A COMPREHENSIVE SURVEY AND STUDY OF TILAPIA AQUACULTURE IN MALAYSIA WITH EMPHASIS ON PRODUCTION STRATEGIES AND FEED INPUTS

TEH SIH WIN

UNIVERSITI SAINS MALAYSIA

2010

A COMPREHENSIVE SURVEY AND STUDY OF TILAPIA AQUACULTURE IN MALAYSIA WITH EMPHASIS ON PRODUCTION STRATEGIES AND FEED INPUTS

by

TEH SIH WIN

Thesis submitted in fulfilment of the

requirements for the degree of

Master of Science

May 2010

ACKNOWLEDGEMENTS

First of all, I would like to express my greatest gratitude to my supervisor Associate Professor Dr W.K Ng in helping and guiding my studies in the completion of this thesis. Thanks to the WorldFish Center for funding the survey and to Dr. A.G. Ponniah for his initial coordination efforts. I would also like to thank Dr. D.P. Bureau (University of Guelph, Canada) for seconding Mr. K. Chowdhury to assist us in the field surveys under the auspices of the CGIAR-Canada Linkage Fund.

The contributions of the State Department of Fisheries (Perak, Selangor, Penang, Negeri Sembilan, Pahang and Terengganu) and the Department of Agriculture (Sarawak and Sabah) in arranging for the various trips to tilapia farms are gratefully acknowledged. Special thanks to O.L. Chen (WorldFish Center) for her participation in some of the field trips and her technical support for the survey data statistical analysis. Many thanks to L.P. Ng (WorldFish Center) for the disbursement and monitoring of allocated research funds.

I would like to thank the efforts of all individuals and farmers who contributed to the survey, data collection and feed samples analysis of the survey. Special thanks to Soon Soon Oilmills for providing raw feed ingredients and technical support in the feeding trial. Thanks to Fisheries Research Centre (Pulau Sayak) for helping in mixing and pelleting experimental feed.

I would also like to express my gratefulness to my colleagues in Fish Nutrition Laboratory (Universiti Sains Malaysia), Y. Wang and wife, E.L. Chan, C. Victor, C.B. Koh, C.Y. Teoh and K.S. Lee for their support and help during final sampling. Sincere thanks and appreciations go to K.S. Lee for helping in tough tasks throughout the feeding trial and checking my manuscript. Last but not least, I would like to thank my family for being understanding and supportive throughout my study.

TABLE OF CONTENTS

		Page
ACKNOWLEDGEMENTS		ii
TABLE OF CONTENTS		iii
LIST OF TABLES		vii
LIST OF FIGURES		ix
LIST OF PLATES		x
LIST OF ABBREVIATION AND SYMBOLS		xi
ABSTRAK		xiii
ABSTRACT		xv
CHAPTER 1:	**INTRODUCTION**	1
CHAPTER 2:	**LITERATURE REVIEW**	7
2.1	Historical Introduction of Aquaculture and Tilapia	7
2.2	Prospect and Potential of Tilapia Farming	9
2.2.1	Global	9
2.2.2	Southeast Asia	10
2.3	Status of Aquaculture in Malaysia	13
2.3.1	Freshwater Aquaculture Production	14
2.3.2	Economical Feasibility of Farming Tilapia in Malaysia	16
2.4	Feed and Feeding Tilapia	18
2.5	Nutrient Requirements for Tilapia	19
2.5.1	Energy	19
2.5.2	Protein and Essential Amino Acids	20
2.5.3	Lipids	22
2.5.4	Carbohydrates	22

2.5.5 Vitamins and Minerals 24

2.6 Water Quality Requirements 25

2.7 Alternative Protein and Lipid Sources in Tilapia Diets 26

2.7.1 Substitution of Fishmeal with Soybean Meal 28

2.7.2 Substitution of Fish Oil with Full Fat Soybean Meal 31

2.7.3 Anti-nutritional Factors in Soybean Meal 32

2.7.4 Digestibility of Dehulled Soybean Meal and Full Fat Soybean in Aquafeeds 34

CHAPTER 3: MATERIALS AND METHODS 36

3.1 Introduction 36

3.2 Part 1: Field Survey and Sampling 36

3.2.1 Survey Questionnaire 36

3.2.2 Comparative Study 37

3.2.3 Production Function 38

3.2.4 Empirical Model 39

3.3 Part 2: Feeding Trial 41

3.3.1 Fish and Layout of Experimental Units 41

3.3.2 Experimental Diets 42

3.3.3 Preparation of Experimental Diets 44

3.3.4 Sample Collection 45

3.3.5 Growth Performances and Feed Utilisation Efficiency 46

3.3.6 Biological Indices 47

3.3.7 Production Yield 48

3.4 Digestibility Study 48

3.4.1 Digestibility Coefficients 49

3.4.2 Chromic Oxide Determination 49

3.5 Determination of Amino Acid in Experimental Diets by Reversed Phase High Performance Liquid Chromatography (RP-HPLC) 50

3.6 Proximate Analysis 51

3.7 Statistical Analysis 52

CHAPTER 4: RESULTS 53

4.1 Part 1: Field Survey and Sampling 53

4.1.1 Land Status and Water Source 55

4.1.2 Basic Farm Information 58

4.1.3 Basic Respondents' Information 58

4.1.4 Socio-economic Aspects 61

4.1.4.1 Stocking Information 61

4.1.4.2 Labour 63

4.1.5 Feed Inputs 64

4.1.6 Production and Productivity 71

4.1.6.1 Empirical Results: Descriptive Analyses of the Performance of Tilapia 71

4.1.6.2 OLS Regression Estimates of Average Weight at Harvest and Tobit Analysis of Survival 72

4.1.6.3 Harvest and Pricing 73

4.1.7 Biochemical Analysis 74

4.2 Part 2: Feeding Trial 80

4.2.1 Experimental Diets 80

4.2.2 Growth Performances and Feed Utilisations 82

4.2.3 Biological Indices and Haematological Parameters 84

4.2.4 Production Yield 88

4.2.5 Initial Proximate Composition and Final Tissue Lipid and Muscle Protein Content 89

4.3 Digestibility study 91

4.3.1	Apparent Dry Matter and Nutrient Digestibility	91
4.4	Bi-weekly Water Quality Monitoring	93
CHAPTER 5:	**DISCUSSION**	95
5.1	Part 1: Field Survey	95
5.1.1	Land Issues	95
5.1.2	Investment and Funding Issues	96
5.1.3	Technology and Labour Issues	97
5.1.4	Marketing Issues	100
5.2	Part 2: Feeding Trial	101
5.2.1	Growth Performance and Feed Utilisation	102
5.2.2	Biological Indices and Haematological Parameters	105
5.2.3	Production Yield	107
5.2.4	Tissue Proximate Composition	108
5.2.5	Apparent Digestibility Coefficients	109
CHAPTER 6:	**CONCLUSIONS**	111
REFERENCES		113
APPENDICES		
A	Survey Questionnaire	
B	Proximate Analysis	
LIST OF PUBLICATIONS		

LIST OF TABLES

		Page
Table 2.1	Tilapia production in Southeast Asian countries from 2000 to 2006, tons / '000 US$[1] (FAO, 2009).	12
Table 2.2	Summary of protein and amino acids requirements for Tilapia (*Oreochromis* sp.) and omnivorous species.	21
Table 2.3	Vitamin premix (per kg feed) for intensive tilapia farming (Jauncey, 1998).	25
Table 2.4	Essential amino acid profile of fishmeal and soybean meal (g/16 g N) (Hertrampf and Pieded-Pascual, 2000).	29
Table 3.1	Categorisation of tilapia farms using farming water area and productivity.	38
Table 3.2	Data used in production function analysis across culture system.	39
Table 3.3	Ingredient and proximate composition (g/100g dry diet) of the experimental diets.	43
Table 4.1	Number of farms visited in each state in Malaysia.	53
Table 4.2	Number of farms surveyed in each state categorised by farmed water surface area and producer.	59
Table 4.3	Average farmed water surface area in each state categorised by farmed water surface area and producer.	60
Table 4.4	Average stocking rate (no./m^2/year) of farms farmed water area less than one hectare for each state.	62
Table 4.5	Average stocking rate (no./ha/year) of farms with farmed water area more than one hectare for each state.	62
Table 4.6	Average feeding rate per year (kg/m^2/year) for farms with farmed water area less than one hectare by state and producer.	68
Table 4.7	Average feeding rate per year (ton/ha/year) for farms with farmed water area more than one hectare by state and producer.	68
Table 4.8	Aquaculture production costs by item and state presented as percentage (%) of total.	70
Table 4.9	Input levels of tilapia farming across production systems.	71

Table 4.10	OLS estimates of the average weight at harvest and tobit estimates of the survival model for tilapia production in Malaysia.	72
Table 4.11	Declared composition of feeds by type and company brand of feed used by tilapia farmers.	75
Table 4.12	Analysed proximate composition (% dry matter basis) of feed and feed ingredients.	77
Table 4.13	Amino acid compositions (% of protein) of experimental diets.	81
Table 4.14	Growth performances of GIFT and red hybrid tilapia fed with diets containing different protein levels for 98 days.	83
Table 4.15	Feed utilisation efficiency of GIFT and red hybrid tilapia fed with diets containing different protein levels for 98 days.	86
Table 4.16	Biological indices of GIFT and red hybrid tilapia fed with diets containing different protein levels for 98 days.	87
Table 4.17	Gut length index and stomach index of GIFT and red hybrid tilapia fed with diets containing different protein levels for 98 days.	88
Table 4.18	Production yields of GIFT and red hybrid tilapia fed with diets containing different protein levels for 98 days.	90
Table 4.19	Final tissue lipid and protein content (% wet weight) of GIFT and red hybrid tilapia fed with diets containing different protein levels for 98 days.	91
Table 4.20	Apparent dry matter and nutrient digestibility (%) of the GIFT and red hybrid tilapia fed with diets containing different protein levels for 98 days.	92
Table 4.21	Water quality parameters at farm monitored bi-weekly throughout feeding trial.	94

LIST OF FIGURES

		Page
Figure 1.1	World fisheries and aquaculture production from 1950 – 2006 (FAO, 2009).	2
Figure 2.1	Percentage of Cichlidae productions by species in 2004 and 2006 (FAO, 2009).	9
Figure 2.2	Major cichlids producers and total value by continent, 1950 – 2006 (FAO, 2009).	10
Figure 2.3	Estimated production and value from freshwater aquaculture system, 1997 – 2006 (DOF, 2006a).	14
Figure 2.4	Aquaculture productions in Malaysia by culture system (DOF, 2006a).	15
Figure 2.5	Freshwater aquaculture species cultured in Malaysia (DOF, 2006a).	15
Figure 2.6	Global productions of fishmeal and soybean meal from 1973 to 2009 (FAO, 2009; USDA, 2009).	30
Figure 3.1	A model of average production function (A).	38
Figure 3.2	Layout plan of experimental units.	42
Figure 4.1	Number of tilapia culture systems surveyed in each state (n=104).	54
Figure 4.2	Number of survey respondents from the different age groups.	60
Figure 4.3	Number of farms using various brands of commercial feed.	65
Figure 4.4	Distribution of feed brands used in survey farms by state.	67

LIST OF PLATES

		Page
Plate 4.1	Examples of tilapia culture systems found in Malaysia. Clockwise from top left corner: earthen ponds, ex-mining pool, cement tanks and floating cages.	56
Plate 4.2	Workers at a commercial farm carefully weighing fingerlings before stocking in grow-out ponds.	63
Plate 4.3	Example of manual feeding (left) and auto feeder (right) observed at the farms.	64
Plate 4.4	Examples of farm-made and supplementary feeds such as (clockwise from top left) fermented POME, copra cake, kitchen wastes, cooked poultry offal, palm kernel cake and corn-based feed.	66
Plate 4.5	Harvesting process at community-based program farm in Terengganu. Clockwise from top left; preparation before harvest; fish grading; batch weighing of fish; live fish ready to be transported to restaurant when both buyer and farmer agreed on the price and grade.	74

LIST OF ABBREVIATIONS

AA	Amino acid
ADB	Asian Development Bank
ADC	Apparent digestibility coefficient
AIZ	Aquaculture Industrial Zone
ANFs	Anti-nutritional factors
ANOVA	Analysis of variance
AOAC	Association of Official Analytical Chemist
CP	Charoen Pokphand, Star Feed Mills
Cr_2O_3	Chromium(III) oxide
DCP	Dicalcium phosphate
DM	Dry matter
DO	Dissolved Oxygen
DOA	Department of Agriculture, Malaysia
DOF	Department of Fisheries, Malaysia
EAA	Essential amino acid
EPA	Environmental Protection Agency, United States
FA	Farm water area
FAO	Food and Agriculture Organization
FCR	Feed conversion ratio
FELCRA	Federal Land Consolidation and Rehabilitation Authority
FELDA	Federal Land Development Authority
g.r.	Guaranteed Reagent
GAqP	Good Aquaculture Practise
GDP	Gross Domestic Product
GIFT	Genetic Improvement of Farmed Tilapias/ Genetically improved Farmed Tilapia
GLI	Gut length index
GSI	Gonadosomatic index
HCl	Hydrogen chloride
HDPE	High-Density Polyethylene
HIP	High Impact Project
HSI	Hepatosomatic index
HNO_3	Nitric acid
hrs	Hours
ICLARM	International Center for Living Aquatic Resources Management
IPF	Intraperitonial fat index
IU	International Unit
KH_2PO_4	Potassium dehydrogenate orthophosphate
LP	Large producer

LVHD	Low volume high density
M	Molecular mass
ME	Metabolic energy
MOA	Ministry of Agriculture, Malaysia
MP	Medium producer
mt	Metric ton
N	Nitrogen
NaCl	Sodium chloride
NaOH	Sodium Hydroxide
NAP3	Third National Agricultural Policy, Malaysia
NEAA	Non-essential amino acid
NFE	Nitrogen free extract
NRC	National Research Council, United States
OLS	Ordinary Least Squares
PER	Protein efficiency ratio
PITC	Phenylisothiocyanate
POME	Palm Oil Mill Effluent
PTC	Phenylthiocarbamyl
RP-HPLC	Reversed phase high performance liquid chromatography
SBM	Soybean meal
SEA	Southeast Asia
SGR	Specific growth rate
SL	Standard length
SP	Small producer
SPLAM	Farm Certification Scheme
T	Transmittance
TDS	Total dissolved solid
TL	Total length
TOL	Temporary Operation License
UNDP	United Nations Development Program
US$	US Dollar
USM	Universiti Sains Malaysia
v/v	Volume to volume
VSI	Viscerosomatic index

TINJAUAN DAN KAJIAN MENYELURUH AKUAKULTUR TILAPIA DI MALAYSIA DENGAN PENEKANAN PADA STRATEGI PENGELUARAN DAN INPUT MAKANAN

ABSTRAK

Satu kajian mengenai akuakultur tilapia telah dikendalikan selama 10 bulan di antara November 2006 dan Ogos 2007 untuk mengumpul data tentang amalan ternakan ikan tilapia di Malaysia. Data-data terkumpul melalui temu-bual dengan 104 orang petani dari lapan negeri merangkumi Negeri Sembilan, Pahang, Perak, Pulau Pinang, Sabah, Sarawak, Selangor dan Terengganu dengan pernekanan terhadap sistem penternakan dan input makanan. Berdasarkan jawapan-jawapan diterima, sistem-sistem ternakan utama yang digunakan di Malaysia adalah kolam tanah (40%), penternakan dalam sangkar (32%) dan kolam bekas tapak lombong (24%). Keputusan statistik berdasarkan data input daripada tinjauan menunjukkan penternakan dalam sangkar sebagai sistem terbaik dengan hasil pengeluaran tertinggi walaupun tidak mempunyai perbezaan ketara. Tambahan pula, kos makanan didapati sebagai kos pengeluaran tertinggi (> 50%) untuk penternakan tilapia di Malaysia terutamanya bagi sistem penternakan dalam sangkar (66.68 – 71.77%). Kos pengeluaran yang tinggi didapati berkaitan dengan penggunaan makanan ikan komersial dalam lebih daripada 90% ladang-ladang yang ditinjau. Tiga jenama makanan ikan utama yang paling banyak digunakan ialah Cargill (33%), Star Feedmills (30%) dan Dindings (21%). Peningkatan dalam harga makanan ikan komersial dan penternakan tilapia merah hibrid yang mempunyai kadar pertumbuhan yang lebih perlahan mengakibatkan penternakan tilapia di Malaysia semakin kurang menguntungkan dari segi ekonomi. Oleh itu, satu eksperimen telah dikendalikan untuk mengkaji potensi protein tumbuhan sebagai makanan tilapia dan mencadangkan penggunaan "Genetically Improved Farmed Tilapia" (GIFT) dalam akuakultur untuk meningkatkan pengeluaran dan mengurangkan kos pemakanan.

Kajian pemakanan selama 98 hari telah dikendalikan untuk menentukan kesan-kesan beberapa tahap protein dan lipid terhadap prestasi pertumbuhan, komposisi tisu dan indeks biologi bagi GIFT (*Oreochromis niloticus*) dan tilapia merah hibrid (*Oreochromis sp.*). Tiga diet berasas tepung kacang soya (melalui proses penapisan minyak) dan minyak kacang soya (terkandung dalam soya penuh lemak) dirumuskan untuk mengandungi 25, 30 dan 35% protein kasar masing-masing. Kesemua diet (S30, S35 and S40) dirumuskan untuk mengandungi 6 – 7% lipid mentah dengan 5% serbuk ikan dan 0.5% minyak ikan ditambahkan sebagai pemikat. Prestasi pertumbuhan, FCR dan pekali kebolehcernaan adalah nyata sekali lebih baik ($P < 0.05$) dalam ikan GIFT berbandingan tilapia merah hibrid. Diet S40 didapati merupakan diet terbaik berbanding dengan makanan tilapia komersial (S32). Jumlah kos pengeluaran adalah lebih rendah sebanyak 45% bagi ikan GIFT dan 36% bagi tilapia merah hibrid masing-masing berbanding dengan diet komersial. Pada keseluruhannya, pertumbuhan ikan dalam kajian ini adalah memuaskan. Penggantian tepung ikan dan minyak ikan dengan tepung kacang soya terbukti berjaya mengurangkan kos pengeluaran dari segi kos pemakanan tanpa menjejaskan prestasi pertumbuhan dan kesihatan spesies yang diternak.

A COMPREHENSIVE SURVEY AND STUDY OF TILAPIA AQUACULTURE IN MALAYSIA WITH EMPHASIS ON PRODUCTION STRATEGIES AND FEED INPUTS

ABSTRACT

A survey was conducted over a period of 10 months between November 2006 and August 2007 to collect data on tilapia culture practised in Malaysia with emphasis on farming systems and feed inputs. A total of 104 farmers from eight states comprising Negeri Sembilan, Pahang, Perak, Pulau Pinang, Sabah, Sarawak, Selangor and Terengganu were interviewed. Based on the responses received, major farming systems used in Malaysia were earthen ponds (40%), cage culture (32%) and ex-mining pools (24%). Statistical results suggested cage culture as the best performing system with the highest production yield although not significantly different ($P > 0.05$). Feed costs (> 50%) were found to be the highest contributor to production cost of culturing tilapia in Malaysia especially in cage culture systems (66.68 – 71.77%). High production cost was found to be caused by the use of commercial tilapia feed in over 90% of the farms surveyed. Three major aquafeed brands used by the farmers observed during the survey were Cargill (33%), Star Feedmills (30%) and Dindings (21%). Increase in commercial feed price and cultivation of the slower growing red hybrid tilapia (the main species farmed in Malaysia) has made tilapia culture in Malaysia less economically attractive in recent years. Therefore, a feeding trial was conducted to source for possible plant protein-based diets for red hybrid tilapia and to suggest a better strain for culture in an effort to help boost tilapia production while reducing feed costs.

A 98-day feeding trial was conducted to determine the effects of various dietary protein and lipid sources on growth performance, tissue proximate composition and biological indices of red hybrid tilapia (*Oreochromis sp*.) and Genetically Improved Farmed Tilapia (*Oreochromis niloticus*). Three soybean protein (solvent extracted dehulled soybean meal) and soybean oil (as in contained dehulled full fat soybean meal) based diets were formulated to contain 25, 30 and 35% crude protein. Performances of the formulated diets (S30, S35 and S40) were compared against a commercial diet of 32% crude protein (C37). All formulated diets contained 6 – 7% crude lipid with 5% fishmeal and 0.5% fish oil added as attractant. Growth performance, food conversion ratio and digestibility coefficients were significantly ($P < 0.05$) better in the GIFT strain compared to red hybrid tilapia. Diet S40 was found to be the best performing diet. Total production costs of fish fed S40 were lowered by 20.4% and 75.8% in GIFT and red hybrid tilapia, respectively, compared to those fed the commercial diet. Overall, growth performances of both strains were satisfactory. Near total substitution of fishmeal and fish oil with solvent extracted dehulled soybean meal and full fat dehulled soybean meal proved to be successful in reducing feed costs without adversely affecting the growth performance and health of the cultured species.

CHAPTER 1

INTRODUCTION

Globally, marine capture fisheries are diminishing each year and most of the major fishing areas have reached their maximum potential whereby 52% of global fish stock have been fully exploited and 17% over-exploited (Bostford et al., 1997; Garcia and de Leiva Moreno, 2000; FAO, 2005). The recent increase in fuel prices has also paralysed the fishing fleet of many countries as it is no longer profitable to catch fish in the oceans. On the contrary, per capita consumption of fish is increasing each year due to the rapidly expanding world population. Consequently, feeding our growing world population with adequate animal protein and maintaining the performances of food sources in the effort to increase yield and production output has become a major issue.

Capture fisheries production stays virtually plateau since the 90's and has shown signs of depletion each year (Figure 1.1). Nevertheless, capture fisheries and aquaculture supplied the world with 106 million tons of food fish in 2004, equivalent to 16.6 kg per capita supply (live weight equivalent) excluding aquatic plants (FAO, 2006b). World fisheries production in 2005 has even marked an increase of over 1 million tons compared with the previous year albeit the decline in capture fisheries, compensated by the increase in aquaculture production (FAO, 2006b).

According to the Food and Agriculture Organization (2006b), aquaculture has become the fastest food production sector in the world, expanding at an annual rate of about 8%. Aquaculture production has grown progressively since the 90's and marked a significant contribution of more than 50% of the world fisheries production in 2006 (Figure 1.1). As a result, the aquaculture industry can be foreseen as the sector with the greatest potential to meet the demand for food fish worldwide in the near future.

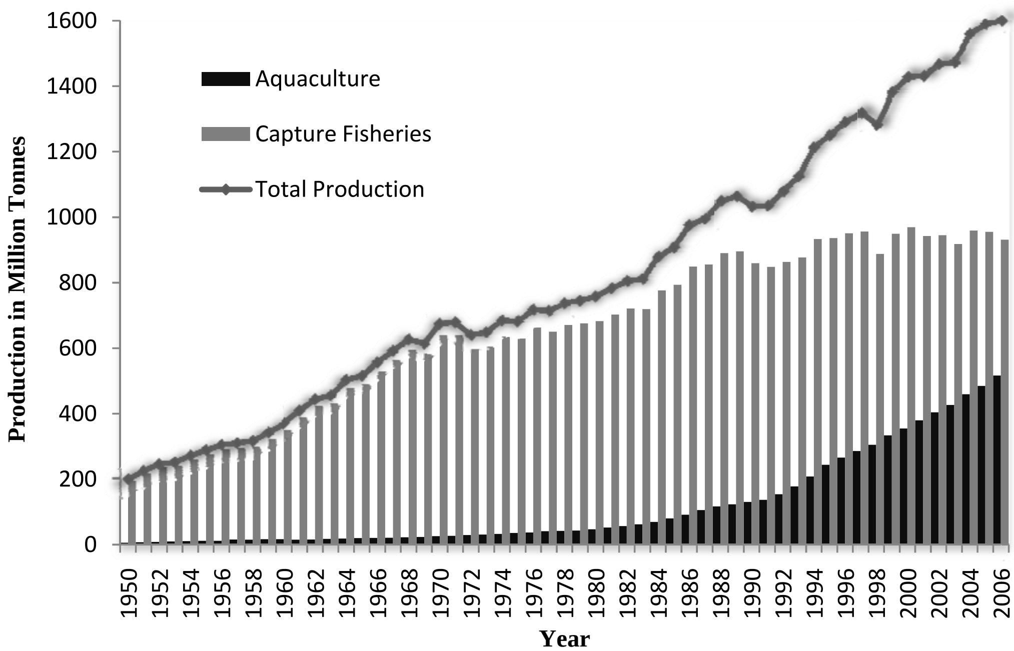

Figure 1.1 World fisheries and aquaculture production from 1950 – 2006 (FAO, 2009)

Furthermore, the global farming of tilapia has been growing rapidly since the 70's with increased popularity in the consumption of this freshwater cichlid. In 2005, the growth in Asia is the most notable, contributing up to 90% of world tilapia production (FAO, 2006b). Production rocketed from approximately 88,000 tons in 1985 to 1,748,000 tons in 2005 in the region. The current global tilapia production has exceeded 2,400,000 tons (FAO, 2009).

The Malaysian government has thus targeted tilapia as the major freshwater aquaculture species in the country under the third National Agricultural Policy (NAP3, 1998 – 2010) (MOA, 1999). Plans were formulated to target a total tilapia production of 160,000 metric tons in the country by the year 2010. In 2006, the official estimate of tilapia production in Malaysia was only about 30,000 tons.

In order to help, support and monitor the government's efforts in increasing tilapia production, a field survey was conducted to gather baseline data on parameters such as land status, water use, culture systems, farming practices, feed inputs and management, production costs, tilapia markets and price, access to seed, labour and support services, and other farm profile data. Considering that feed costs can account for up to 85% of the operation costs of tilapia farms depending on the type of culture system practiced, a major emphasis of Part 1 will be to evaluate the feed inputs used in the farming of tilapia in Malaysia.

The objectives of Part 1 are as follows:

1. To collect on-farm up-to-date data on tilapia farming in Malaysia through interview with farmers and their representatives by a single interviewer to reduce bias. Tilapia farms of various sizes and production capacity were selected for the comprehensive field survey.

2. To evaluate the production strategies and feed inputs used in the various tilapia farming systems in Malaysia.

3. To perform biochemical analysis on feedstuffs collected from tilapia farms including commercial feeds and ingredients, and/or farm-made feeds where available.

4. To use empirical mathematical models to estimate production function on the farm; highlighting production, costs and problems of tilapia farming in Malaysia.

5. To recommend strategies to stimulate the expansion of the tilapia farming industry in Malaysia.

No doubt growth in aquaculture is a possible solution for sustainable fisheries. As the solution to the management of depleting fisheries, aquaculture is believed to be able to relieve pressure on the current deteriorating marine fisheries industry. However, there are conflicts between aquaculture and marine fisheries. Apart from being the solution, it is also the contributor to the collapse of the world fisheries stock (Naylor et al., 2000; Naylor et al., 2001). As one of the major protein source in most aquafeed production, intensive and semi-intensive aquaculture systems consumed 2 – 5 times more fish protein in the form of fishmeal to feed farmed species than is supplied by the industry.

On the other hand, the cost of feeds is one of the major obstacles in aquaculture production. As the biggest single variable cost, it can go up to more than 70% of the total production cost, keeping tilapia farming from becoming economically lucrative. However, feeding cost can be reduced by minimising protein in feeds and/or substituting expensive marine fish meal and fish oil with cheaper plant ingredients because substituting vegetable oil for fish oil in freshwater fish is technically possible (De Silva and Gunasekera, 1989; Lim and Akiyama, 1992; Cremer et al., 2002a, 2002b; Bahurmiz and Ng, 2007).

In the search for cheaper raw material of plant origin in fish feed, it is important to ensure that the substitution does not affect the growth rate or health of the fish as well as quality of the final product. Owing to the fact that plant protein has a different amino acid profile than fish protein, it is necessary to ensure that the amino acid profile of diets with plant protein provide adequate amounts of essential amino acids for the fish.

Therefore, one possible candidate could be soybean meal. It is the oilseed meal that has the most similar profile as fishmeal amongst the other plant protein sources (Torsvik, 1998; Hempel, 1999). Although livestock, especially poultry and swine industry (Naylor et al., 2001), used to be the major consumer of fishmeal, soybean meal has taken over the role of fishmeal as the major protein source in livestock feeds. Yet, the incorporation of soybean meal is still relatively small scale for aquafeeds which is dominated by fishmeal.

Consequently, in the effort to evaluate the possibility of near total substitution of fishmeal with plant protein, an experiment was conducted in the second part of the study to evaluate the performance of dehulled soybean meal and full fat dehulled soybean meal in formulated aquafeeds when compared with a commercial extruded feed.

The objectives for Part 2 are as follows:

1. To formulate economical and practical alternative feeds for commercial tilapia aquaculture.

2. To conduct a feeding trial in the effort to evaluate the actual performances of the formulated diets under farm condition.

3. To evaluate the effect of feeding formulated plant protein based diets and commercial diet on the growth performances and feed utilisation of two

strains of Tilapia; Genetically Improved Farm Tilapia (GIFT) and Red hybrid tilapia (*Oreochromis sp.*).

4. To evaluate the nutrient profile of the feed and end product using various statistical analysis and biochemical profiling.

5. To evaluate the digestibility of formulated feeds in comparison with commercial feed.

CHAPTER 2

LITERATURE REVIEW

2.1 Historical introduction of aquaculture and tilapia

Aquaculture by definition is the farming of organisms in an aquatic environment, inclusive of culturing fish, molluscs and aquatic plants, in a fresh, marine or brackish environment (Pillay and Kutty, 2005; Stickney, 2005; El-Sayed, 2006). Since it is an expressive and comprehensive term, clarification must be made to denote the culture system, cultured species and the water body where the culture was practised.

The practise of aquaculture can be traced back to ancient China and Egypt about 4000 to 5000 years ago (Ackefors et al., 1994; Pillay and Kutty, 2005). Although the documented time of aquaculture varies, most publications reported the first publication on aquaculture was written around 500 B.C. by a Chinese fish culturist, Fan Li (Ackefors et al., 1994; Pillay and Kutty, 2005; Stickney, 2005). However, the first tilapia culturist is believed to be the Egyptians who raised tilapia in earthen ponds around 2500 B.C. (Pillay and Kutty, 2005; Shelton and Popma, 2006).

In the past three decades, aquaculture has expanded, intensified, and made major technological advances. Most of the world's recent increases in per capita food fish supply have been obtained from aquaculture. Worldwide, more than 1 billion people rely on fish as an important source of animal protein, healthy lipids, and essential micronutrients.

Cichlids are native to the African continent. To date, there are at least 900 known species and estimated to be more than 1300 species worldwide (Kullender, 1998). Of all the known species, none is marine except for some hybrids cultured in Bahamas and the Caribbean (Stickney, 2005). The introduction of the species outside the African continent was documented in the early twentieth century to some 90 countries all over the world (Shelton and Popma, 2006).

Although Cichlidae is the most species diversified fish family, only a few species are commercially important and farming significant. Species identified as commercially important are the Nile tilapia (*Oreochromis* spp.), including *O. niloticus*, *O. aureus* and various crosses of red hybrids of the former two species with *O. mossambicus* (Stickney, 2005; Shelton and Popma, 2006).

These tilapias have many characteristics that favour the aquaculture industry including relatively short culture period (about 6 months), high tolerance to poor water quality and high stocking density, and high productivity rates. Figure 2.1 depicts the top three cultured tilapia species produced in 2004 and 2006. Nile tilapia was the most cultured and produced species, followed by Mozambique tilapia and tilapia not elsewhere included (tilapia nei).

The Mozambique tilapia (*O. mossambicus*) was first introduced to Malaysia during World War II. A recent study by Bhassu et al. (2004) revealed the genetic make-up of the tilapia population in Malaysia. They examined various strains of tilapia (Chitralda, Philippines, Taiwan strains and *O. mossambicus*) obtained from various regional and local commercial breeders. The cultured species in Malaysia was identified as *O. niloticus* and *O. mossambicus* or the cross-breed of both (*Oreochromis* sp.).

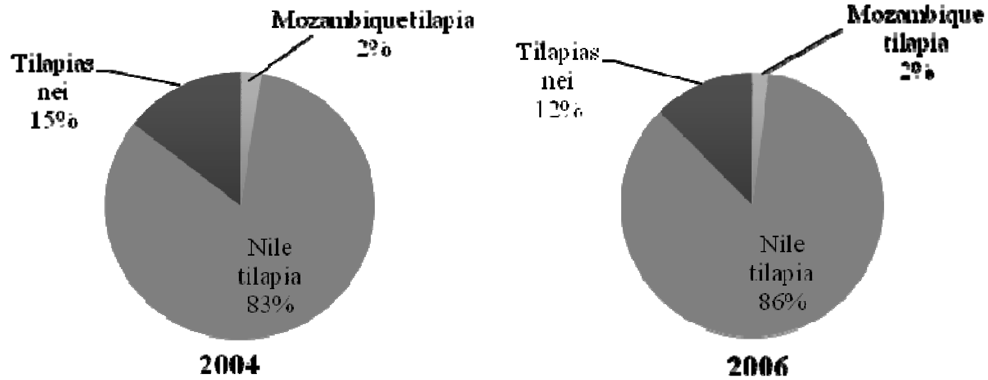

Figure 2.1 Percentage of Cichlidae productions by species in 2004 and 2006 (FAO, 2009).

Today, more than 90% of tilapia is produced by more than 100 countries around the world (outside their native Africa). These freshwater cichlids have become an increasingly important food commodity worldwide, being the second most farmed freshwater species after carp.

2.2 Prospect and potential of tilapia farming

2.2.1 Global

Aquaculture has been growing more rapidly than any other animal food-producing sector in the world. Between 1970 and 2000, global aquaculture production grew at an average annual rate of 9.2%, compared with only 1.4% for capture fisheries and 2.8% for terrestrial farmed meat production. In 2000, global aquaculture production was 45.7 million mt, valued at US$ 56.5 billion. Finfish accounted for 23 million mt, or about half of total aquaculture production.

Global production of cichlids is growing steadily at an annual rate of 8 to 11% since 2001 (Figure 2.2). In 2006, tilapia production was 2.3 million mt valued at about US$ 2.78 million. Ever since FAO started reporting aquaculture productions, almost 70% of world tilapia production has been originated from Asia (FAO, 2009). China alone contributed up to 80% of total tilapia production in Asia, making her the largest tilapia producing nation worldwide. In order to supply enough food fish for the growing population, China is likely to continue topping the list of major tilapia producing country.

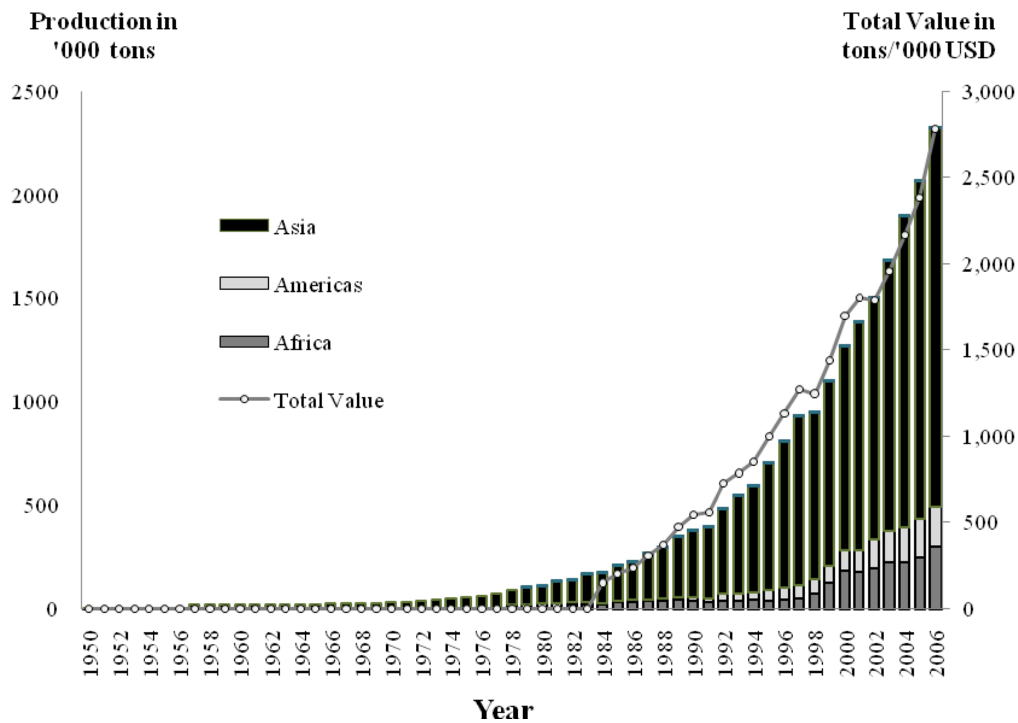

Figure 2.2 Major cichlid producers and total value by continent, 1950 – 2006 (FAO, 2009).

2.2.2 Southeast Asia

Nile tilapia farming in Southeast Asia began to prosper in the 1970s, particularly in the Philippines and Thailand. There were contemporary, region-wide advances in tilapia hatchery technology, and in pond and cage husbandry. These advances contributed in boosting production of farmed tilapia and masked the lack of attention to their genetics in the 1970s and 1980s. During the 1980s, some consequences due to the lack of attention to tilapia genetics began to emerge. The period from the 1960s to the 1980s represented about 40 tilapia generations of missed opportunity for genetic improvement (ADB, 2004).

The bottleneck of tilapia production was identified as the poor genetic quality and diversity of Asian farmed tilapia (Pullin, 1988). Hence, the International Center for Living Aquatic Resources Management (ICLARM, now the WorldFish Center) initiated the GIFT (Genetic Improvement of Farmed Tilapias) project in 1988 funded by the United Nations Development Program (UNDP) and the Asian Development Bank (ADB) (Gupta and Acosta, 2004). The project highlights the improvement breeds of Nile tilapia for better production yield and lower production cost (Dey and Gupta, 2000).

The GIFT project was found to be successful. The culture performance of the GIFT strain compared to the best local non-GIFT strains in China, Philippines and Thailand was found to outperform the local fish. GIFT strains were able to survive well in pond and cage systems, present higher body weight at harvest and resulted in lower production costs (Dey and Gupta, 2000; Gupta and Acosta, 2004).

As a result, the Philippines has always been a major tilapia producer in Southeast Asia (SEA), followed by Indonesia and Thailand. All three countries have adopted the low-cost production of GIFT tilapia. However, Malaysians favour the red hybrid tilapia (*Oreochromis* sp.) over the GIFT owing mostly to the appearance of the red hybrid tilapia. Nevertheless, Malaysia ranked fourth in this region with 29,810 mt produced in 2006, valued at over 36 million US$ (Table 2.1). All the major tilapia productions in SEA including Thailand, Indonesia, the Philippines and Malaysia are produced in inland freshwater or brackish water systems.

In general, tilapia production is increasing steadily in the Philippines, Indonesia and Malaysia. With growing concern on healthy eating, the growing population and attempts to feed the poor with adequate animal protein, there is still room and potential for the tilapia industry in the SEA to grow.

Table 2.1 Tilapia production in Southeast Asian countries from 2000 to 2006, tons / '000 US$[1] (FAO, 2009).

Country	2000	2001	2002	2003	2004	2005	2006
Brunei Darussalam	14 (41)	NR[2]	52 (124)	50 (122)	46 (163)	46 (164)	50 (178)
Cambodia	370 (881)	359 (836)	376 (827)	476 (1,047)	500 (1,100)	400 (880)	600 (1,320)
Indonesia	85,179 (187,238)	105,106 (226,015)	109,768 (87,478)	123,748 (102,032)	139,651 (105,119)	189,570 (145,910)	219,234 (176,482)
Lao People's Dem. Rep.	18,928 (39,749)	22,499 (44,889)	26,872 (53,744)	29,205 (58,410)	29,205 (58,410)	19,590 (22,920)	19,590 (25,467)
Malaysia	18,471 (25,347)	16,253 (21,233)	20,757 (22,179)	22,560 (30,582)	25,642 (35,469)	28,635 (39,681)	29,810 (36,271)
Myanmar	NR[2]	NR[2]	1,000 (3,000)	1,500 (4,500)	2,000 (6,000)	2,000 (6,000)	10,000 (30,000)
Philippines	92,579 (102,161)	106,746 (100,977)	122,399 (113,795)	129,996 (116,763)	145,869 (132,589)	163,004 (172,069)	202,040 (241,746)
Singapore	37 (143)	52 (131)	142 (298)	65 (187)	53 (144)	37 (111)	40 (99)
Thailand	82,581 (57,903)	84,510 (51,103)	83,936 (62,719)	98,376 (66,348)	160,407 (119,649)	155,065 (125,612)	153,064 (121,666)

[1] Numbers in parentheses are values in thousand US dollar rounded up to the closest round number.
[2] NR = not recorded

2.3 Status of aquaculture in Malaysia

The Malaysian government has targeted to produce 600,000 mt of seafood from aquaculture by the year 2010 under the Third National Agricultural Policy (NAP3, 1998-2010) (MOA, 1999). NAP3 is a guideline formulated by the Malaysian government for the development of the agriculture sector which includes fisheries sector. It emphasises development towards a fully modern and commercialised capture fisheries and aquaculture industry through exploitation of available resources on a sustainable basis.

NAP3 promotes commercial scale aquaculture which will be adequately equipped with modern fisheries infrastructure and supported by comprehensive human resource development programs. Under the NAP3, the targeted total production of freshwater fish is 220,000 mt by the year 2010 with tilapia identified as the major fish species contributing about 160,000 mt.

However, freshwater aquaculture production reported in 2006 (DOF, 2006a) was only 62,574 mt (Figure 2.3) with tilapia production contributing 28,886 mt despite a 78% increase in tilapia production since 2001. As a result, much remains to be done to accomplish the tilapia production target by the year 2010.

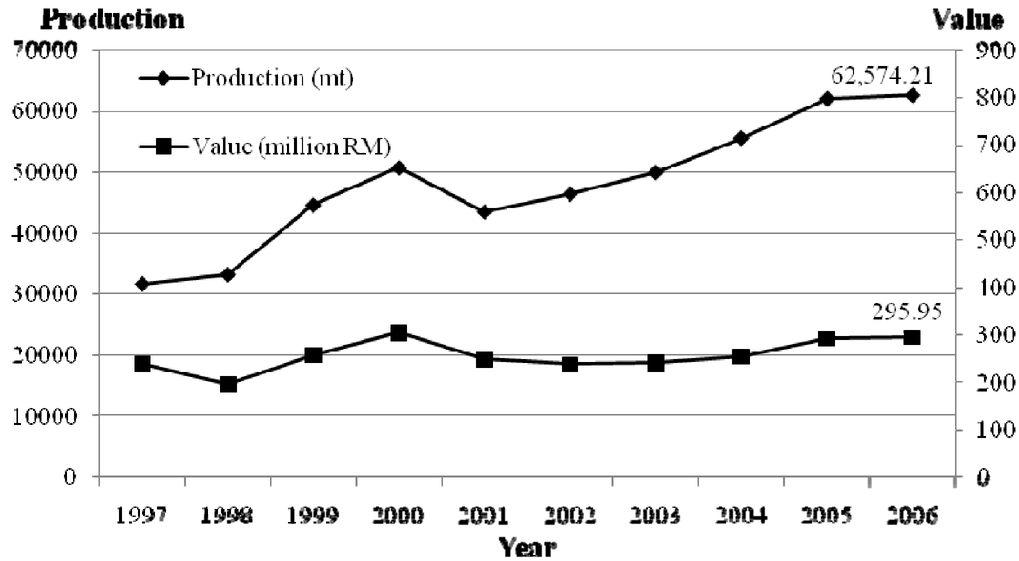

Figure 2.3 Estimated production and value from freshwater aquaculture system, 1997 – 2006 (DOF, 2006a).

2.3.1 Freshwater aquaculture production

The fisheries sector in Malaysia contributed 1.42 million mt of seafood valued at RM 5.2 billion in 2005 (DOF, 2006b). Freshwater aquaculture contributed about 29% of total aquaculture production in 2006 (DOF, 2006b) with production coming from various culture systems such as ponds, ex-mining pools, cages and tanks/pens (19%, 5%, 4% and 1%, respectively) totalling 61,652 mt (Figure 2.4). The three major freshwater species farmed in Malaysia are tilapia, catfish and carps constituting 50, 38 and 6% of total freshwater aquaculture production, respectively (Figure 2.5).

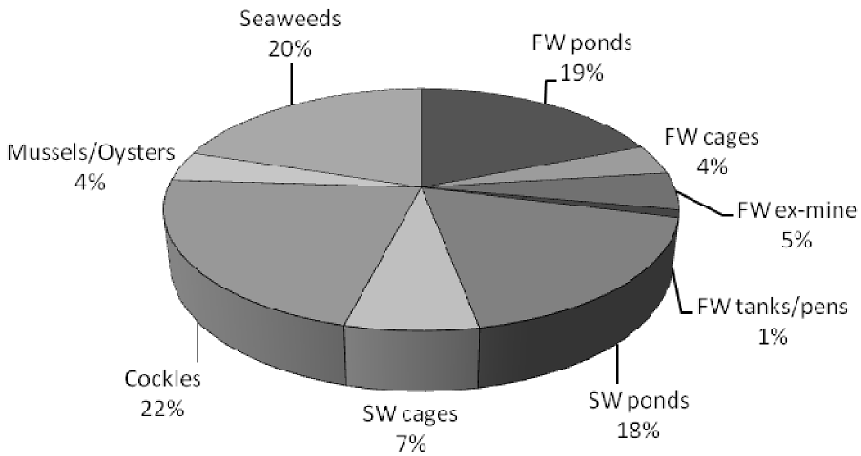

Figure 2.4 Aquaculture productions in Malaysia by culture system (DOF, 2006a).

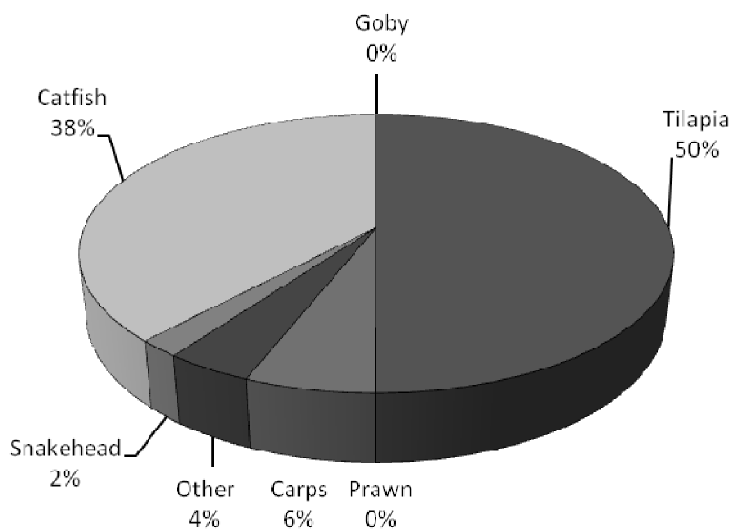

Figure 2.5 Freshwater aquaculture species cultured in Malaysia (DOF, 2006a).

Other freshwater species include snakeheads, marble gobies and freshwater prawns. About 28,886 mt of tilapia were produced in 2006 out of which 23,438 mt were red hybrid tilapia. The major tilapia species farmed in Malaysia is the red hybrid tilapia (*Oreochromis* sp.), accounting for about 81% of total tilapia production, the remaining being the black tilapia (*O. niloticus*, *O. mossambicus* or hybrids thereof).

In comparison with her immediate neighbours Indonesia and Thailand, Malaysia still has a lot of catching up to do before she can be considered a major tilapia producing country. Due to easy access to fish and fish products, Malaysia is among the countries with the highest fish consumption in the world. As a cheap source of animal protein, fish is considered an important food item by locals. The Malaysian annual per capita consumption of fish was recorded as one of the highest (58.4 kg) between 2000 and 2002 (FAO, 2006a).

However, the per capita consumption recorded in 2005 was only 53 but it is expected to rise further to 56 kg per capita in the year 2010 (Othman, 2006). With the need for national food security, poverty alleviation and to increase seafood exports, the Malaysian government has embarked on an ambitious plan to boost the agriculture industry (including aquaculture) in the country.

2.3.2 Economical feasibility of farming tilapia in Malaysia

The aquaculture sector in Malaysia contributed 0.366% of the total value of Gross Domestic Product (GDP) in 2001 and generated employment for over 20 thousand people in the country (FAO, 2006a). The distribution of red hybrid tilapia fry in 2006 was estimated at 934.38 million pieces produced by 106 breeding centres and involved 6,671 ha of freshwater bodies (DOF, 2006a). Total culturists in the same year were estimated at 20,642 people. Following the FAO estimation (2006a), assuming the employment of four workers per farmer, the aquaculture sector was able to generate working opportunities for over 80 thousand people in Malaysia in 2006.

In order to achieve 160 thousand mt by 2010, at least 21% annual increase of tilapia production between 2007 and 2010 is needed. Much effort have been done by the government sector such as releasing 8.37 million pieces of fish fry into various public water bodies and distributing 24.84 million fries to culturists in 2006 (DOF, 2006a). Various incentive programs were also implemented to draw more educated young entrepreneurs into the aquaculture sector. Lakes and reservoirs such as Tasik Kenyir in Terengganu were gazetted as High Impact Project Aquaculture Industrial Zone (HIP-AIZ). Tilapia farmers in these areas fulfilling certain criteria are given help in terms of financial support, technical support for farm set-up and farm facilities upon approval by the local DOF or DOA.

On the other hand, the export of tilapia is restricted and dominated by a few private tilapia producers in the country. These exporters are recognised by the Malaysian government for practising Good Aquaculture Practise (GAqP) and rewarded with the Farm Certification Scheme (SPLAM) (Othman, 2006). Export of tilapia commodities are mainly live fish to nearby Singapore or Thailand. As GAqP is not a requirement for finfish farming in Malaysia due to the lack of guidelines for finfish aquaculture activities, most culturists in this country do not practise GAqP since the maintenance is costly and time consuming. Unfortunately, this also limits the selling of tilapia products to international markets which fetch a higher price than the local market.

Although the Malaysian government is keen on promoting tilapia farming in Malaysia, to attain the 21% annual growth in production will not be an easy task with the current production rate. Since feeding costs can account for up to 85% of total production costs, it is considered a major obstacle to overcome. Undoubtedly, potential for the tilapia industry in Malaysia remains high with the support of various programs launched by the government and considering its potential in the international and domestic markets. Moreover, there is currently no baseline data to support the actual status of tilapia production in this country especially in regards to farming systems and feed inputs which pose the biggest threat to the tilapia industry in Malaysia. Therefore, it is timely a comprehensive survey of tilapia farming industry in Malaysia is conducted in order to help and support the efforts to increase tilapia production in the country.

2.4 Feed and feeding tilapia

Aquaculture is a profit oriented commercial farming of aquatic animal. Therefore, feeding tilapia becomes crucial to the economic feasibility of farming tilapia as feed is often the highest production cost among others. Besides, different species has specific requirements in dietary nutrition to promote maximum growth.

Tilapias (Genus *Oreochromis*) are all omnivorous, feeding on a wide variety of food ranging from planktonic organisms (zooplankton and phytoplankton) to plant materials. Nevertheless, food preference vary in physiology, nutrition and feeding behaviour among species and maturation stages (Hertrampf and Piedad-Pascual, 2000; Pigott and Tucker, 2002). As such, it requires a wide range of general knowledge on the targeted species to formulate the most suitable feed at the least possible cost. Most importantly, the feed should not negatively impact the health of the farmed animal or the final consumer of the fish.

2.5 Nutrient requirements for tilapia

The main purpose of feeding is to provide complete nutritional feedstuffs to the farmed animal to enhance growth and support life maintenances and other activities. Imbalanced diets or deficiency in certain substances may cause retardation in fish and make them susceptible to diseases. As such, balanced feeds should contain adequate amounts of energy, protein and amino acids, lipid, carbohydrate, vitamins and minerals in order to fulfil all the nutrient requirements of the cultured species.

2.5.1 Energy

Energy is essential in dietary nutrition to sustain life processes of tilapia including metabolism, reproduction, physical activities and growth (Tacon, 1987; NRC, 1993; Bureau et al., 2002; Pillay and Kutty, 2005). Albeit the importance of energy in dietary requirements, it is not a nutrient. However, the intake of proteins, lipids and carbohydrates directly results in the release of energy through a series of oxidation processes of these major energy-yielding nutrients (Bureau et al., 2002).

Poikilothermal animals like tilapia do not require as much energy as warm blooded animals in maintaining body temperature or excretion of urea and uric acid. Ammonia in their body is excreted directly through gills and as faecal material. Except for a small amount of energy lost through heat loss, fish are able to utilise more energy for tissue building under optimal conditions compared to terrestrial livestock (Pillay and Kutty, 2005). Therefore, it is very important to supply the fish with adequate energy because net energy after dissipation for maintenances and various metabolic processes will be retained in the body as new tissues.

2.5.2 Protein and essential amino acids

Protein is the most expensive component in tilapia feed. These complex nitrogenous substances are composed of combinations of basic amino acids (AA) units. Digestion of dietary protein results in the breakdown of the complex mixture into AA or peptide chains of a few AA (Pillay and Kutty, 2005). These AA can be divided into essential amino acids (EAA) and non-essential amino acids (NEAA). AA profile of dietary proteins differs significantly among various protein sources (NRC, 1993).

Moreover, protein is also identified as one of the major energy yielding nutrients (Gatlin, 2002) because the process of protein digestion releases energy for the uses thereafter. As the basic building nutrient, protein cannot be stored but is continually utilised by the fish in replacing existing protein during maintenance, and building new proteins during growth and reproduction (Wilson, 2002), while the remainder is converted into energy. Although the optimum level of crude protein in tilapia diets varies, Viola and Zohar (1984) had suggested 30 – 35% to be the optimum crude protein level in grower feed for hybrid tilapia (*Oreochromis*). Typical commercial diets for intensive culture usually contain 32% of crude protein (Lovell, 2002).

In fact, fish do not have a true protein requirement. The requirement in dietary protein is a means to obtain a well-balanced mixture of NEAA and EAA (Shiau, 2002; Wilson, 2002). Therefore, EAA and AA functions to fuel sufficient metabolic energy (ME) for carbohydrate and lipid metabolism (Tacon, 1987). Yet, the ten EAA required for the task cannot be synthesised by the animal body. Threonine, valine, leucine, isoleucine, methionine, tryptophan, lysine, histidine, arginine and phenylalanine (the EAAs) can only be obtained by the animal through consumption of dietary protein.

The amino acids composition in fishmeal is closest to that of the dietary EAA requirements of fish (NRC, 1993) making it the favourite protein source in commercial aquafeed. Besides being costly, excess protein intake requires more energy for deamination, leaving less for building new tissues. In the cases of deficiency, ME priority is given to life maintenance. Thus, imbalanced protein and amino acids in the diet (either in excess or deficit) will result in the collapse of the immune system (Gatlin, 2002) and cause retardation. As a result, a balanced dietary protein and amino acids requirements in feed (Table 2.2) refer to the minimum amount needed for the fish to achieve maximum growth (NRC, 1993; Fagbenro, 2000; Gatlin, 2002).

Table 2.2 Summary of protein and amino acids requirements for tilapia (*Oreochromis* sp.) and omnivorous species.

	Tilapia[1]	**Omnivorous grower**[2]	***Oreochromis niloticus***[3]
Energy (kcal DE/kg)	3,000	-	-
Protein (Crude Protein, %)	32	35	32
Percent amino acids as percentage of diets			
Arginine	1.18	1.51	1.28
Histidine	0.48	0.64	0.47
Isoleucine	0.87	0.98	0.81
Leucine	0.95	1.79	1.34
Lysine	1.43	2.07	-
Methionine + cystine	0.90	0.91	1.06
Phenylalanine + tyrosine	1.55	1.83	1.50
Threonine	1.05	0.81	1.03
Tryptophan	0.28	0.21	0.19
Valine	0.78	1.16	0.94

[1] NRC, 1993.
[2] Tacon, 1987.
[3] Fagbenro, 2000.

2.5.3 Lipids

Lipids are the most energy-rich nutrients, providing 9.5 kcal/g compared to 5.6 and 4.1 kcal/g provided by dietary protein and dietary carbohydrates, respectively (Tacon, 1987). Energy content in lipids is readily available for metabolism by aquatic animal. The protein-sparing properties in dietary lipids are able to provide a concentrated source of energy that is readily utilisable (Gatlin, 2002; Sargent et al., 2002). The level of dietary lipid inclusion can be formulated to maximize the protein-sparing effect, retaining more dietary protein to be converted into muscle protein (Sargent et al., 2002) thus enhancing growth.

In order to reduce the use of more expensive ingredients such as protein, NRC (1993) proposed that feed for a particular species should be formulated to the optimum energy to protein ratio. Besides energy storage, dietary lipids increase palatability of feed (Hertrampf and Piedad-Pascual, 2000), sustains normal health and growth (Gatlin, 2002), assists in absorption of fat-soluble vitamins and also a source of essential fatty acids (fuel to generate metabolic energy).

However, excessive dietary lipids can disturb the balance of nutrient compositions and increase fat deposition in vital organ which in turn adversely affect the health and growth of the fish instead of promoting growth and yield. The inclusion rate for grower omnivorous species suggested by Tacon (1987) is 6% in 1:1 fish oil to plant oil ratio.

2.5.4 Carbohydrates

Carbohydrate is the cheapest and most abundant ingredient among the energy-yielding nutrients in fish diets. Similar to protein, there is no specific requirement for carbohydrate established for fish (Tacon, 1987). Carbohydrates are also a protein sparing nutrient (Pillay and Kutty, 2005) and the principal source of metabolic energy (Tacon, 1987). Diets without the inclusion of carbohydrates results in the catabolism of more priced nutrients such as protein and lipid for energy. Thus, sufficient inclusion of carbohydrate in proper balance with the other nutrients in fish diet is necessary to achieve higher growth rate and reduce feed price (Gatlin, 2002). In the commercial feed industry, carbohydrates also act as binder and filler for extruded feeds.

Carbohydrate requirement in feed vary among species, depending on the complexity of carbohydrate structure and source (Pillay and Kutty, 2005). Warm water omnivorous species, such as tilapia, are able to utilise a higher concentration of soluble carbohydrates in the form of uncooked starch (Tacon, 1987; NRC, 1993; Lovell, 2002; El-Sayed, 2006). However, tilapia digests lipids and proteins better than carbohydrates. Moreover, excess inclusion of carbohydrate in tilapia diet will depress growth and yield caused by anti-nutrient inhibitors present in various carbohydrate sources.

Study shows heat treatment can partly solve this problem and that larger fish are able to utilise carbohydrate better than smaller fish (El-Sayed, 2006). For example, commercial extruded feed prepared under high moist temperature will cause starch to gelatinise and therefore improve digestibility. Nevertheless, inclusion rate should not exceed 40% in grower diet with maximum crude fibre of 4% (Tacon, 1987).

2.5.5 Vitamins and Minerals

Minerals and vitamins are essential nutrients for all living organisms including aquatic animals. Minerals are inorganic elements and vitamins are organic elements in fish diets and fish body. Although both elements constitute a minute fraction of the feed, deficiency in these components is likely to adversely affect tissue formation, interrupt various metabolic processes, suppress growth and eventually, death of the animal.

Unlike terrestrial animal, fish are able to derive certain minerals form its surrounding water. Therefore, the amount of absorption depends greatly on the availability of minerals, salinity, temperature and pH of the surrounding water. Aquatic animals absorb minerals in ion forms through the process of drinking water or through their gills, skin and fins. Minerals in fish are essential constituents of the exoskeleton and important for osmoregulation (Tacon, 1987). NRC (1993) identified nine essential minerals for fish namely calcium, phosphorus, magnesium, iron, copper, manganese, zinc, selenium and iodine, to remain healthy and maintain normal performances. However, only magnesium, phosphorus and zinc are quantified for the requirement of juvenile tilapia.

On the other hand, vitamins are required by the animal in trace amounts from exogenous sources because vitamins are either not synthesised by the animal or insufficient to meet its needs (Tacon, 1987; NRC, 1993; Hertrampf and Piedad-Pascual, 2000). Therefore, vitamins must be supplied through feed to ensure normal fish growth (NRC, 1993). Although, qualitative and quantitative amounts of vitamin requirements for tilapia is unknown (NRC, 1993), Jauncey (1998) suggested a general premix for intensive farming of tilapia (Table 2.3). He also suggested that cyanocobalamin (B12), inositol, choline and menadione (vitamin K) can be excluded from the premix.

Table 2.3 Vitamin premix (per kg feed) for intensive tilapia farming (Jauncey, 1998).

Vitamins	Quantity
Thiamine (B1)	0 – 1 mg
Riboflavin (B2)	3 – 5 mg
Pyridoxine (B6)	0 – 1 mg
Retinol (A)	500 IU
Cholecaciferol (D3)	200 IU
Tocopherol (E)	10 mg
Pantothenic acid	3 – 5 mg
Nicotinic acid (Niacin)	6 – 10 mg
Ascorbic acid	50 mg
Folic acid	0 – 0.5 mg
Biotin	0 – 0.5 mg

2.6 Water quality requirements

Environmental characteristics are major factors that affect the well being of tilapia under culture conditions. The reproduction and feeding habits, digestibility and survival rate of culture tilapia is directly affected by physical environmental parameters such as pH, salinity, dissolved oxygen and temperature (Halver and Hardy, 2002). Although different species show different ability to adapt to these changes, tilapia demonstrates a wide range of tolerance to these parameters.

The success of tilapia culture in Asian countries owes very much to the tropical and sub-tropical temperatures. The optimum temperature for maximum performance is between 28 – 32°C (Lovell, 2002; El-Sayed, 2006). Their activities