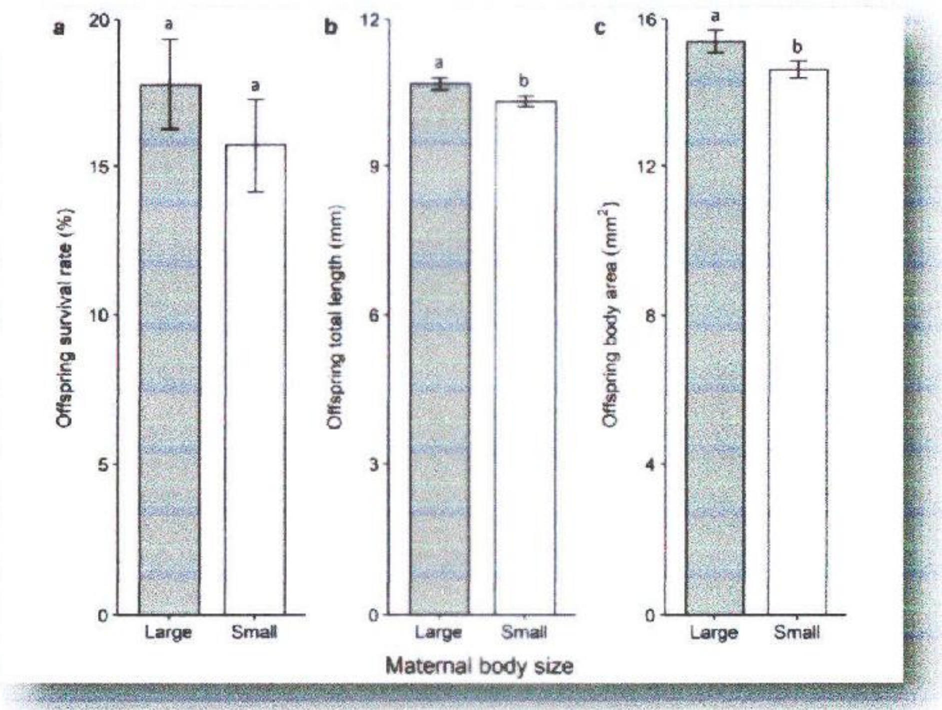

Figure 18: Maternal body size effects on offspring

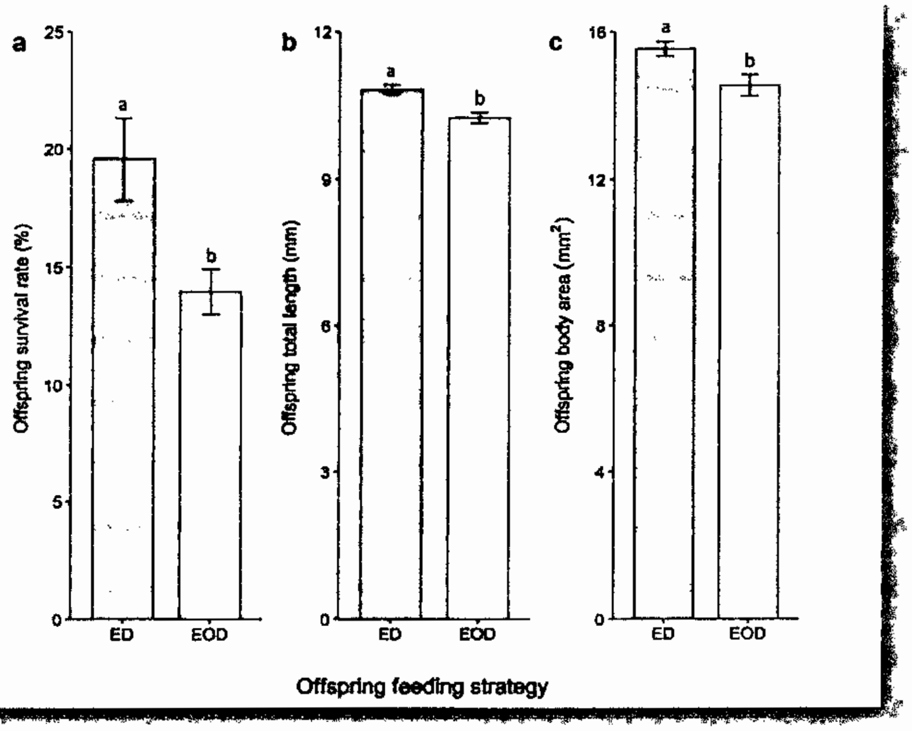

Figure 19: Offspring feeding strategy effects on offspring

The offspring total length was found significantly bigger which was spawned by the larger females than the smaller mother's group (ANOVA: $F_{1,30}$=4.78, *P*=0.03, *d*=0.77 and Fig. 18b). The offspring total length was also found significantly larger when they were assigned to ED feeding group rather than the EOD treatment (ANOVA: $F_{1,30}$=14.96, *P*<0.001, *d*=1.36 and Fig. 19b). The experiment showed no significant effect of the maternal size-by-offspring feeding (ANOVA: $F_{1,30}$=0.04 and *P*=0.85).

The experiment also found that offspring body area was significantly greater in larger female group than the smaller female group (ANOVA: $F_{1,30}$=4.13, *P*=0.05, *d*=0.72 and Fig. 18c), while offspring of ED group had significantly larger body area than EOD group (ANOVA: $F_{1,30}$=8.17, *P*=0.007, *d*=1.01 and Fig. 19c). Consistent with the offspring total length, no interactive effect of maternal size-by-offspring feeding was found on offspring body area (ANOVA: $F_{1,30}$=0.06 and *P*=0.80).

Chapter-5

5.0 Discussion

5.1 Maternal size effect

L. rohita is the topmost freshwater aquaculture species in India, Bangladesh, Myanmar, Nepal and Pakistan which culture and production mostly depend on hatchery produced larvae. Many of the hatcheries do not maintain broodstocks quality especially size selective breeding strategy which has a great impact on gamete quality (Johnston et al. 2007; Hixon et al. 2014; Barneche et al. 2018) and offspring fitness (Johnson et al. 2011; Kindsvater et al. 2013; Falica et al. 2017).

The present study revealed that larger females produced significantly higher amount of eggs and hatchlings which also showed better offspring fitness. In European hake (*Merluccius merluccius*), the fecundity and egg diameter were found positively significantly correlated with the female size (Mehault et al. 2010). Vallin and Nissling (2000) showed that larger females of cod (*Gadus morhua*) produced greater sized and better quality eggs than smaller females. In a meta-analysis with the data of 342 marine fish, Barneche et al. (2018) revealed that fecundity, volume and energy content of eggs were disproportionately higher in larger mothers than smaller mothers. In the present study, average egg weight and hatching rate were significantly positively correlated with the maternal body size (Fig. 20) which corroborates the findings of the above-mentioned studies.

The present study also revealed that offspring survival rate (although not significant through ANOVA analysis) and size were significantly positively correlated, while deformation rate was negatively correlated with maternal size (Fig. 20). However, the correlation outcomes did not show any trade-off between traits. The findings of positive associations between traits are consistent with other studies., such as Kindsvater et al. (2013) found that older and larger females produced significantly larger offspring than the younger and smaller females in swordtail (*Xiphophorus birchmanni*), whereas Falica et al. (2017) disclosed with a quantitative genetic study in Chinook salmon (*Oncorhynchus tshawytscha*) that maternal size and non-additive effects were the most important influencing factors for larval size which could explain a total of 87% of total larval phenotypic variation. In another study, Sogard et al. (2008) explored that older and larger females in five species of rockfish (*Sebastes* spp.) produced disproportionately more larvae per unit biomass with higher quality (size and condition) than younger and smaller females.

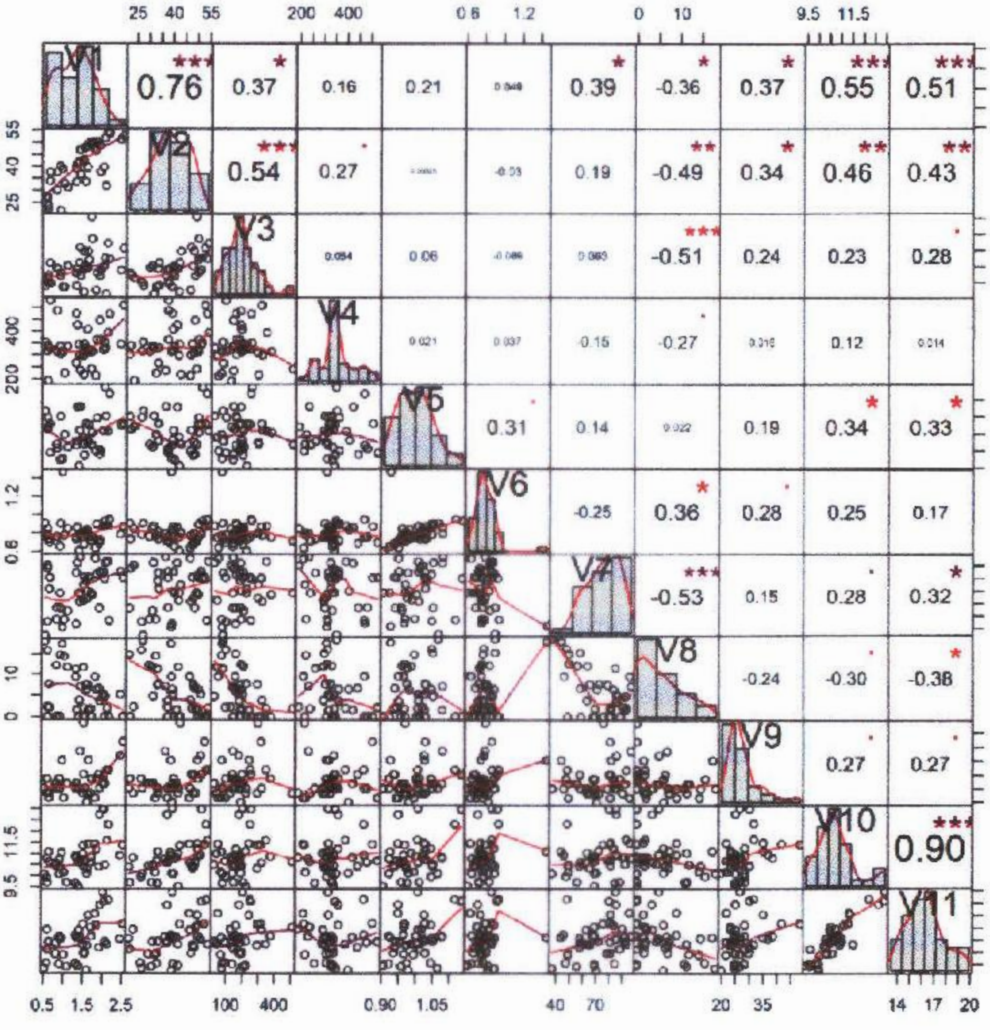

Figure 20: Maternal size effect

The possible reasons of better performances of larger females have been suggested by different studies which could be the variation of females size-dependent reproductive resources (Hagmayer et al. 2018), their energy allocation strategy (Barneche et al. 2018) and trade-offs (Brosset et al. 2016), environmental variability (Jørgensen et al. 2011; Faria et al. 2018), etc. For instance, larger females normally possess greater reproductive resources and therefore, normally produce higher quantity and quality of eggs (Hixon et al. 2014). A recent meta-analysis with 342 marine fish confirmed that larger mothers invested disproportionately more energy to enhance the number and size of eggs (Barneche et al. 2018). Since reproduction is an energetically expensive event in life, small females may obtain benefit by trading off the energy allocation between maintenance (i.e. growth) and reproduction (Brosset et al. 2016). For example, small females of pipefish (*Syngnathus typhle*) allocated more energy for growth rather than fecundity (Berglund 1991), while larger females of eastern mosquito fish (*Gambusia holbrooki*) invested more energy for higher fecundity trading off with offspring size (O'Dea et al. 2015). Further evidence showed that environmental factors such as stressors or stimulators could significantly influence females to manipulate reproductive outcomes in many fishes (Izquierdo et al. 2001; Faria et al. 2018). To avoid any confounding effect of environmental variability during this present study, all females were reared almost under same conditions. However, the higher reproductive performances of larger females of experimental *L. rohita* in the present study might be due to their higher physiological resources, reproductive target-oriented energy investment or hidden energy allocation trade-offs by the smaller females.

5.2 Offspring feeding effect

It has been well documented that quantity and quality of feed can significantly affect growth, behavior, immunity and other traits of fish larvae (Shan et al. 2008; Takeuchi 2014; Navarro-Guillén et al. 2017). Since larval feeding cost is one of the major expenses in hatchery and nursery production systems, farmers try to minimize this cost by adopting different strategies. Feed deprivation is one of the common feeding techniques that was also suggested by some aquaculture scientists to minimize fish feeding cost (Urbinati et al. 2014; Ali et al. 2016). In the present study, offspring of ED feeding group showed significantly better growth performance than those reared in EOD treatment and this finding is in accordance with some other studies. For example, Ali et al. (2016) demonstrated that feeding Nile tilapia (*Oreochromis niloticus*) everyday provided higher final body weight, weight gain and specific growth rate than those of feed deprivation at weekends during the 26 days experiment. In another study, Okumus and Bascinar (2001) found that daily fed juveniles of rainbow trout (*O. mykiss*) obtained the highest final body weight and better condition factor than those fed five days in a week and every other day.

Some studies of compensatory growth research recommended for a short-term periodic feed deprivation which could help the temporarily starved fish to improve digestive capacity and coping with oxidative stress, but this short-term starvation also inhibited the lipid synthesis which might affect severely to uptake nutrients and energy after subsequent feeding (Yengkokpam et al. 2013; Urbinati et al. 2014). Perhaps the EOD feeding strategy at the very early stage in the present study might cause severe stress to the offspring which could reduce significantly metabolic activities and failed to uptake required nutrients and energy for traits development. To notice this stressful feeding strategy, Yengkokpam et al. (2013) reported that feed deprivation of *L. rohita* fingerlings beyond two days per week could cause severe stress which might reduce metabolic activities and adversely affected growth and health.

5.3 Maternal size-by-offspring feeding effects

The present study revealed no significant interactive effect of maternal size and offspring feeding on any offspring trait. Thus, the findings clearly showed that maternal condition and offspring feeding strategy were the most influential factors. The non-significant interactive effect indicated no genotype-by-environment effect (Falconer and Mackay 1996) which revealed no significantly better fitness of larger mother produced offspring reared in EOD treatment than the offspring of smaller mother kept in ED group or vice versa (Figs. 21a, b and c). However, a recent study revealed the maternal size-by-offspring feeding effect on female age and male size at maturity, and these interactions were apparent even though the offspring were fed with a restricted amount of diet (Vega-Trejo et al. 2018). Whilst a very limited study was conducted with fish regarding this interesting issue, evidence with other aquatic organisms provided the information about interactive effects of parental condition-by-offspring environment (Mitchell and Read 2005; Luquet and Tariel 2016).

The plausible explanation of having no interactive effects in this present study could be because of very strong maternal and environmental impacts which might not compromise with any change in rearing environment (feeding). Therefore, the relative variation in all offspring traits was occurred only because of highly significant influence of maternal size and offspring feeding strategy separately (Figs. 21a, b and c). These findings suggest that larger females' influence on offspring fitness was deemed because of feed deprivation, while everyday feeding to offspring of smaller females also failed to express their traits normally due to a very strong maternal effect. This non interactive outcome implies an important message to the stakeholders to be very careful about maternal size as well as proper offspring feeding during their breeding and spawning programs.

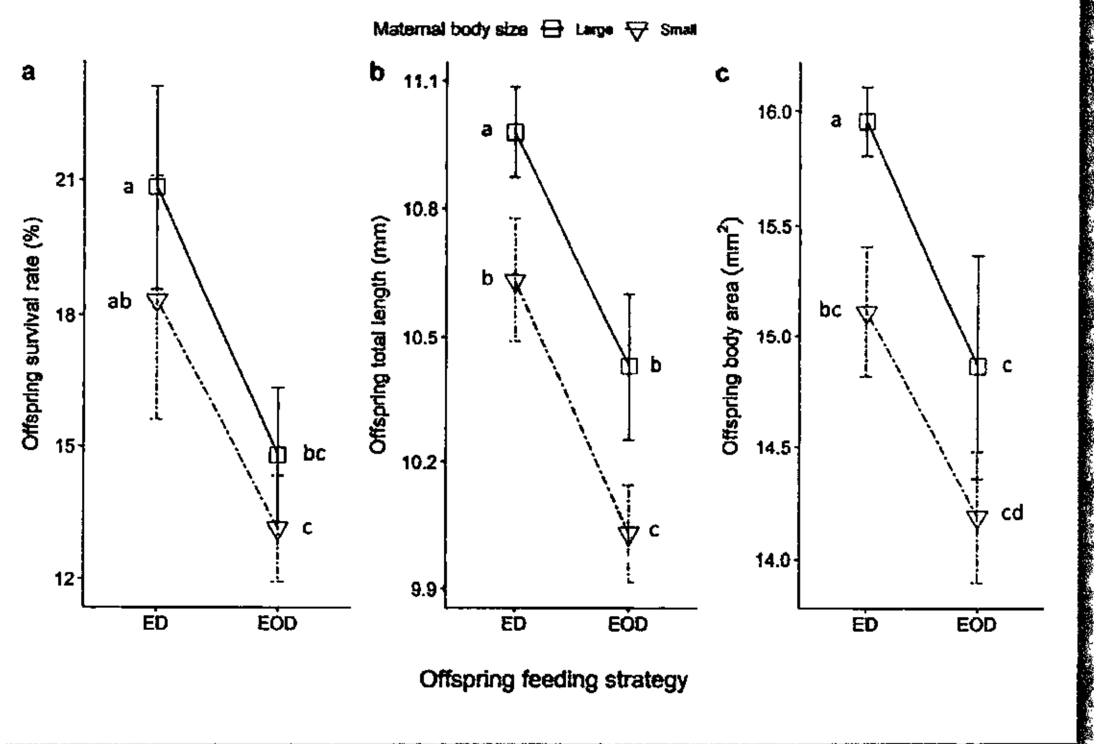

Figure 21: Maternal size-by-offspring feeding effects

Chapter-6

6.0 Conclusion

Parental (maternal and paternal) phenotypic traits (genetic factors) and environmental condition (non-genetic factors) have considerable importance that directly affect the phenotypic traits of offspring and susceptible to produce more viable phenotypic variation. The present study has been conducted to explore the (1)'maternal size' and (2)'maternal size-by-offspring feeding' effects on Rohu (*L. rohita*), an important Indian major carp, considering spawning performance (hatching rate, survival rate) and offspring fitness (total length, body area). The result has revealed (1) significant maternal effects (size) on hatching rate, fitness (total length & body area), egg weight; while large mother have higher positive impacts than small sized mother and (2) significant positive feeding impacts on survival rate and fitness, where ED (everyday feeding) offspring group were more fit than EOD (every alternative day) offspring group. But findings were insignificant in case of some other selected factors such as "maternal size-by-offspring" feeding has no significant interactive effects on offspring fitness and survival rate. Maternal size also revealed no significant effects on survival rate.

However, the overall results provide a manifestation of benefits for 'larger female' and 'everyday feeding' and provide a suggestion to the commercial carp hatchery manager and farmers to ensure mature brood and good feeding opportunity for sustainable production of this species. Finally, to have more confirmation about this issue and to explore more significance variation, still some further research is required to be carried out based on their mating tactics for higher reproductive success and thereby, good offspring production in some other commercially important fish species.

Chapter-7

7.0 Reference

Abidi SF, Khan MA (2010) Dietary tryptophan requirement of fingerling Indian major carp, *Labeo rohita* (Hamilton). J World Aquacult Soc 41:700–709.

Abidi SF, Khan MA (2011) Total sulphur amino acids requirement and cystine replacement value for fingerling rohu,. *Labeo rohita*: effects on growth, nutrient retention and body composition. Aquac Nutr 17:583–594. doi: 10.1111/j.1365-2095.2010.00799.x

Ali TES, Martínez-Llorens S, Moñino AV, Cerda MJ, Tomás-Vidal A (2016) Effects of weekly feeding frequency and previous ration restriction on the compensatory growth and body composition of Nile tilapia fingerlings. Egypt J Aquat Res 42:357–363. doi: 10.1016/j.ejar.2016.06.004

Arlinghaus R, Matsumura S, Dieckmann U (2010) The conservation and fishery benefits of protecting large pike (*Esox lucius* L.) by harvest regulations in recreational fishing. Biol Conserv 143:1444-1459. doi: 10.1016/j.biocon.2010.03.020

Balfry SK, Heath DD, Iwama GK (1997) Genetic analysis of lysozyme activity and resistance to vibriosis in farmed Chinook salmon, *Oncorhynchus tshawytscha* (Walbaum). Aquac Res 28:893–899. doi: 10.1046/j.1365-2109.1997.00920.x

Bang A, Gronkjær P, Clemmesen C, Hoie H (2006) Parental effects on early life history traits of Atlantic herring (*Clupea harengus* L.) larvae. J Exp Mar Biol Ecol 334:51–63. doi: 10.1016/j.jembe.2006.01.003

Barneche DR, Robertson DR, White CR, Marshall DJ (2018) Fish reproductive-energy output increases disproportionately with body size. Science 360:642–645. doi: 10.1126/science.aao6868

Berejikian BA, VanDoornik DM, Atkins JJ (2011) Alternative male reproductive phenotypes affect offspring growth rates in Chinook salmon. Trans Am Fish Soc 140:1206-1212. doi: 10.1080/00028487.2011.618351

Berg OK, Hendry AP, Svendsen B, Bech C, Arnekleiv JV, Lohrmann A (2001) Maternal provisioning of offspring and the use of those resources during ontogeny: variation within and between Atlantic Salmon families. Funct Ecol 15:13–23. doi: 10.1046/j.1365-2435.2001.00473.x

Berglund A (1991) Egg competition in a sex-role reversed pipefish: Subdominant females trade reproduction for growth. Evolution 45:770–774. doi: 10.1111/j.1558-5646.1991.tb04346.x

Birkeland C, Dayton PK (2005) The importance in fishery management of leaving the big ones. Trends Ecol Evol 20:356-358. doi: 10.1016/j.tree.2005.03.015

Bobe J, Labbé C (2010) Egg and sperm quality in fish. Gen Comp Endocrinol 165:535–548. doi: 10.1016/j.ygcen.2009.02.011

Bonduriansky R, Day T (2009) Nongenetic inheritance and its evolutionary implications. Annu Rev Ecol Evol Syst 40:103–125. doi: 10.1146/annurev.ecolsys.39.110707.173441

Bonduriansky R, Head M (2007) Maternal and paternal condition effects on offspring phenotype in *Telostylinus angusticollis* (Diptera: Neriidae). J Evol Biol 20:2379-2388. doi: 10.1111/j.1420-9101.2007.01419.x

Brooks S, Tyler CR, Sumpter JP (1997) Egg quality in fish: what makes a good egg? Rev Fish Biol Fisher 7:387–416. doi: 10.1023/A:1018400130692

Brosset P, Lloret J, Muñoz M, Fauvel C, Van Beveren E, Marques V, Fromentin JM, Ménard F, Saraux C (2016) Body reserves mediate trade-offs between life-history traits: New insights from small pelagic fish reproduction. R Soc Open Sci 3:160202. doi: 10.1098/rsos.160202

Butts IAE, Litvak MK (2007) Parental and stock effects on larval growth and survival to metamorphosis in winter flounder (*Pseudopleuronectes americanus*). Aquaculture 269:339-348. doi: 10.1016/j.aquaculture.2007.04.012

Cahu C, Infante ZJ (2001) Substitution of live food by formulated diets in marine fish larvae. Aquaculture 200:161–180. doi: 10.1016/S0044-8486(01)00699-8

Chambers RC, Leggett WC (1996) Maternal influences on variation in egg sizes in temperate marine fishes. Am Zool 36:180–196. doi: 10.1093/icb/36.2.180

Chatakondi NG (2012) Evaluating hybrid catfish egg quality. Global Aquaculture Advocate. In: Global Aquaculture Advocate, p. 5. Retrieved from:

https://www.aquaculturealliance.org/advocate/evaluating-hybrid-catfish-egg-quality/. Accessed 21 October 2019

Chattopadhyay NR (2016) Reproductive cycle, maturation, and spawning: A practical guide for hatcheries. In: Chattopadhyay NR (ed) Induced fish breeding. Elsevier, pp 15–42.

Cogliati KM, Unrein JR, Stewart HA, Schreck CB, Noakes DL (2018) Egg size and emergence timing affect morphology and behavior in juvenile Chinook Salmon, *Oncorhynchus tshawytscha*. Ecol Evol 8:778–789. doi: 10.1002/ece3.3670

Cohen J (1988) Statistical power analysis for the behavioral sciences, 2nd edn. Lawrence Earlbaum Associates, Hillsdale, NJ.

Coyle SD, Mengel GJ, Tidwell JH, Webster CD (2004) Evaluation of growth, feed utilization, and economics of hybrid tilapia, *Oreochromis niloticus* x *Oreochromis aureus*, fed diets containing different protein sources in combination with distillers dried grains with solubles. Aquac Res 35:365–370. doi: 10.1111/j.1365-2109.2004.01023.x

Das PC, Kamble SP, Velmurugan P, Pradhan D (2019) Evaluation of minor carps intercropping in carp polyculture vis-à-vis other grow-out cropping patterns of carp farming. Aquac Res 50:1574–1584. doi: 10.1111/are.14034

Davis TS, Landolt PJ (2012) Body size phenotypes are heritable and mediate fecundity but not fitness in the lepidopteran frugivore *Cydia pomonella*. Naturwissenschften 99:483–491. doi: 10.1007/s00114-012-0923-3

Devigili A, Kelley JL, Pilastro A, Evans JP (2012) Expression of pre- and postcopulatory traits under different dietary conditions in guppies. Behav Ecol 24:740-749. doi: 10.1093/beheco/ars204

Dey A, Sarma K, Kumar U, Mohanty S, Kumar T, Bhatt BP (2019) Prospects of rice-fish farming system for low lying areas in Bihar, India. Org Agric 9:99–106. doi: 10.1007/s13165-017-0204-8

Duarte CM, Alcaraz M (1989) To produce many small or few large eggs: A size-independent reproductive tactic of fish. Oecologia 80:401–404. doi: 10.1007/BF00379043

Einum S (2003) Atlantic salmon growth in strongly food-limited environments: effects of egg size and paternal phenotype. Environ Biol Fishes 67:263–268. doi: 10.1023/A:1025818627731

Einum S, Fleming IA (1999) Maternal effects of egg size in brown trout (*Salmo trutta*): norms of reaction to environmental quality. Proc R Soc B 266:2095–2100. doi: 10.1098/rspb.1999.0893

Evans JP, Kelley JL, Bisazza A, Finazzo E, Pilastro A (2004) Sire attractiveness influences offspring performance in guppies. Proc R Soc Lond Biol 271:2035–2042. doi: 10.1098/rspb.2004.2815

Evans ML, Neff BD (2009) Non-additive genetic effects contribute to larval spinal deformity in two populations of Chinook salmon (*Oncorhynchus tshawytscha*). Aquaculture 296:169–173. doi: 10.1016/j.aquaculture.2009.08.018

Evans ML, Neff BD, Heath DD (2010) Quantitative genetic and translocation experiments reveal genotype-by-environment effects on juvenile life-history traits in two populations of Chinook salmon (*Oncorhynchus tshawytscha*). J Evol Biol 23:687–698. doi: 10.1111/j.1420-9101.2010.01934.x

Falconer DS, Mackay TFC (1996) Introduction to quantitative genetics. Longman, Harlow, UK.

Falica BK, Higgs DM (2013) Paternal genetic effects on offspring swimming performance vary with age of juvenile Chinook salmon, *Oncorhynchus tshawytscha*. Evol Biol 40:355-365. doi: 10.1007/s11692-012-9217-0

Falica BK, Lehnert SJ, Pitcher TE, Heath DD, Higgs DM (2017) Ontogentic shifts in genetic and maternal effects on length and survival in Chinook salmon (*Oncorhynchus tshawytscha*). Aquaculture 468:218–225. doi: 10.1016/j.aquaculture.2016.10.003

FAO (2019) Fishery and Aquaculture Statistics (Ed.), Global Production by Production Source 1950–2017 (FishstatJ), FAO Fisheries and Aquaculture Department (online) (2019) Rome. Updated 2019 www.fao.org/fishery/statistics/software/fishstatj/en. Accessed 25 October 2019

Faria AM, Lopes AF, Silva CSE, Novais SC, Lemos MF, Gonçalves EJ (2018) Reproductive trade-offs in a temperate reef fish under high pCO2 levels. Mar Environ Res 137:8–15.

doi: 10.1016/j.marenvres.2018.02.027

Fox CW, Bush ML, Wallin WG (2003) Maternal age affects offspring lifespan of the seed beetle, *Callosobruchus maculatus*. Funct Ecol 17:811-820. doi: 10.1111/j.1365-2435.2003.00799.x

Fox CW, Czesak ME (2000) Evolutionary ecology of progeny size in arthropods. Annu Rev Entomol 45:341–369. doi: 10.1146/annurev.ento.45.1.341

Freeman-Gallant CR (1998) Fitness consequences of male parental care in Savannah sparrows. Behav Eco l9:486–492. doi: 10.1093/beheco/9.5.486

Garrido S, Ben-Hamadou R, Santos AMP, Ferreira S, Teodósio MA, Cotano U, Irigoien X, Peck MA, Saiz E, Ré P (2015) Born small, die young: Intrinsic, size-selective mortality in marine larval fish. Sci Rep 5:17065. doi: 10.1038/srep17065

Giesing ER, Suski CD, Warner RE, Bell AM (2011) Female sticklebacks transfer information via eggs: Effects of maternal experience with predators on offspring. Proc R Soc B Biol Sci 278:1753–1759. doi: 10.1098/rspb.2010.1819

Gruebler MU, Naef-Daenzer B (2010) Survival benefits of post-fledging care: Experimental approach to a critical part of avian reproductive strategies. J Anim Eco 79:334–341. doi: 10.1111/j.1365-2656.2009.01650.x

Hagmayer A, Furness AI, Reznick DN, Pollux BJA (2018) Maternal size and body condition predict the amount of post fertilization maternal provisioning in matrotrophic fish. Ecol Evol 8:12386-12396. doi: 10.1002/ece3.4542

Heath DD, Blouw DM (1998) Are maternal effects in fish adaptive or merely physiological side effects? In: Maternal Effects as Adaptations, p. 178–201. New York, NY: Oxford University Press.

Heath DD, Fox CW, Heath JW (1999) Maternal effects on offspring size: variation through early development of Chinook salmon. Evolution 53:1605–1611. doi: 10.1111/j.1558-5646.1999.tb05424.x

Hixon MA, Johnson DW, Sogard SM (2014) BOFFFFs: On the importance of conserving old-growth age structure in fishery populations. ICES J Mar Sci 71:2171–2185. doi: 10.1093/icesjms/fst200

Hossain MA, Islam MS (2006) Optimization of stocking density of freshwater prawn *Macrobrachium rosenbergii* (de Man) in carp polyculture in Bangladesh. Aquac Res 37:994–1000. doi: 10.1111/j.1365-2109.2006.01518.x

Hutchings JA (1991) Fitness consequences of variation in egg size and food abundance in brook trout *Salvelinus fontinalis*. Evolution 45:1162–1168. doi: 10.1111/j.1558-5646.1991.tb04382.x

Huuskonen H, Haakana H, KEKÄLÄINEN J (2009) Offspring performance is linked to parental identity and male breeding ornamentation in whitefish. Biol J Linn Soc 98:532-539. doi: 10.1111/j.1095-8312.2009.01315.x

Islam MS, Alam MS (2004) Randomly amplified polymorphic DNA analysis of four different populations of the Indian major carp, *Labeo rohita* (Hamilton). J Appl Ichthyol 20:407-412. doi: 10.1111/j.1439-0426.2004.00588.x

Iyengar VK, Eisner T (1999) Heritability of body mass, a sexually selected trait, in an arctiid moth (*Utetheisa ornatrix*). Proc Natl Acad Sci USA 96:9169–9171. doi: 10.1073/pnas.96.16.9169

Izquierdo MS, Fernández-Palacios H, Tacon AGJ (2001) Effect of broodstock nutrition on reproductive performance of fish. Aquaculture 197:25–42. doi: 10.1016/S0044-8486(01)00581-6

Jablonka E, Raz G (2009) Transgenerational epigenetic inheritance: prevalence, mechanisms, and implications for the study of heredity and evolution. Q Rev Biol 84:131–176. doi: 10.1086/598822

Jana BB, Nandy S, Lahiri S, Bag SK, Ghosh P, Bhakta JN, Ghosh D, Biswas JK, Bhattacharjee A, Jana S (2019) Does solar heated structure mimicking greenhouse effective to impede winter growth reduction of some tropical fishes? Aquaculture 499:51–60. doi: 10.1016/j.aquaculture.2018.09.017

Janhunen M, Peuhkuri N, Primmer CR, Kolari I, Piironen J (2011) Does breeding ornamentation signal genetic quality in arctic charr, *Salvelinus alpinus*? Evol Biol 38:68–78. doi: 10.1007/s11692-010-9100-9

Janhunen M, Piironen J, Peuhkuri N (2010) Parental effects on embryonic viability and growth in Arctic charr *Salvelinus alpinus* at two incubation temperatures. J Fish Biol 76:2558-2570. doi: 10.1111/j.1095-8649.2010.02648.x

Jhingran VG, Pullin RS V. (1985) Induced spawning of Chinese and Indian major carps and common carp breeding. In: A hatchery manual for the common, Chinese and Indian major carps. ICLARM Reviews and Studies 11. Asian Development Bank (ADB) and International Center for Living Aquatic Resources Management (ICLARM), Manila, Philippines, pp 43–58

Johnsen A, Andersen V, Sunding C, Lifjeld JT (2000) Female bluethroats enhance offspring immunocompetence through extra-pair copulations. Nature 406:296–299. doi: 10.1038/35018556

Johnson DW, Christie MR, Moye J, Hixon MA (2011) Genetic correlations between adults and larvae in a marine fish: Potential effects of fishery selection on population replenishment. Evol Appl 4:621–633. doi: 10.1111/j.1752-4571.2011.00185.x

Johnston TA, Wiegand MD, Leggett WC, Pronyk RJ, Dyal SD, Watchorn KE, Kollar S, Casselman JM (2007) Hatching success of walleye embryos in relation to maternal and ova characteristics. Ecol Freshw Fish 16:295–306. doi: 10.1111/j.1600-0633.2006.00219.x

Jomori RK, Carneiro DJ, Martins MIEG, Portella MC (2005) Economic evaluation of *Piaractus mesopotamicus* juvenile production in different rearing systems. Aquaculture 243:175–183. doi: 10.1016/j.aquaculture.2004.09.034

Jørgensen C, Auer SK, Reznick DN (2011) A model for optimal offspring size in fish, including live-bearing and parental effects. Am Nat 177:E119–E135.doi: 10.1086/659622

Kamler E (2005) Parent–egg–progeny relationships in teleost fishes: an energetics perspective. Rev Fish Biol Fish 15:399–421. doi: 10.1007/s11160-006- 0002-y

Kangassalo K, Valtonen TM, Roff D, Pölkki M, Dubovskiy IM, Sorvari J, Rantala MJ (2015) Intra and trans generational effects of larval diet on susceptibility to an entomopathogenic fungus, *Beauveria bassiana*, in the greater wax moth, *Galleria mellonella*. J Evol Biol 28:1453-1464. doi: 10.1111/jeb.12666

Kekalainen J, Huuskonen H, Tuomaala M, Kortet R (2010) Both male and female sexual ornaments reflect offspring performance in a fish. Evolution 64:3149–3157. doi: 10.1111/j.1558-5646.2010.01084.x

Kestemont P (1995) Different systems of carp production and their impacts on the environment. Aquaculture 129:347–372. doi: 10.1016/0044-8486(94)00292-V

Khan MA, Jafri AK, Chadha NK (2004) Growth and body composition of rohu, *Labeo rohita* (Hamilton), fed compound diet: Winter feeding and rearing to marketable size. J Appl Ichthyol 20:265–270. doi: 10.1111/j.1439-0426.2004.00550.x

Khatun N, Islam MT, Sultana N, Mrong S, Huq MA (2017) Present status of carp hatchery and breeding operations in Bangladesh: A review. Agric Livest Fish 4:123–129. doi: 10.3329/ralf.v4i2.33724

Kindsvater HK, Rosenthal GG, Alonzo SH (2013) Maternal size and age shape offspring size in a live-bearing fish, *Xiphophorus birchmanni*. PLoS One 8: e48473. doi: 10.1371/annotation/e8d4f506-c582-4413-9eb9-2b1b49ad1c81

Klemme I, Ylönen H, Eccard JA (2008) Long-term fitness benefits of polyandry in a small mammal, the bank vole *Clethrionomys glareolus*. Proc Royal Soc B 275:1095-1100.doi: 10.1098/rspb.2008.0038

Kolkovski S (2013) Micro diets as alternatives to live feeds for fish larvae in aquaculture: Improving the efficiency of feed particle utilization. In: Allan GL (ed) Advances in aquaculture hatchery technology. Elsevier, pp 203–222.

Kotakorpi M, Tiainen J, Olin M, Lehtonen H, Nyberg K, Ruuhijärvi J, Kuparinen A (2013) Intensive fishing can mediate stronger size-dependent maternal effect in pike (*Esox lucius*). Hydrobiologia 718:109-118. doi: 10.1007/s10750-013-1607-5

Kucharczyk D, Targońska K, Hliwa P, Gomułka P, Kwiatkowski M, Krejszeff S, Perkowski J (2008) Reproductive parameters of common carp (*Cyprinus carpio* L) spawners during natural season and out-of-season spawning. Reprod Biol 8:285–289. doi: 10.1016/S1642-431X(12)60018-7

Lakens D (2013) Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. Front Psychol 4. doi:

10.3389/fpsyg.2013.00863

Lee CS (2003) Biotechnological advances in finfish hatchery production: A review. Aquaculture 227:439–458. doi: 10.1016/S0044-8486(03)00522-2

Levine TR, Hullett CR (2002) Eta squared, partial eta squared, and misreporting of effect size in communication research. Hum Commun Res 28:612–625. doi: 10.1111/j.1468-2958.2002.tb00828.x

Ljungström G, Francis TB, Mangel M, Jørgensen C (2019) Parent-offspring conflict over reproductive timing: Ecological dynamics far away and at other times may explain spawning variability in Pacific herring. ICES J Mar Sci 76:559–572. doi: 10.1093/icesjms/fsy106

Luquet E, Tariel J (2016) Offspring reaction norms shaped by parental environment: Interaction between within- and trans-generational plasticity of inducible defenses. BMC Evol Biol 16:209. doi: 10.1186/s12862-016-0795-9

Mangiafico S. (2016) Summary and analysis of extension program evaluation in R, version 1.15.0. Retrieved from: http://rcompanion.org/handbook/J_01.html http://rcompanion.org/handbook/J_01.html

McAdam AG, Boutin S, R′eale D, Berteaux D (2002) Maternal effects and the potential for evolution in a natural population of animals. Evolution 56:846–851. https://doi.org/10.1111/j.0014-3820.2002.tb01396.x

McBride RS, Somarakis S, Fitzhugh GR, Albert A, Yaragina NA, Wuenschel MJ, Alonso-Fernández A, Basilone G (2015) Energy acquisition and allocation to egg production in relation to fish reproductive strategies. Fish Fish 16:23–57. doi: 10.1111/faf.12043

McCormick MI (2006) Mothers matter: crowding leads to stressed mothers and smaller offspring in marine fish. Ecology 87:1104-1109. doi: 10.1890/0012 9658(2006)87[1104:MMCLTS]2.0.CO;2

McLennan D, Armstrong JD, Stewart DC, McKelvey S, Boner W, Monaghan P, Metcalfe NB (2016) Interactions between parental traits, environmental harshness and growth rate in determining telomere length in wild juvenile salmon. Mol Ecol 25:5425-5438. doi: 10.1111/mec.13857

Mehault S, Domínguez-Petit R, Cerviño S, Saborido-Rey F (2010) Variability in total egg production and implications for management of the southern stock of European hake. Fish Res 104:111–122. doi: 10.1016/j.fishres.2010.03.019

Migaud H, Bell G, Cabrita E, McAndrew B, Davie A, Bobe J, Herraez MP, Carrillo M (2013) Gamete quality and broodstock management in temperate fish. Rev Aquac 5:S194–S223. doi: 10.1111/raq.12025

Mir IN, Sahu NP, Pal AK, Makesh M (2017) Synergistic effect of L-methionine and fucoidan rich extract in eliciting growth and non-specific immune response of *Labeo rohita* fingerlings against *Aeromonas hydrophila*. Aquaculture 479:396–403. doi: 10.1016/j.aquaculture.2017.06.001

Misra CK, Das BK, Mukherjee SC, Pattnaik P (2006) Effect of long term administration of dietary β-glucan on immunity, growth and survival of *Labeo rohita* fingerlings. Aquaculture 255:82-94. doi: 10.1016/j.aquaculture.2005.12.009

Mitchell SE, Read AF (2005) Poor maternal environment enhances offspring disease resistance in an invertebrate. Proc R Soc B Biol Sci 272:2601–2607. doi: 10.1098/rspb.2005.3253

Mohapatra S, Chakraborty T, Prusty AK, Das P, Paniprasad K, Mohanta KN (2012) Use of different microbial probiotics in the diet of rohu, *Labeo rohita* fingerlings: Effects on growth, nutrient digestibility and retention, digestive enzyme activities and intestinal microflora. Aquac Nutr 18:1–11. doi: 10.1111/j.1365-2095.2011.00866.x

Morrison KR, Ngo V, Cardullo RA, Reznick DN (2017) How fish eggs are preadapted for the evolution of matrotrophy. Proc R Soc B Biol Sci 284:20171342. doi: 10.1098/rspb.2017.1342

Mousseau TA, Fox CW (1998) The adaptive significance of maternal effects. Trends Ecol Evol 13:403–407. doi: 10.1016/S0169-5347(98)01472-4

Murry BA, Farrell JM, Schulz KL, Teece MA (2008) The effect of egg size and nutrient content on larval performance: Implications to protracted spawning in northern pike (*Esox lucius* Linnaeus). Hydrobiologia 601:71–82. doi: 10.1007/s10750-007-9267-y

Musharraf M, Khan MA (2019a) Dietary zinc requirement of fingerling Indian major carp, *Labeo rohita* (Hamilton). Aquaculture 503:489-498. doi: 10.1016/j.aquaculture.2019.01.039

Musharraf M, Khan MA (2019b) Requirement of fingerling Indian major carp, *Labeo rohita* (Hamilton) for dietary iron based on growth, whole body composition, haematological parameters, tissue iron concentration and serum antioxidant status. Aquaculture 504:148-157. doi: 10.1016/j.aquaculture.2019.02.002

Nadeau PS, Hinch SG, Pon LB, Patterson DA (2009) Persistent parental effects on the survival and size, but not burst swimming performance of juvenile sockeye salmon *Oncorhynchus nerka*. J Fish Biol 75:538-551. doi: 10.1111/j.1095-8649.2009.02302.x

Nakagawa S, Johnson PCD, Schielzeth H (2017) The coefficient of determination R^2 and intra-class correlation coefficient from generalized linear mixed-effects models revisited and expanded. J R Soc Interface 14:20170213. doi: 10.1098/rsif.2017.0213

Navarro-Guillén C, Yúfera M, Engrola S (2017) Daily feeding and protein metabolism rhythms in Senegalese sole post-larvae. Biol Open 6:77–82. doi: 10.1242/bio.021642

Newman T, Jhinku N, Meier M, Horsfield J (2016) Dietary intake influences adult fertility and offspring fitness in zebra fish. PLoS One 11:e0166394. doi: 10.1371/journal.pone.0166394

O'Dea RE, Vega-Trejo R, Head ML, Jennions MD (2015) Maternal effects on offspring size and number in mosquito fish, *Gambusia holbrooki*. Ecol Evol 5:2945–2955. doi: 10.1002/ece3.1577

Okumus I, Bascinar N (2001) The effect of different numbers of feeding days on feed consumption and growth of rainbow trout [*Oncorhynchus mykiss* (Walbaum)]. Aquac Res 32:365–367. doi: 10.1046/j.1365-2109.2001.00566.x

Perez KO, Munch SB (2010) Extreme selection on size in the early lives of fish. Evolution Int J Org Evolution 64:2450-2457. doi: 10.1111/j.1558-5646.2010.00994.x

Pitcher TE, Neff BD (2007) Genetic quality and offspring performance in Chinook salmon: Implications for supportive breeding. Conserv Genet 8:607–616. doi: 10.1007/s10592-006-9204-z

Politis SN, Sørensen SR, Mazurais D, Servili A, Zambonino-Infante JL, Miest J, Clemmesen C, Tomkiewicz J, Butts I (2018) Molecular ontogeny of first-feeding European eel larvae. Front Physio 9:1477. doi: 10.3389/fphys.2018.01477

Pradhan C, Giri SS, Mohanty SN, Narasimmalu R (2019) Effect of different feeding levels of plant-ingredient-based feed on fillet fatty acid profile, carcass trait, and sensory characteristics of Indian major carps in earthen pond polyculture. J World Aquac Soc 50:374–389. doi: 10.1111/jwas.12532

R Development Core Team (2018) R: A language and environment for statistical computing, version 3.5.2. R Foundation for Statistical Computing, Vienna, Austria. Retrieved from: https://www.r-project.org/

Rahman MM (2008) Capture-based aquaculture of wild-caught Indian major carps in the Ganges region of Bangladesh. In: A. Lovatelli and P.F. Holthus (eds). Capture based aquaculture. Global overview.FAO Fisheries Technical Paper.No. 508. Rome, FAO. pp. 127–140

Rahman MM, Kelley JL, Evans JP (2013) Condition-dependent expression of pre- and postcopulatory sexual traits in guppies. Ecol Evol 3:2197–2213. doi: 10.1002/ece3.632

Rodriguez-Munoz R, Tregenza T (2009) Genetic compatibility and hatching success in the sea lamprey (*Petromyzon marinus*). Biol Lett 5:286–288. doi: 10.1098/rsbl.2008.0650

Rollinson N, Rowe L (2016) The positive correlation between maternal size and offspring size: Fitting pieces of a life-history puzzle. Biol Rev 91:1134–1148. doi: 10.1111/brv.12214

Saha S, Hassan MA, Sharma AP (2015) Effect of dietary probiotics supplementation on growth performance of rohu, *Labeo rohita* fingerlings. Int J Pharma Bio Sci 6:1260–1268.

Sahoo L, Meher PK, Mahapatra KD, Saha JN, Jayasankar P, Das P (2017) A molecular tool for parentage analysis in Indian major carp,*Labeo rohita* (Hamilton, 1822). Aquac Int 25:1159-1166. doi: 10.1007/s10499-016-0104-z

Sarder MRI (2007) Freshwater fish seed resources in Bangladesh. In: Bondad-Reantaso MG (ed) Assessment of freshwater fish seed resources for sustainable aquaculture: A FAO fisheries technical paper, 501st edn. Food and Agricultural Organization (FAO), Rome, Italy, pp 105–127

Sarker PK, Bureau DP, Hua K, Drew MD, Forster I, Were K, Hicks B, Vandenberg GW (2013)

Sustainability issues related to feeding salmonids: a Canadian perspective. Rev Aquac 5:199–219. doi: 10.1111/raq.12013

Sarma K, Prajapati M, Mankodi P (2017) Morphological description and taxonomic account of *Labeo* species (Cypriniformes, Family: Cyprinidae) from Gujarat, India. J Entomol Zool Stud 5:1120-1125.

Sehgal HS, Toor HS (1991) Offspring fitness and fecundity of an Indian major carp, *Labeo rohita* (Ham.), in relation to egg size. Aquaculture 97:269-279. doi: 10.1016/0044-8486(91)90269-D

Shan X, Huang W, Cao L, Wu Y (2008) Advances in studies of the effects of starvation on growth and development of fish larvae. J Ocean Univ China 7:319–326. doi: 10.1007/s11802-008-0319-3

Sogard S, Berkeley S, Fisher R (2008) Maternal effects in rockfishes *Sebastes* spp.: A comparison among species. Mar Ecol Prog Ser 360:227–236. doi: 10.3354/meps07468

Swain P, Dash S, Bal J, Routray P, Sahoo PK, Sahoo SK, Saurabh S, Gupta SD, Meher PK (2006) Passive transfer of maternal antibodies and their existence in eggs, larvae and fry of Indian major carp, *Labeo rohita* (Ham.). Fish Shellfish Immun 20:519-527.

Takeuchi T (2014) Progress on larval and juvenile nutrition to improve the quality and health of seawater fish: A review. Fish Sci 80:389–403.doi: 10.1007/s12562-014-0744-8

Tallamy DW (1984) Insect parental care. Bioscience 34:20–24. doi: 10.2307/1309421

Talwar PK, Jhingran AG (1991) Inland fishes of India and adjacent countries (Vol. 2). Boca Raton, Florida.

Thompson GA, Volpedo AV (2018) Diet composition and feeding strategy of the new world silverside *Odontesthes argentinensis* in a temperate coastal area (South America). Mar Coast Fish 10:80–88. doi: 10.1002/mcf2.10005

Thongprajukaew K, Rodjaroen S (2017) Intermittent feeding induces compensatory growth of juvenile yellow mystus (*Hemibagrus nemurus*). Aquat Living Resour 30:6. doi: 10.1051/alr/2017001

Trippel EA, Kraus G, K¨oster FW (2005) Maternal and paternal influences on early life history traits and processes of Baltic cod *Gadus morhua*. Mar Ecol Prog Ser 303:259–267. doi:10.3354/meps303259

Ullah A, Basak A, Islam MN, Alam MS (2015) Population genetic characterization and family reconstruction in brood bank collections of the Indian major carp *Labeo rohita* (Cyprinidae: Cypriniformes). Springer Plus 4:774. doi: 10.1186/s40064-015-1571-9

Urbinati EC, Sarmiento SJ, Takahashi LS (2014) Short-term cycles of feed deprivation and refeeding promote full compensatory growth in the Amazon fish matrinxã (*Brycon amazonicus*). Aquaculture 433:430–433. doi: 10.1016/j.aquaculture.2014.06.030

Vallin L, Nissling A (2000) Maternal effects on egg size and egg buoyancy of Baltic cod, *Gadus morhua* :Implications for stock structure effects on recruitment. Fish Res 49:21–37.doi: 10.1016/S0165-7836(00)00194-6

Vega-Trejo R, Head ML, Jennions MD, Kruuk LEB (2018) Maternal-by-environment but not genotype-by-environment interactions in a fish without parental care. Heredity 120:154–167. doi: 10.1038/s41437-017-0029-y

Vijendravarma RK, Narasimha S, Kawecki TJ (2010) Effects of parental larval diet on egg size and offspring traits in Drosophila. Biol Lett 6:238–241. doi: 10.1098/rsbl.2009.0754

Wahab MA, Kadir A, Milstein A, Kunda M (2011) Manipulation of species combination for enhancing fish production in polyculture systems involving major carps and small indigenous fish species. Aquaculture 321:289–297. doi: 10.1016/j.aquaculture.2011.09.020

Wahab MA, Reza MJ, Ali MM, Nahiduzzaman M (2019) The Potential for homestead pond polyculture of tilapia and carps in coastal Bangladesh. J Fish Sci 1. doi: 10.30564/jfs.v1i1.882

Wang H-Y, Einhouse DW, Fielder DG, Rudstam LG, Vandergoot CS, VanDeValk AJ, Zorn TG, Höök TO (2012) Maternal and stock effects on egg-size variation among walleye *Sander vitreus* stocks from the Great Lakes region. J Great Lakes Res 38:477–489. doi: 10.1016/j.jglr.2012.06.002

Wang X, Ross KE, Saillant E, Gatlin III DM, Gold JR (2006) Quantitative genetics and heritability of growth-related traits in hybrid striped bass (*Morone chrysops*♀ × *Morone saxatilis*♂). Aquaculture 261:535-545. doi: 10.1016/j.aquaculture.2006.07.032

Wedekind C, Evanno G, Urbach D, Jacob A, Muller R (2008) 'Good-genes' and 'compatible-genes' effects in an Alpine whitefish and the information content of breeding tubercles over the course of the spawning season. Genetica 134:21–30. doi: 10.1007/s10709-007-9164-3

Wright RM, Shoesmith EA (1988) The reproductive success of pike, *Esox lucius*: aspects of fecundity, egg density and survival. J Fish Biol 33:623-636. doi: 10.1111/j.1095-8649.1988.tb05505.x

Xu J, Wang Q (2013) Trade-off between adult body size and juvenile survival: an experimental test of parental effects in the Mediterranean flour moth. Aust J Entomo l52:403-406. doi: 10.1111/aen.12038

Yengkokpam S, Debnath D, Pal AK, Sahu NP, Jain KK, Norouzitallab P, Baruah K (2013) Short-term periodic feed deprivation in *Labeo rohita* fingerlings: Effect on the activities of digestive, metabolic and anti-oxidative enzymes. Aquaculture 412–413:186–192. doi: 10.1016/j.aquaculture.2013.07.025

Youngson NA, Whitelaw E (2008) Transgenerational epigenetic effects. Annu Rev Genomics Hum Genet 9:233–257. doi: 10.1146/annurev.genom.9.081307.164445

Zakia IA (2010) Rohu: *labeo rohita*. In: BdFISH Feature. Retrieved from http://en.bdfish.org/2010/02/rohu-labeo-rohita/. Accessed 21 November 2019

Chapter-8

8.0 Appendix