Dietary protein and energy interactions in African catfish

*Clarias gariepinus* (Burchell, 1822)

Thesis submitted to the University of Stirling
for the degree of Doctor of Philosophy

By

Md. Zulfikar Ali
B. Sc. Fisheries (Honours),
M. Sc. Fisheries in Fisheries Technology

Institute of Aquaculture
University of Stirling
Stirling, Scotland
United Kingdom

July 2001
Dedicated

to

My parents, my wife Nipu

and

my children Zisan and Nahin
DECLARATION

I do hereby declare that this thesis has been achieved by myself and is the result of my own investigations. It has neither been accepted, nor is being submitted, for any other degree or qualification. All sources of information have been duly acknowledged.

....................................................
(Md. Zulfikar Ali)

....................................................
(Dr. Kim Jauncey)
Principal Supervisor
In the name of Almighty Allah, the most gracious the most merciful

ACKNOWLEDGEMENTS

I feel pleasure to express my sincere thanks and gratitude to my supervisor Dr. Kim Jauncey for his relentless effort, guidance, supervision, encouragement and warm-hearted intelligence throughout my study at the Institute of Aquaculture, University of Stirling. I am also deeply grateful to him for his patiently painstaking reviewing and editing of this thesis. Special thanks due to Dr. Rod Wootten as my second supervisor for his assistance and encouragement.

I wish to express my sincere appreciation and thanks to Mr Allan Porter, Miss Fiona McGhee and Mrs Rosemary Miller for their friendly help and co-operation with all analyses in the Aquaculture Nutrition Laboratories. Thanks are also due to Mr Keith Ranson, Mr Willie Hamilton and Mr Stuart Wilson for their help in the Tropical Aquarium, Mr Billy Struthers and Mrs Nora Pollock in the Water Quality Laboratory, and Mr Richard Collins, Mrs Debbie Faichney and Mrs Maureen Menzies in the Histology Laboratory. My thanks are also extended to the staff of stores especially Mrs Betty Stenhouse, Mr Charlie Harrower and Mrs Jane Lewis, and to the staffs of main office namely Sarra Watson and Lianne Muirhead.

I would like to thank my fellow colleagues and Lab partners Dr. Mohammed Al-Owafeir, Mr. Noe Sanchez-Perez, Mr. Dio Nhampulo, Dr. Panagiotis A Pantazis, Mr. Atilla Ozdemir and Mrs. Beatriz Basso for their excellent friendship and exchange of ideas that inspired me in a variety of nutritional themes through valuable discussions. The moments we spent together at the Aquaculture Nutrition Unit that will never fade away in my memories. I am particularly thankful to Dr. Mohammed Al-Owafeir for his untiring assistance, encouragement and valuable co-operation at the beginning of my PhD studies. I would also like to thank all of those, students or staffs at the Institute of Aquaculture, who not only facilitated my research but also created a pleasant working environment.

I am indebted to my employer, Bangladesh Fisheries Research Institute (BFRI) for providing me the opportunity to undertake this study. I do gratefully acknowledge the financial award from the World Bank under Agricultural Management Project-FRI part (ARMP-IDA Credit 2815-BD) for this study.
My heartfelt respect and special thanks must go to my beloved parents, in-laws, sisters and all relatives back home whose sublime blessings, love and sacrifice inspired me most in my voyage to learning. I also gratefully acknowledge my boundless gratitude to my cousin Dr. M. Asadur Rahman (former Vice-Chancellor, BAU) and my uncle Professor Abdur Razzaque (BAU) back home for their never-ending support, blessings and love to encourage me to higher studies.

I hereby express gratitude to Dr. M. A. Mazid (DG, BFRI), Dr. M. G. Hussain (Director, BFRI) and Professor Dr. Md. Arshad Hossain (BAU) for their sincere encouragement that made me decide to undertake this study at the Institute of Aquaculture. I would like extend my sincere thanks to Professor Dr. Subhash C Chakrabarty (BAU) for his constructive criticism and inspiration while preparing this thesis. Most specially I must thank my friends, my well-wishers and lovely neighbour Jean and James for their enormous support that made my own and my family stay enjoyable and unforgettable here at Stirling.

Finally, and by no means least important, I pledge my abiding gratitude and love to my wife Nipu and my children Zisan and Nahin for their love, patience, sacrifice and constant inspirations that undoubtedly helped me keep my sanity all through these hard times.
ABSTRACT

In order to investigate the interactions of dietary protein and energy and their utilisation by African catfish, *Clarias gariepinus* (Burchell, 1822) (12.43 ± 0.05 g), a series of four nutritional experiments (triplicate groups of 20 fish per 30-L tank at 28 ± 1°C, for 8 weeks) were carried out using fish meal based diets. Optimum dietary protein to energy ratio (P/E ratio) and optimum lipid to carbohydrate ratio (L/CHO ratio) were investigated. Based on optimised dietary P/E ratio and L/CHO ratio, optimum feeding regime and compensatory growth were also investigated in this species.

In the experiments to optimise P/E ratio and L/CHO ratio fish were offered each diet at 5% of their body weight per day adjusted fortnightly. In the optimum feeding regime experiments, fish were offered each diet to appetite or to a restricted level. The restricted regimes were achieved by offering fish decreasing fixed feeding rates with increasing dietary protein level. Studies on compensatory growth were conducted in two phases each of 4 weeks. In the first phase, triplicate groups of 30 fish and in the second phase triplicate groups of 20 fish (per 30-L tank) were offered the diet in six mixed feeding schedules at two feeding regimes i.e. appetite and restricted. The restricted regime was achieved by offering fish 1% (maintenance ration) of their body weight per day adjusted after fortnightly weighing.

Optimum dietary P/E and L/CHO ratios were 20.54-mg protein/kJ of GE and 0.40 g/g respectively, with a crude protein level over 40% and gross energy of more than 20 kJ/g GE. The results of investigating feeding regimes suggest that dietary protein level could be reduced from over 40% to 35% by feeding to appetite based on the above optimised dietary P/E and L/CHO ratios. Addition of dietary energy as lipid at varying protein levels resulted in increased growth, protein and energy utilisation in *C. gariepinus*. Based on optimised dietary P/E ratio, dietary carbohydrate levels were increased (with concomitant reduction in dietary lipid levels) resulting in a trend towards higher growth performance, protein and energy utilisation. Protein and energy utilisation did not vary (P > 0.05) with feeding regime or dietary protein level. *C. gariepinus* showed partial compensatory growth under alternating periods of feeding a restricted (maintenance requirements) and appetite ration and also showed higher feed, protein, lipid and energy utilisation efficiencies in comparison to appetite feeding.
Increase in dietary lipid produced an increment in carcass lipid deposition, both in whole body and liver in all studies. Fish in all treatments did not show significant differences (P < 0.05) in body protein content. Optimum P/E ratio studies, with varying dietary protein and energy level, produced higher liver glycogen, plasma glucose and plasma triglycerides at higher dietary carbohydrate level with lower protein diets. In the studies to optimise lipid to CHO ratio comparatively lower (P < 0.05) plasma glucose and plasma cholesterol deposition were observed while no consistent trends were found in liver glycogen deposition in fish fed higher dietary lipid with concomitant lower CHO levels. Studies on optimising feeding regime, with varying protein levels, did not show any significant differences (P < 0.05) in liver glycogen, plasma glucose, plasma triglycerides and plasma cholesterol in response to dietary treatment.

In all studies fish fed the experimental diets showed insignificant differences (P > 0.05) in plasma amino acid levels and digestive enzyme activities (protease and lipase) while intestinal α-amylase activity increased with increasing dietary carbohydrate level. Histological examination of intestine & liver in all studies showed no abnormalities. In conclusion, these studies suggest that manipulation and optimisation of dietary protein and energy intakes plays a very significant role in African catfish, *Clarias gariepinus* nutrition.
# LIST OF CONTENTS

DEDICATION........................................................................................................ ii
DECLARATION.................................................................................................. iii
ACKNOWLEDGEMENTS..................................................................................... iv
ABSTRACT.......................................................................................................... vi
LIST OF CONTENTS........................................................................................... viii
LIST OF TABLES................................................................................................ xiv
LIST OF FIGURES............................................................................................ xvii

Chapter 1. General Introduction................................................................. 1

1.1 Importance and Status of Aquaculture.................................................. 2
1.2 Aquaculture Nutrition................................................................. 7
1.2.1 Introduction to Dietary Requirements.............................................. 9
1.2.2 Protein.................................................................................................. 11
1.2.2.1 Quantitative Dietary Protein Requirements................................. 12
1.2.2.2 Qualitative Dietary Protein Requirements..................................... 16
1.2.2.3 Dietary Protein Sources............................................................... 16
1.2.3 Protein and Energy................................................................. 18
1.2.3.1 Protein Metabolism for Energy.................................................... 19
1.2.3.2 Dietary Lipid as Energy Sources.................................................. 23
1.2.3.2.1 Lipid Metabolism for Energy................................................... 25
1.2.3.3 Dietary Carbohydrate as Energy Sources...................................... 28
1.2.3.3.1 Carbohydrate Metabolism for Energy................................. 32
1.2.4 Protein and Energy Ratio............................................................... 36
1.2.5 Nutrient Digestion and Digestibility................................................ 40
1.2.5.1 Protein Digestibility................................................................. 42
1.2.5.2 Lipid Digestibility................................................................. 42
1.2.5.3 Carbohydrate Digestibility.......................................................... 43
1.2.5.4 Factors Affecting Digestion of Food in Fish................................. 44
1.2.5.4.1 Fish species........................................................................... 44
1.2.5.4.2 Fish age and size .............................................................. 45
1.2.5.4.3 Physiological condition ..................................................... 45
1.2.5.4.4 Water temperature .......................................................... 45
1.2.5.4.5 Water salinity ................................................................. 45
1.2.5.4.6 Food composition ............................................................ 46
1.2.5.4.7 Feeding rate and frequency ................................................ 46
1.3 Catfish, *Clarias* species .......................................................... 47
1.3.1 The African Catfish, *Clarias gariepinus* ........................................ 47
1.3.2 Nutrition of African Catfish, *Clarias gariepinus* ............................. 49
1.4 Aim and Objectives of the Present Study .......................................... 55

## Chapter 2. General Materials and Methods ........................................ 57

2.1 Experimental System ................................................................. 58
2.2 Experimental Fish ................................................................. 60
2.3 Experimental Diets ................................................................. 60
2.3.1 Diet Formulation ................................................................. 60
2.3.2 Diet Preparation ................................................................. 62
2.4 Experimental Practices ............................................................ 63
2.4.1 Acclimation and Weighing Procedure ......................................... 63
2.4.2 Experimental Period ............................................................ 63
2.4.3 Fish Feeding ................................................................. 63
2.4.4 Faeces Collection ............................................................. 64
2.5 Water Quality Management ....................................................... 64
2.6 Experimental Analyses .............................................................. 66
2.6.1 Chemical Analysis ............................................................. 66
2.6.2 Biological Evaluation .......................................................... 73
2.7 Liver Lipid Extraction .............................................................. 76
2.8 Determination of Liver Glycogen ................................................ 77
2.9 Histological Analysis ............................................................... 80

2.10 **Enzyme Studies** ................................................................. 80
2.10.1 Collection of Intestine and Liver ........................................... 80
2.10.2 Enzyme ................................................................. 81
Chapter 4. Approaches to optimising dietary non-protein energy, lipid to carbohydrate ratio in African catfish, *Clarias gariepinus* (Burchell, 1822)................................................................. 127

4.1 Introduction................................................................. 128
4.2 Materials and Methods.................................................. 131
  4.2.1 Experimental System................................................. 131
  4.2.2 Experimental Fish.................................................... 131
  4.2.3 Experimental Diets................................................... 131
  4.2.4 Experimental Practices............................................. 132
  4.2.5 Water Quality Management...................................... 133
  4.2.6 Experimental Analyses............................................. 133
4.3 Results............................................................................. 137
  4.3.1 Growth, Survival and Feed Performance....................... 137
  4.3.2 Nutrient and Energy Utilisation.................................. 138
  4.3.3 Apparent Nutrient, Energy and Dry matter Digestibility.......... 144
  4.3.4 Body Composition and Histology.................................. 144
  4.3.5 Digestive Enzymes................................................... 147
  4.3.6 Blood Plasma Components........................................ 150
4.4 Discussion....................................................................... 154

Chapter 5. Approaches to optimising feeding regime in African catfish, *Clarias gariepinus*, (Burchell, 1822) with various concentrations of dietary protein and energy............................................... 167

5.1 Introduction.................................................................... 168
5.2 Materials and Methods.................................................. 170
  5.2.1 Experimental System................................................. 170
  5.2.2 Experimental Fish.................................................... 170
  5.2.3 Experimental Diets................................................... 170
  5.2.4 Experimental Procedure........................................... 171
  5.2.5 Water Quality Management...................................... 171
Chapter 5. The evaluation of mixed feeding schedules with respect to compensatory growth, feed conversion, nutrient utilisation and body composition in African catfish, Clarias gariepinus (Burchell, 1822)

6.1 Introduction
6.2 Materials and Methods
6.2.1 Experimental System
6.2.2 Experimental Fish
6.2.3 Experimental Diets
6.2.4 Experimental Practices
6.2.5 Water Quality Management
6.2.6 Experimental Analysis
6.3 Results
6.3.1 Growth, Survival and Feed Performance
6.3.2 Apparent Nutrient and Energy Utilisation
6.3.3 Whole Body Carcass Composition
6.3.4 Organ Indices
6.3.5 Eviscerated Carcass Composition
6.3.6 Viscera Composition
6.3.7 Liver Composition
6.4 Discussion
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1</td>
<td>Introduction</td>
<td>240</td>
</tr>
<tr>
<td>7.2</td>
<td>Discussion</td>
<td>240</td>
</tr>
<tr>
<td>7.3</td>
<td>Conclusions and Recommendations</td>
<td>245</td>
</tr>
<tr>
<td>7.4</td>
<td>Suggestions for Future Work in this Field</td>
<td>246</td>
</tr>
<tr>
<td></td>
<td>REFERENCES</td>
<td>247</td>
</tr>
<tr>
<td></td>
<td>APPENDIX 1. Histology</td>
<td>274</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table 1.1 Estimated dietary protein requirement of selected fish species (for maximum growth and expressed as a percentage of the diet)………………………………………………………………………………… 14

Table 1.2 Optimum protein : energy ratio (P/E ratios) in the diets for various fish species (CP = Crude protein; GE = Gross energy; DE = Digestible energy; ME = Metabolizable energy, as the basis of calculation)………………………………………………………………………………………………………………… 38

Table 2.1 Description of the experimental system……………………………………… 58

Table 2.2 Composition of the vitamin premix used in experimental diets.. 61

Table 2.3 Composition of mineral premixes used in experimental diets… 62

Table 2.4 Water quality measured during all experimental combined together with suggested acceptable ranges…………………………………… 65

Table 3.1 Formulation and composition of the experimental diets and proximate analysis (percent dry weight)……………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………………
Table 4.1  Formulation and composition of the experimental diets and proximate analysis (percentage dry weight)................................. 134

Table 4.2  Essential amino acid composition (EAA, g/100g protein) of the experimental diet 3, and EAA requirements of African catfish, *Clarias gariepinus*................................................................. 135

Table 4.3  Mean growth performance, feed and nutrient utilisation efficiency of *Clarias gariepinus* various dietary lipid to carbohydrate ratios for 56 days.......................................................... 140

Table 4.4  Body composition (% wet weight) of *Clarias gariepinus* at the start and end of the experiment.................................................... 146

Table 4.5  Liver lipid, liver glycogen (% wet weight) and organ indices (VSI and HSI) in *Clarias gariepinus*.................................................. 146

Table 4.6  Protease, lipase and α-amylase activities of intestine and liver in *Clarias gariepinus* at the end of the experiment....................... 148

Table 4.7  Blood plasma concentrations of glucose, triglycerides and cholesterol in *Clarias gariepinus* at the end of the experiment.. 151

Table 4.8  Plasma amino acid levels (µM / ml of blood plasma) in *Clarias gariepinus* at the end of the experiment........................................... 153

Table 5.1  Formulation and composition of the experimental diets and proximate analysis (% dry weight basis)............................................ 173

Table 5.2  Essential amino acid composition (EAA, g/100g protein) of the experimental diet 2, and EAA requirements of African catfish, *Clarias gariepinus*.......................................................... 174

Table 5.3  Mean growth performance, feed and nutrient utilisation efficiency of *Clarias gariepinus* at various protein levels and two feeding regimes for 56 days.......................................................... 179

Table 5.4  Body composition (% wet weight basis) of African catfish, *Clarias gariepinus* at the start and end of the experiment...... 184

Table 5.5  Liver lipid, liver glycogen (% wet weight) and organ indices (VSI and HSI) of African catfish, *Clarias gariepinus* under different treatments........................................................................... 184

Table 5.6  Protease, lipase and amylase activities in intestine and liver of African catfish, *Clarias gariepinus* at the end of the experiment.......................................................... 186
Table 5.7  Blood plasma concentrations of glucose, triglycerides and cholesterol in African catfish, *Clarias gariepinus* at the end of the experiment…………………………………………………………. 189

Table 5.8  Plasma amino acid levels (µM / ml of blood plasma) in *Clarias gariepinus* at the end of the experiment…………………………………………………………191

Table 6.1  Formulation and composition of the experimental diets and proximate analysis (% dry weight basis)…………………………………………………………. 205

Table 6.2  Essential amino acid composition (EAA, g/100g protein) of the experimental diet and EAA requirements of African catfish, *Clarias gariepinus*…………………………………………………………. 206

Table 6.3  Phase I (weeks 0 – 4). Growth performance, feed intake and feed utilisation in *Clarias gariepinus* maintained on mixed feeding schedules…………………………………………………………. 212

Table 6.4  Phase II (weeks 4 – 8). Growth performance, feed intake and feed utilisation in *Clarias gariepinus* maintained on mixed feeding schedules…………………………………………………………. 213

Table 6.5  Overall (weeks 0 – 8). Growth performance, feed intake and feed utilisation in *Clarias gariepinus* maintained on mixed feeding schedules…………………………………………………………. 214

Table 6.6  Whole body carcass composition of *Clarias gariepinus* (% mean wet weight) fed mixed feeding schedules at the middle and end of the experiment…………………………………………………………. 221

Table 6.7  Organ indices, eviaceromatic index (EVSI), visceromatic index (VSI) and hepatosomatic index (HSI) of *Clarias gariepinus* fed mixed feeding schedules at the middle and end of the experiment…………………………………………………………. 223

Table 6.8  Eviscerated (EV) carcass composition of *Clarias gariepinus* (% mean wet weight) fed mixed feeding schedules at the middle and the end of the experiment…………………………………………………………. 224

Table 6.9  Viscera composition of *Clarias gariepinus* (% mean wet weight) fed mixed feeding schedules at the middle and the end of the experiment…………………………………………………………. 226

Table 6.10 Liver composition of *Clarias gariepinus* (% mean wet weight) fed mixed feeding schedules at the middle and the end of the experiment…………………………………………………………. 228
LIST OF FIGURES

Figure 1.1 World Fisheries Production (FAO, 2000)---------------------------- 4
Figure 1.2 World Aquaculture Production in 1998 by Continent (FAO, 1998)…………………………………………………………… 5
Figure 1.3 World Aquaculture Production in 1998: Breakdown by Environment (FAO, 2000)…………………………………………………………… 5
Figure 1.4 Main pathways of protein (amino acid) metabolism................. 21
Figure 1.5 Main pathways of lipid (fatty acid) metabolism...................... 26
Figure 1.6 Main pathways of carbohydrate metabolism.......................... 33
Figure 2.1 Schematic three dimensional view of experimental system…….. 59
Figure 3.1 The mean fortnightly growth response of African catfish, \textit{Clarias gariepinus} maintained on the six experimental diets over 8 weeks……………………………………………………. 105
Figure 3.2 Mean growth performance, feed and nutrient efficiency of \textit{Clarias gariepinus} fed various levels of dietary protein to energy ratios…………………………………………………….. 107
Figure 3.3 The protease and lipase activities of intestine and liver in \textit{Clarias gariepinus} fed different experimental diets…………… 113
Figure 3.4 Blood plasma concentrations of glucose, triglycerides and cholesterol in \textit{Clarias gariepinus} fed various dietary protein to energy ratios…………………………………………………… 116
Figure 4.1 The mean fortnightly growth response of African catfish, \textit{Clarias gariepinus} maintained on the five experimental diets over 8 weeks……………………………………………………. 139
Figure 4.2 Mean growth performance, feed and nutrient utilisation efficiency of \textit{Clarias gariepinus} fed different levels of dietary lipid to carbohydrate ratios…………………………………………………… 141
Figure 4.3 Dose response analysis: The polynomial relation of percent live weight gain and apparent net protein utilisation with dietary carbohydrate to lipid ratios (g/g) in \textit{Clarias gariepinus}………… 143
Figure 4.4 The protease, lipase and amylase activities of intestine and liver in \textit{Clarias gariepinus} fed different dietary lipid to carbohydrate ratios…………………………………………………… 149
| Figure 4.5 | Blood plasma concentrations of glucose, triglycerides and cholesterol in *Clarias gariepinus* fed various dietary lipid to carbohydrate ratios | 152 |
| Figure 5.1 | The mean fortnightly growth response of African catfish, *Clarias gariepinus* maintained on various dietary protein levels and two feeding regimes over 8 weeks | 178 |
| Figure 5.2 | Mean growth performance, feed and protein utilisation efficiency and protein utilisation of African catfish, *Clarias gariepinus* fed various levels of dietary protein with two feeding regimes | 181 |
| Figure 5.3 | The protease, lipase and α-amylase activities in intestine and liver of *Clarias gariepinus* fed different treatments | 187 |
| Figure 5.4 | Blood plasma concentrations of glucose, triglycerides and cholesterol in *Clarias gariepinus* at the end of the experiment | 190 |
| Figure 6.1 | The mean fortnightly growth response of African catfish, *Clarias gariepinus* maintained mixed feeding schedules over 8 weeks | 211 |
| Figure 6.2 | Growth performance (weight gain, specific growth rate) and feed intake of African catfish, *Clarias gariepinus* fed mixed feeding schedules in different experimental period | 215 |
| Figure 6.3 | FCE, protein intake and PER of African catfish, *Clarias gariepinus* fed mixed feeding schedules in different experimental period | 216 |
| Figure 6.4 | Apparent net protein utilisation (ANPU) and apparent net energy utilisation (ANEU) in African catfish, *Clarias gariepinus* fed mixed feeding schedules in different experimental period | 217 |