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Studies on the nutritional quality of plant materials used as fish feed in Northern Vietnam

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Eidesstattliche Erklärung

Hiermit versichere ich, diese Arbeit selbstständig angefertigt und keine anderen, als die angegebenen Hilfsmittel verwendet zu haben. Zitate sind im Text kenntlich gemacht. Diese Arbeit ist noch nicht in dieser oder anderer Form einer Prüfungsbehörde vorgelegt worden.

Stuttgart den 08. 06. 2009. Euloge brice Dongmeza

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1. Summary

Aquaculture output has been growing at a high pace for decades. According to recent data published by the FAO, in 2007, 49% of fish and fishery products (excluding fish meal) consumed as food were farmed. This share is expected to reach 50% in 2008. Fish demand has risen worldwide as populations have grown and incomes have increased; thus fish are highly likely to continue becoming more expensive over the next two decades. However, this expansion might also cause a significant rise in the price of fishmeal which could endanger the availability of fish to the lower income groups and poor people in developing countries. Consequently the use of supplementary feeds in fish culture is therefore expected to increase. Fisheries and aquatic products are an important source of protein in Vietnamese diets. Nevertheless, in the upland areas, fish is scarce and expensive, and signs of protein malnutrition such as discoloration of hair and skin could be frequently observed among the poor inhabitants of Son La province, Northern Vietnam where the average price for fish on the local market was approximately 1.4 US$ kg^{-1} in 2005 which can be considered high, particularly when compared to the monthly per capita income in Son La of approximately 13.4 US$. In some villages nearly all households have at least one pond. The major inputs to the ponds system are crop leaves and residues and occasionally grasses and weeds. Fish are cultured in tilapia and cyprinid-based polyculture, the main species being grass carp which is the only species capable of efficiently ingesting and digesting the soluble cell contents of the leaf material used as input to the pond system. Despite these constraints, fish farming contributes enormously to food security in the region and generates incomes. Fish fed exclusively from macrophyte diets grow slow, and thus the annual fish production is low in the region. Up to now, none of the feeds currently used in Son La Province have been tested to assess the nutritional potential of the plant feed ingredients currently used as feed for fish in northern Vietnam. Neither their use as feed for grass carp, nor the seasonality of the chemical composition has been studied; furthermore, the digestibility and the antinutrient content of these plant residues and materials have not been investigated. It has widely been recognized that encouraging the further development of aquaculture production can contribute in a sustainable manner to food security and poverty alleviation in developing countries.

Therefore, it is the objective of this study to present a quantitative and qualitative evaluation of the gross chemical composition, energy and antinutrient content of the plant residues used as fish feed in the course of the year in Son La Province, Northern Vietnam. Subsequently feeding experiments were conducted and the apparent digestibility and metabolisability of the nutrients and energy of some of these plant residues in grass carp were determined.

All the experiments were conducted simultaneously in a computer controlled respirometric system, which allowed feeding and continuous measurement of oxygen consumption and in a water recirculation aquaria system where the faeces collection was more viable.

During the analysis, the plant materials were divided into two groups:

the first group contained plant material available all year round like bamboo, banana and cassava leaves. Banana leaves had a constant chemical composition and antinutrient content all over the year. Significant temporal changes were detected in the crude protein, acid detergent fibre, ash and energy as well as in the phenolic and phytic acid (PA) content of cassava leaves. Significant changes were also observed in the lipid and neutral detergent fibre content of the bamboo leaves whereas their antinutrient content remained constant during the course of the year. Only the saponin (SAP) from cassava leaves had a pronounced haemolytic activity against cattle erythrocytes.

The second group contained feed items occasionally fed to fish by farmers. The results of proximate analysis showed a great variability in the crude protein, crude fibre, ash and energy content of the plant feedstuffs expressed as % dry matter (DM) which ranged respectively between 1.4 and 27.4%, 2.4 to 30.5%, 2.9 to 30.4% and 8.5 to 22.1 kJ g^{-1}. Analysis of antinutrients showed that with the exception of napier grass and cassava tubercle tannic acid was detected in all other feedstuffs with concentration varying from 0.1 to 4.9% DM; SAP concentration ranged from 0.9 to 9.9% DM, however it was not detected in cassava tubercle and shingle flatsedge. The cyanide content of the different cassava products ranged between 323 ppm (in peels) to 102 ppm in tubercle. The amount of PA content was high (8.8% DM) for napier grass, but it was generally within the tolerable limits of fish for the other feedstuffs analysed in this study.

During the feeding experiment fish were fed six different plant feedstuffs (additionally to the same amount of a reference diet fed also to a control group). Significant additional body weight increase was obtained with grass carp fed additional amount of dried banana or fresh maize leaves. Whereas for grass carp fed additional dried maize or bamboo leaves, weed mixture or barnyard grass we had a significant diminution of the expected body weight gain (BWG). The apparent digestibility coefficient for crude protein, lipid and energy of the supplemented banana leaves were 92.9 ± 2.5, 62.4 ± 7.0 and 25.2 ± 0.7% respectively and of fresh maize leaves 70.6 ± 5.5, 35.9 ± 12.0 and 39.5 ± 6.8% respectively.

The O_2 consumption of the fish fed the different experimental diets was measured and it was found that the metabolic cost (amount of O_2 per unit of BWG) of the diets containing plant leaves was higher than those of the control groups and was significantly higher for the diets containing bamboo leaves or weed mixture.

In this study, the analysis of the different feedstuffs fed to fish in northern Vietnam showed that some of them had relatively high protein and low fibre content (banana and cassava leaves); however, for some feedstuff the antinutrient content was high.

The results of the present study indicate that the protein and other nutrients of banana and fresh maize leaves are valuable supplements in fishmeal-based diets for grass carp as they meet the nutritional demands and excel a fast growth of these fish. The findings clearly show that fresh and dry maize leaves have a contrary effect on the growth of grass carp. The role of dietary plant fibres and some antinutriants on nutrient assimilation in grass carp could be elucidated in this work.

The information provided in this study is a good base for scientists and extension workers to develop improved feeding strategies based on plant material available locally for grass carp. These findings should be further tested under pond conditions as they could lead to an increase of fish productivity with plant based feeds and enhance the livelihood of the small-scale farmers in the rural areas in Vietnam.

2. Zusammenfassung

Die Aquakulturproduktion ist in den letzten zehn Jahren stetig und signifikant gestiegen. Nach neuesten Berechnungen der FAO stammen 49% der in 2007 weltweit konsumierten Fische und Fischprodukte aus Aquakultur. Für 2008 wird erwartet dass dieser Anteil sogar noch auf 50% steigen wird. Die Gründe für diesen Zuwachs liegen in der weltweiten Zunahme der Bevölkerung und deren Einkommen. Es wird auch erwartet, dass die Preise für Fischprodukte wie z.B. Fischmehl steigen werden. Dieser preisliche Anstieg könnte für einkommensschwache Haushalte in Entwicklungsländern eine erhebliche Bedrohung ihrer Ernährungssicherung darstellen. Einhergehend mit einer erhöhten Fischproduktion, wird sich auch der Bedarf an Futterzusätzen erhöhen.

Fisch und andere Aquakulturprodukte sind eine wichtige Proteinquelle in der vietnamesischen Küche. Jedoch ist Fisch in den Hochlandgebieten, wie z.B. der nordvietnamesischen Provinz Son La, selten und teuer. Häufig wurden bei der ärmeren Bevölkerung von Son La Proteinmangel beobachtet, z.B. in Form von Pigmentstörungen von Haaren und Haut. Die Durchschnittspreise für Fisch lagen dort auf dem lokalen Markt bei ca. 1.4 US\$ kg^{-1} in 2005, was im Vergleich zu dem monatlichen Pro-Kopf-Einkommen von 13.4 US\$ einen beträchtlichen Anteil darstellt.

In Son La wird in den Tälern Aquakultur betrieben. Fische werden in Polykulturteichen gehalten und im Wesentlichen mit Blättern und Nebenprodukten der pflanzlichen Produktion sowie mit Unkräutern und Gräsern gefüttert. Die produzierten Fische bestehen überwiegend aus Karpfen und Tilapien. Dabei ist nur die am meisten verwendete Art, der Graskarpfen, anatomisch und physiologisch daran angepasst, pflanzliches Material mechanisch und enzymatisch aufzubrechen und dadurch die Zellinhalte aufzunehmen und zu verwerten.

Obwohl die Aquakultur in der Region fast ausschließlich auf der Fütterung von minderwertigem Pflanzmaterial besteht, trägt die Fischzucht einen wesentlichen Beitrag zur Ernährungssicherung und Einkommensgenerierung der lokalen Bevölkerung bei. Es wurde weitgehend anerkannt, dass die weitere Entwicklung der Aquakultur nachhaltig die

Ernährungssicherung und die Reduktion der Armut fördern könnte. Bis heute wurden jedoch keine der Futtermittel, die in Son La eingesetzt werden getestet um ihr nutritives Potential als Fischfutter zu bestimmen. Weder das Futter für die Graskarpfen, noch deren jahreszeitlich bedingten Variationen in der chemischen Zusammensetzung wurden bisher analysiert. Des Weiteren wurden auch nicht die Verdaulichkeit und die antinutritiven Inhaltsstoffe der genutzten Pflanzen untersucht.

Folglich ist es die Zielsetzung dieser Arbeit, eine quantitative und qualitative Auswertung der in Son La eingesetzten Futtermittel für Fische zu präsentieren. Dabei wurde die grobe chemische Zusammensetzung, der Energiegehalt und die Art und Menge der antinutritiven Inhaltsstoffe analysiert.

Anschließend wurden Fütterungsexperimente mit Graskarpfen durchgeführt und die scheinbare Verdaulichkeit und Metabolisierbarkeit der in einiger dieser Pflanzenrückstände enthaltenen Nährstoffe und Energie ermittelt. Alle Experimente wurden parallel in zwei Systemen durchgeführt, a) in einem computergesteuerten Respirometrischen System, das eine kontinuierliche Messung des Sauerstoffverbrauchs ermöglichte und b) in einem geschlossenen Wasserkreislaufsystem, in dem der Fischkot gesammelt werden konnte.

Während der Analyse wurden die Pflanzenrückstände in zwei Gruppen geteilt:

die erste Gruppe enthielt das pflanzliche Material, welches ganzjährig verfügbar war, wozu Bambus-, Bananen- und Maniokblätter zählten. Bananenblätter, die in verschiedenen Jahreszeiten gesammelt wurden, wiesen durchgehend eine konstante chemische Zusammensetzung und antinutritiven Stoffgehalt auf. Bedeutende jahreszeitliche Änderungen in Maniokblättern wurden im Rohprotein, Fett, in neutrallöslichem Fasergehalt, der Asche und dem Energiegehalt, sowie der Menge an phenolischen Substanzen und Phytinsäure festgestellt. Im Jahresverlauf zeigten auch Bambusblätter signifikante Unterschiede in ihren Fett- und neutrallöslichen Fasergehalten, während die Menge an antinutritiven Substanzen konstant blieb. Die Saponine der Maniokblätter hatten eine ausgeprägte hämolytische Aktivität gegen Vieherythrozyten.

Die zweite Gruppe enthielt Futtermittel, die den Fischen nur gelegentlich von den Bauern gefüttert wurden. Die Ergebnisse der chemischen Analyse zeigten eine große Variabilität in Rohprotein (1.4 - 27.4% der Trockenmasse (TM)), Rohfaser (2.9 - 30.4% TM), Energie (8.5 - 22.1 kJ g^{-1} TM) und im Aschegehalt (2.4 - 30.5% TM)der pflanzlichen Futterstoffe.

Die Analyse der antinutritiven Inhaltsstoffe zeigte, dass mit Ausnahme von Napiergras und Maniokwurzeln, in allen weiteren Futtermitteln Tannine (Gerbsäuren) mit Konzentrationen zwischen 0.1 bis 4.9% der TM vorhanden waren. Der Saponingehalt reichte von 0.9 bis 9.9% der TM, wobei sie nicht in Maniokwurzeln und Zyperngras festgestellt wurden. Der Zyanidgehalt der unterschiedlichen Maniokprodukte erstreckte sich zwischen 102 ppm in den Wurzeln bis zu 323 ppm in den Schalen. Mit Ausnahme von Napiergras, in dem der Phytinsäuregehalt mit 8.8% der TM sehr hoch war, lagen die Phytinsäurewerte der anderen in dieser Studie untersuchten Futtermittel deutlich unter dem für Fische tolerierbaren Richtwert.

Während der Fütterungsversuche wurden den Fischen zusätzlich zu einem Fischmehl-basierten Grundfutter sechs verschiedenen Pflanzenmaterialien (Maniok-, Bananen-, Bambus- und frische und trockene Maisblätter, Hühnerhirse und ein Mix aus Unkräutern) gefüttert. Die Kontrollgruppe bekam nur das Grundfutter in der gleichen Menge, wie die Fische, die zugefüttert wurden. Die zugefütterten Fische bekamen also insgesamt eine größere Menge Futter und mehr Nährstoffe als die Fische der Kontrollgruppe. Graskarpfen, die zusätzlich zum Grundfutter auch noch frische Mais- oder getrocknete Bananenblätter erhielten, zeigten einen signifikant gesteigerten Körpergewichtzuwachs im Vergleich zur Kontrollgruppe. Im Gegensatz dazu zeigten Graskarpfen die zusätzlich mit getrockneten Mais- oder Bambusblättern, Hühnerhirse oder dem Mix aus Unkräutern gefüttert wurden ein deutlich geringeres Wachstum als die Fische aus der Kontrollgruppe.
Die scheinbaren Verdaulichkeitskoeffizienten lagen bei Bananenblättern bei 92.9 ± 2.5% für Rohprotein, 62.4 ± 7.0% für Fett und 25.2 ± 0.7% für Energie. Bei frischen Maisblättern lagen die Koeffizienten bei 70.6 ± 5.5% für Rohprotein, 35.9 ± 12.0% für Fett und 39.5 ± 6.8% für Energie.
Die durchgeführten Sauerstoffverbrauchsmessungen ergaben, dass die metabolischen Kosten (verbrauchte Menge O_2 pro Einheit Massenzunahme) für die Fischgruppen, die mit Blättern

oder Gräsern zugefüttert wurden, allgemein höher waren, als die der Kontrollgruppen; für die Fische deren Futter zusätzlich Bambusblätter, Unkräuter oder Gras enthielten war der O_2 Verbrauch pro Einheit Massenzunahme sogar signifikant höher als die der Kontrollgruppen.
Die in dieser Studie enthaltenen Analysen der in Nordvietnam eingesetzten Fisch-Futtermittel zeigten, dass einige einen relativ hohen Anteil an Proteinen und einen geringen Anteil an Fasern hatten, wie z.B. Bananen und Maniokblätter. Jedoch zeigten einige Futtermittel ebenfalls einen hohen Gehalt an antinutritiven Inhaltsstoffen auf.
Die Ergebnisse dieser Studie deuten an, dass das Protein und die anderen Nährstoffe von Bananen- und frischen Maisblättern eine wertvolle Ergänzung für fischmehlbasierte Graskarpfenfutter sind, da sie den Bedarf der Fische decken und das Wachstum beschleunigen. Zusätzlich zeigen die Ergebnisse deutlich, dass getrocknete und frische Maisblätter einen gegensätzlichen Effekt auf das Wachstum der Fische haben.
Die Rolle der pflanzlichen Fasern und einiger antinutritiver Nährstoffe auf die Nährstoffassimilation in Graskarpfen konnte in dieser Studie beleuchtet werden. Die hier präsentierten Informationen stellen eine gute Basis für Wissenschaftler und staatliche Berater dar, um auf lokal verfügbaren, pflanzlichen Futtermitteln basierende Fütterungsstrategien zu entwickeln. Diese Ergebnisse sollten jedoch noch unter lokalen Bedingungen getestet werden, um eine gesteigerte Produktivität, erreicht durch pflanzenbasierte Futtermittel, nachzuweisen. Eine solche gesteigerte Produktivität würde letztendlich zu einer verbesserten Lebensgrundlage für die Kleinbauern in den ländlichen Gegenden Vietnams führen.

3. General Introduction

3.1 Introduction

Aquaculture output has been growing at a high pace for decades. The total world aquaculture production in the year 2006 was 51.7 mmt or 36% of total world fisheries landings of 143.6 mmt (FAO 2007).

In 2007, 49 % of fish and fishery products (excluding fish meal) consumed as food were farmed, a share expected to reach 50 % in 2008. This will be an important milestone in the history of aquaculture and in world fisheries supply.

The transition to an increasing reliance on culturing fish and other aquatic organisms has been the result of a combination of several factors, the most important being the inability of natural supplies to keep pace with rising demand (Williams, 1996). Fish demand has risen worldwide as populations have grown, incomes have increased, the nutritional benefits of fish have become better known, and luxury products from aquatic organisms have become status symbols.

Globally, production from capture fisheries has leveled off and most of the main fishing areas have reached their maximum potential. Future increases in demand for fish cannot be met by increasing catches from most natural fishery resource systems (FAO 2006). Thus fish are highly likely to continue becoming more expensive to consumers compared with other food products over the next two decades. Prices for food fish are likely to rise under nearly all scenarios. Therefore rapid aquaculture expansion is the only scenario which can lead to a drop in the projected real prices of low-value food fish. However, this expansion might also cause a significant rise in the price of fishmeal (Delgado *et al.,* 2003); which could endanger the availability of fish to the lower income groups and poor people in developing countries (Williams, 1999). The scenario that could better lead to slightly lower real fish prices is the one that improves efficiency in fishmeal and fish oil conversion through rapid technological progress.

There are some apprehensions that aquaculture will not be able to supply the growing demand for fish, especially the requirements of the lower income groups in the developing countries, unless deliberate interventions are made to either involve these groups in aquaculture production and/or improve aquaculture efficiency and productivity to make fish affordable for these consumers.

3.2 General aspects of the aquaculture system in the study region: the district Yen Chau in the province Son La in Vietnam

The consumption of fish is a tradition of Vietnamese people and aquatic products will remain a primary source for animal protein for them for the foreseeable future. Fisheries and aquatic products provide more than 30 to 40% of the protein in Vietnamese diets (Oxfam, 2000). MoFI estimates that between 60 to 70% of the cultured and caught fisheries products are consumed domestically (DANIDA, 2002). Home consumption of fish in Viet Nam was estimated by FAO at 17.4 kg per capita per year in 1997. Of this 17.4 kg about 5.7 kg was freshwater and diadromous fish (FAO, 2001). A later survey undertaken jointly by Food and Agriculture Organization (FAO), MoFI and Danish International Development Agency (DANIDA) indicates that the actual domestic consumption could be much higher than the above-mentioned estimates (DANIDA, 2002). A continuous increase in the total domestic and per capita consumption of fish was observed in all three surveys.

Freshwater aquaculture is the largest contributor to total aquaculture production (57.3%) (FAO, 2006). Since 1990 aquaculture production has been increasing continuously over the years (see Figure 1) and Viet Nam is currently acknowledged as having the fastest aquaculture growth rate in Asia (FAO, 2007). The target of the Vietnamese national fisheries development plan is to produce 2.0 million tonnes of aquaculture products in 2010 (MoFI, 2004).

Both fisheries and aquaculture activities in Vietnam are concentrated along the coast and in the river deltas.

The period between 1999 and 2001 witnessed a peak in growth of aquaculture in Vietnam, aquaculture now employs about 670 000 workers out of the total of 4 millions in fisheries.

The area under aquaculture has now reached nearly one million hectares (902 900 ha) with a total output of over one million tones which provides about 80 percent of the materials required for the processing and export sectors. The total revenue obtained in 2004 was over 6 000 billion VND (1 US$ = 15 870 VND) with an export turnover of US$ 2.397 billion (MoFI, 2005). The aquaculture sector has been considered as one of the key economic sectors of the nation, according to MoFI (2005).

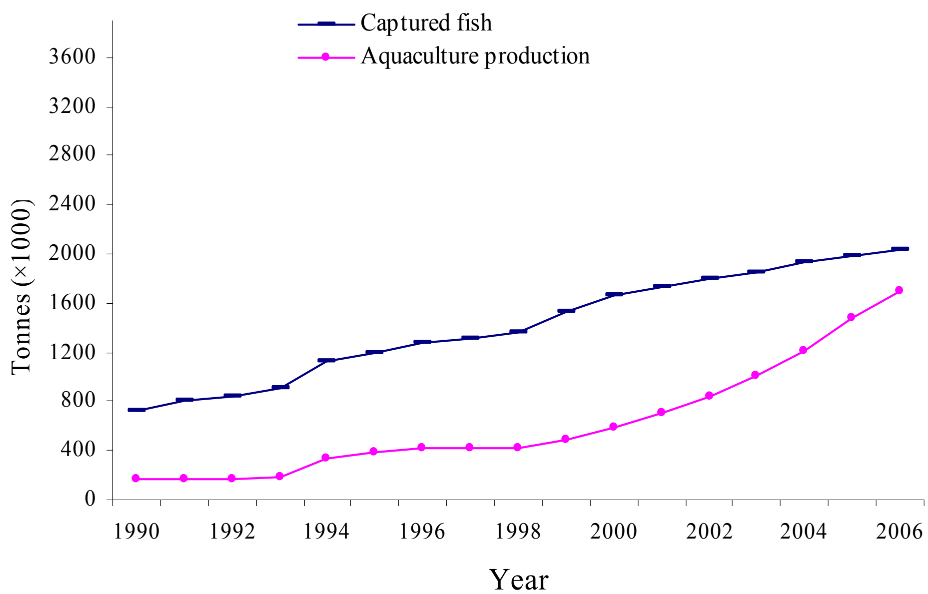

Figure 1: Reported aquaculture production and capture fish in Viet Nam (from 1990 to 2006)
(GSO (General Statistic Office) of Vietnam, 2007)

Son La province is located in the mountainous region of North-Western Vietnam on an altitude of approximately 600 m above sea level (Tuan, 2003) and is considered to be one of the poorest provinces in the country (Minot *et al.*, 2003). The climate is characterized by low temperatures, hoarfrost and little rainfall in winter and high precipitation accompanied with hot temperatures in summer. The poorest people in Vietnam are often found among members of the country's ethnic minorities and the population of remote areas such as the Northern mountainous areas (DFID, 2000; ADB, 2002).

In the upland areas, fish is scarce and expensive, and signs of protein malnutrition such as discoloration of hair and skin could be frequently observed among the inhabitants of Son La province, Northern Vietnam.

In the district Yen Chau of the Son La province, settlements of the ethnic Black Thai minority are located on the valley bottoms with paddy rice as major crop. In addition, maize, cassava and occasionally cotton are produced as cash crops on the hillsides and vegetables and fruits are grown in home gardens. Common animals reared comprise poultry, ruminants and pigs, but fish farming is also a typical activity in this region. Fish are cultured in tilapia and cyprinid-based polyculture, the main species being grass carp. The ponds have a continuous water-flow and the fish are fed mainly grass and leaf material. Depending on the village, 40-70% of all households have at least one pond. The pond size varies between 250 m^2 and 12 000 m^2. However, most ponds are smaller than 1000 m^2. The ponds are integrated with other farming activities through manifold linkages (Steinbronn *et al.,* 2005). Out of the five fish species commonly used in the project region (grass carp (*Ctenopharyngodon idella)*; bighead carp (*Hypophthalmichthys molitrix)*; mud carp (*Cirrhinus mrigala)*; common carp (*Cyprinus carpio)*; tilapia (*Oreochromis niloliticus*)), only grass carp are capable of efficiently ingesting and digesting the soluble cell contents of the leaf material used as input to the pond system. Major inputs to the ponds system are cassava, banana and bamboo leaves and occasionally grasses and weeds, as well as manure from large ruminants and pigs (Steinbronn *et al.,* 2006)

Only slow growth can be expected from fish fed exclusively macrophyte based diets (Wiley and Wilke, 1986). Up to now, none of the feeds currently used in Son La Province has been tested as feed for grass carp, nor have the seasonality of the chemical composition and the digestibility and the antinutritional content of these plant residue materials been investigated. It has been reported in several studies that the use of plant materials (including leaves) is usually restricted because of the presence of one or more endogenous antinutritional factors or antinutrients (Jackson *et al.,* 1982; Wing Keong *et al*., 1989; Makkar and Becker, 1997; Makkar, 2007).

For the pond system, grass carp plays an important role as they shred the leaf material and can fertilize the pond. In the example of grass carp fed duck weed, 45% of the gross energy of the plant feed were still contained in the faeces (Cui et al. 1992). For fish consuming leaves with higher fiber content, this figure is normal and can even be higher. Thus fecal material of the fish (grass carp) can contribute to the detritus pool in the pond.

Although the aquaculture system in Son La shows features which are usually associated with intensive systems such as a frequent water exchange and apparently being supplementary feed-based (Edwards et al., 1988), annual fish yields are relatively low, varying from 300kg/ha (van Anrooy et Evans, 2001) to an average of 1,6t ha^{-1}, according to the General Statistic Office of Vietnam (GSO 2008). This annual production is rather lower in comparison with other integrated carp polyculture systems in Vietnam, which are reported to yield over 6 tons ha^{-1} during a 9-month production season (Luu *et al*., 2002).

The low productivity can partly be explained by the low quality and limited availability of water as well as a food base that is apparently adequate for grass carp, but not for other fish species.

Despite these constraints, fish farming contributes enormously to food security in that region, generates income and plays a significant role in farmers' lives. Low-income people in developing countries, who usually consume comparatively low amounts of animal protein, often depend on fish as a major source of protein in their diets (Kent, 1997).

The average price for fish on the local market was approximately 1.4 US$ kg^{-1} in 2005 (1 US$ = 15 870 VND), which can be considered high, particularly when compared to the monthly per capita income in Son La of approximately 13.4 US$ (GSO, 2004), indicating that local fish demand is in excess of supply leaving farmers a potential scope for increasing their fish production. Small improvements in the system might lead to big increases in fish yields (Steinbronn et al., 2006) and ameliorate the income of the local poor smallholder. It has widely been recognized that encouraging the further development of aquaculture production can contribute in a sustainable manner to food security and poverty alleviation in developing countries (Tacon, 1997; Edwards, 2000; Prein and Ahmed, 2000).

3.3 Grass carp (*Ctenopharyngodon idella* Val.)

The Grass carp is a member of the Cyprinid family (Cyprinidae). It is the only member of the genus, and there are no subspecies (Lin, 1935). Sometimes it is referred to as the white amur. It is a native Chinese freshwater fish with a broad distribution. Grass carp has a long history in aquaculture and is one of the most important species cultured in inland water bodies in China and in many other countries in the world. In 2002, 39 countries and regions reported cultured production of grass carp to FAO. The fact that it is easily cultured and hardy (Dupree and Huner, 1984), has a fast growth rate (Blackburn and Sutton, 1971; Shireman *et al.,* 1977, 1978; Shireman *et al*., 1980), large size (Prowse, 1966), lack of fine inter-muscular bones and most importantly, its feeding habits (Tang, 1970; Lopinot, 1972) make the fish an ideal species for culture in different areas. Rapid expansion of its culture outside China implies that this great potential is being realized.

Grass carp exhibit strong preferences for different macrophyte feeds depending on the aquatic system. It is basically a herbivorous fish (He and Xie, 1966; Opuszynski, 1972; Wen, 1990) that naturally feeds on certain aquatic weeds. Grass carp daily consumption rates are highly variable, depending on the interplay of different factors including temperature, oxygen, food availability, and preference (Chilton II and Muoneke, 1992). Jensen (1986) reported consumption rates of up to 300% body weight/day, but according to Opuszynski (1972), daily consumption at 20°C is about 50% body weight, and maximum daily consumption at 22-33°C is 100-120% body weight. It has been pointed out that fish fed hydrilla *(Hydrilla* spp.*)* consumed 127 ± 17% of their body weight /day (Wattendoff and Anderson, 1987). However, Wiley and Wike (1986), using experimental fish of roughly the same size, never found daily consumption rates exceeding 50% body weight. An inverse linear relationship between grass carp size and consumption was reported by Osborne and Sassic (1981), thus macrophyte consumption by large grass carp, weighing more than 6 kg, may be as low as 25-28% body weight /day (Shireman and Maceina, 1981).

Food habits of grass carp change as they grow and develop (Chilton II and Muoneke, 1992). The fry/larvae feed on zooplankton. Opuszynski (1968) reported that fry feed on animal food until they reach lengths of 3-4 cm and the proportion of macrophytes consumed increases with grass carp growth (Opuszynski, 1972). Watkins *et al.* (1981) examined gut contents of fingerlings ranging from 17 to 117 mm total body length (TL). Fish of 17- 31 mm TL consumed primarily benthic invertebrates. In fish of 32-86 mm TL, periphyton comprised the major portion of the diet. Hydrilla, *Hydrilla* spp., along with bank vegetation comprised 86% of the diet of larger fish: larger fish could naturally tolerate higher amount of macrophytes in their diet and probably made good use of it.

Food habits of grass carp may also be affected by stocking site and situation (Chilton II and Muoneke, 1992). For example, Kilgen and Smitherman (1971) reported that when stocked alone in ponds, grass carp (more than one year old) ate mainly macrophytes (75-95% by volume), but a maximum of 18% of their gut contents were insects. When they were stocked in combination with other species, their diet consisted of 84% macrophytes and only 9% insects.

Consumption by young fish, below 60 g of body weight, tends to be greater when they are fed mixed plant/animal food than when they are fed plant food exclusively. Fischer (1973) suggested that plant food should optimally only comprise about 25% of the grass carp diet; a result suggesting that young grass carp should be omnivorous rather than exclusive herbivores for normal growth to occur (Fischer, 1972a and b). Data from a number of studies suggest that grass carp need cellulose and protein in the diet for optimal growth and health (Chilton II and Muoneke, 1992). In older fish, consumption is twice as high on a pure plant food diet as it is on either an animal food diet or a mixed regime (Chilton II and Muoneke, 1992).

Growth in grass carp is also influenced by which plant species are consumed (Cai and Curtis, 1989).

Although a major part of the food ingested by grass carp is also excreted, a relatively high percentage of the retained material is assimilated. As a result, feed conversion efficiencies (ratio of the weight gain of the fish to the dry weight of food consumed) may be supposed to be very high (Chilton II and Muoneke, 1992). Sutton and Blackburn (1972) reported conversions ranging from 22 to 79%, which are fairly high for herbivorous animals; However, Stott and Orr (1970) reported values as low as 7.5% (for lettuce). In the pond system, they can play an important role as they shred the leaf material, and the high amount of faeces excreted by grass carp can fertilize the pound and increase the zooplankton number and the biomass in the pound (Mitchell *et al*., 1984, Maceina *et al.,* 1992).

Under culture conditions, grass carp can well accept artificial feed such as the by-products from grain processing and vegetable oil extraction meals, and pelleted feeds, in addition to aquatic weeds and terrestrial grasses; the culture of grass carp can be well integrated into crop farming and animal husbandry, to maximize the utilization of natural resources. Thus grass carp can be produced at low cost. On the other hand, it is acceptable to consumers in many countries and it very likely has good potential for development.

There have been great efforts devoted to research on this species. The most important achievement has been success in the development of induced breeding technology which ensures a constant supply of seed for large-scale farming (Konradt, (1968); Bailey and Boyd (1971); Dupree and Huner (1984)). Another important aspect of research was the study of nutritional requirements (Fischer and Lyakhnovich, 1973; Stanley, 1974; Dabrowski, 1977; Liao *et al.,* 1980; Lin *et al.,* 1980; Huisman and Valentijn, 1981; NRC, 1983; Mao *et al*. 1985; Liao and Wang, 1987; Huang and Liu, 1989) on one side, and the access of knowledge on the bioenergetics of grass carp (Carter and Brafield, 1991, Cui *et al.,* 1992) on the other side.

As this species is easily susceptible to diseases, a lot of studies on disease control under culture conditions have also been conducted (Luo and Liu, 1993, Qiu *et al,* 2001, Zhong et al., 2002, Mao et al., 2004). All these efforts over the years promoted the culture of grass carp and boosted its production: with only about 10 000 tonnes year^{-1} in 1950, the global production of farmed grass carp had reached over 3.9 million tonnes year^{-1} by 2006, occupying the third place in the ranking of production for individual species, just in front of the common carp *(Cyprinus carpio)* (with 3.4 million tones in 2006) (Fao, 2007).

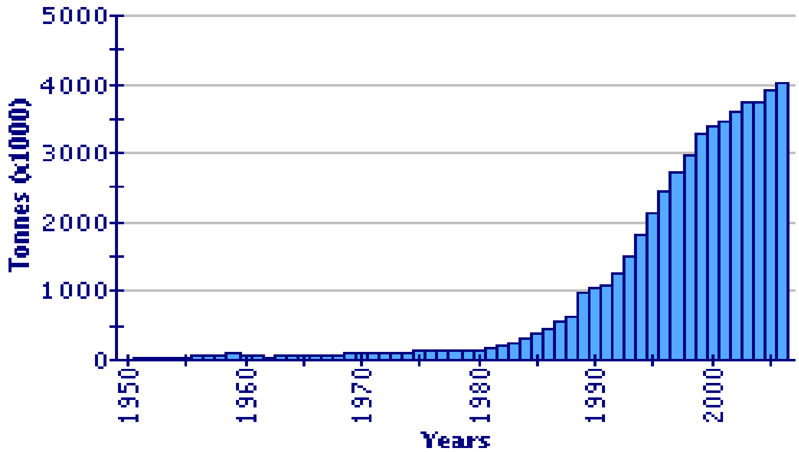

Figure 2: Evolution of the global aquaculture production of grass carp (*Ctenopharyngodon idella* Val.). (FAO Fishery Statistic, 2007)

3.4 Objectives

The main objectives of this study were:

- to make a quantitative evaluation of the gross chemical composition, energy and antinutrient content of the plant materials used as fish feed in the course of the year in Son La Province, Northern Vietnam;

- to assess the apparent digestibility and metabolisability of the nutrients and energy contained in the different plant leaf materials and grasses mainly used as fish feed for grass carp in Northern Vietnam.

The study was conducted in the framework of the Special Research Program "Sonderforschungsbereich 564" titled "Research for Sustainable Land Use and Rural Development in Mountainous Regions of Southeast Asia"

3.5 Hypothesis

The primary hypothesis was that the digestibilities of nutrients in the reference diet are constant and might not be affected by the addition of test ingredients. (Thus the digestibility coefficient of the tested ingredients might all be positive).

In the second hypothesis we assumed that supplementing known amount of plant leaves to grass carp fed a known amount of reference diet might lead to an additional body weight gain as compaired to those fish fed only the reference diet.

3.6 Experimental approach

The feeding experiments to test the digestibility and metabolisability of the different plant residues in grass carp were conducted simultaneously in a computer controlled respirometric system (Focken *et al.,* 1994) which allowed feeding and continuous measurement of oxygen consumption of individual fish, and in aquaria (recirculation system) where faeces collection could be done during the feeding experiment.

Data on oxygen consumption from feeding experiments, together with initial and final carcass chemical composition values were used to set up complete energy budgets for fish, showing proportions for indigestible, metabolized and retained energy. These provided comprehensive information on growth physiology as well as the energy partitioning in the fish fed different experimental diets (as affected by different plant material supplements tested with the reference diet).

We generally assumed in this study that there are no interferences (interactions) between the different components of the diets, i.e. between the reference diet and the tested ingredient. The experimental diets consisted of a basal reference diet for the fish of all the groups and a supplement of test ingredient for the fish of the groups other than the control (or reference group).

4. Investigations on the nutrient and antinutrient content of typical plants used as fish feed in small scale aquaculture in the mountainous regions of Northern Vietnam

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4.1 Abstract

In the upland of Northern Vietnam the aquaculture system of the Black Thai farmers mostly depends on green leaves which they use as major feed input to the ponds. A study was conducted to assess the quality of two groups of plant residues used as fish feed (principally for grass carp) in Northern Vietnam. The first group was constituted of residues commonly fed to fish, such as cassava (*Manihot esculenta*), banana (*Musa nana*), and bamboo (*Bambusa vulgaris*) leaves, and the second group included residues occasionally fed to fish by farmers, such as barnyard grass (*Echinochloa erusgalli)*, mixed weeds from paddy fields, Elephant grass (*Pennisetum purpureum*), mulberry *(Morus)*, maize *(Zea mays)*, sweet potato (*Ipomoea batatas*), peanut *(Arachis hypogaea)*; cassava tubercles and crop residues such as rice bran, cassava peels. In the first group the possible temporal changes in their nutrient, energy and antinutrient contents during the course of the year were evaluated. In the second group the nutrient, energy and antinutrient content were determined. During this study significant temporal changes were observed in the proximate composition, energy and antinutrient contents of banana leaves during the course of the year. Significant ($P<0.05$) temporal changes were observed in the proximate composition of cassava and bamboo leaves as well as in the content of some antinutrient of cassava leaves. The saponin from cassava leaves had a pronounced haemolytic activity against cattle erythrocytes. Results of proximate analysis indicated the high potential of some of these plant materials such as cassava and mulberry leaves as fish feed because of their higher protein and energy content. However, the protein and energy content of these leaves were generally very low when compared to that of the common standard fish feed. Thus, these plant feedstuffs alone may probably not be sufficient to cover the requirements for rapid growth in cultured grass carp. The data presented here could be used for formulating cost-effective and balanced animal feeds for the use of small-scale farmers in rural areas in Northern Vietnam.

5. Digestibility and metabolisability of the major nutrients and energy of Banana and bamboo leaves in grass carp (*Ctenopharyngodon idella*)

Submitted to Aquaculture Research

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5.1 Abstract

In the uplands of Northern Vietnam, culture of grass carp contributes significantly to income and household food security of farmer's ethnic minority Black Thai. Generally Banana and bamboo are important perennial upland plants and, thus their leaves are frequently used by small scale fish farmer as fish feed. A 13 weeks feeding trial was conducted simultaneously in a recirculation and in a respirometric system to determine the apparent digestibility coefficients (ADC) and metabolisability of the nutrients of banana and bamboo leaves, assess crude protein, lipid and gross energy conversion and estimate the energy repartition in grass carp. For this purpose three diets were used: diet "A" (reference diet); diet "B", and "C" contained the same amount of reference diet as in diet A and were supplemented with banana and bamboo leaves respectively. Each treatment in each experimental system had five replicates. Reference and test diets were fed to fish and faecal samples were collected and the oxygen consumption was measured in order to setup an energy budget of fish over the whole experimental period. The body weight gain of the fish fed diet B was significantly higher in aquaria unit. The ADC of the supplemented banana leaves were 92.9 ± 2.5, 52.3 ± 11.4 and 26.2 ± 0.7% for crude protein, lipid and gross energy and the ADC of bamboo leaves were 19.2 ± 15.8, -83.0 ± 26.6 and 8.7 ± 11.9% for crude protein, lipid and gross energy respectively. The fish fed the diet C consumed a significantly higher amount of O_2 per unit of BWG when compared to the fish of the reference group. Generally, the energy losses were high in the case of fish fed plant leaf containing diets. The results of the present study indicated that banana leaf material has good potential for use as supplement in fishmeal-based diet for grass carp.

6. Investigations on the digestibility and metabolisability of the major nutrients and energy of maize leaves and barnyard grass in grass carp (*Ctenopharyngodon idella*)

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6.1 Abstract

In the uplands of Northern Vietnam, culture of grass carp contributes significantly to income and household food security of farmer's ethnic minority Black Thai. Indeed maize is one of the most important upland crops and barnyard grass the most important weed in the paddy rice fields, thus these are frequently used by small scale fish farmer as fish feed. An 8-week feeding experiment was conducted simultaneously in a recirculation and in a respirometric system to determine the digestibility and metabolisability of the nutrients of maize leaves and barnyard grass, to assess their crude protein, lipid and energy conversion and to estimate the energy allocation in grass carp.

The following experimental diets were used: diet "A" (reference diet) containing 39 % crude protein with 19.8 $MJ.kg^{-1}$ gross energy; diets "B", "C", and "D" which contained the same amount of the reference diet as the control diet, supplemented with a known amount of dried barnyard grass, dried maize leaves or fresh maize leaves respectively. Each treatment in each experimental system had five replicates. Reference or test diets were fed to fish and faecal samples were collected and the oxygen consumption was measured in order to setup an energy budget of fish over the whole experimental period. The body weight gain (BWG) of the fish fed diet D was found to be significantly higher than that of the group fed diet A which also in turn was significantly higher than that of fish fed diet B or C. The apparent digestibility coefficients (ADC) of nutrients and gross energy for the different experimental diets in fish kept in the aquaria were, for diets A, B, C and D respectively, 94.1, 60.9, 70.5 and 84.7% for protein, 91.3, 60.7, 76.8 and 71.8% for lipid; 95.9, 44.5, 6, 60.6 and 69.1% for gross energy. The partial ADC of plant leaf ingredients were determined and barnyard grass and dried maize leaves were found to be not only poorly digestible but also having negative impact on the digestibility of the reference diet, while fresh maize leaves were well digested. The results of the present study indicated that fresh maize leaves have a good potential to be used as supplement in diets for grass carp.

7. **Digestibility and metabolisability of the major nutrients and energy of cassava leaves and a mixture of weeds in grass carp *(Ctenopharyngodon idella)***

Submitted to Animal feed Sciences and Technology

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7.1 Abstract

In the uplands of Northern Vietnam, culture of grass carp contributes significantly to income and household food security of farmer's ethnic minority Black Thai. Indeed cassava is one of the most important upland crops and weeds from paddy fields are commonly available in that study region; therefore these are frequently used by small scale fish farmers as fish feed. A 12 weeks feeding trial was conducted simultaneously in a recirculation and in a respiration system to determine the apparent digestibility coefficients (ADC) and metabolisability of the nutrients of cassava leaves and a mixture of weeds, assess crude protein, lipid and energy conversion and estimate the energy allocation/utilization in grass carp. Three diets were used: diet "A" (reference diet); diet "B", and "C" contained the same amount of reference diet as in diet "A" and were supplemented with cassava leaves and a mixture of weeds respectively. All the diets contained 1% of a marker (TiO_2). The fish (initial body weight of 13.9 – 15.5 g) were kept individually in the both different experimental units. Each treatment in each experimental system had five replicates. They were fed the experimental diets at the rate of 7 g/kg$^{-0.8}$ day^{-1} for the groups "A" (control); 14 g/ kg$^{-0.8}$ day^{-1} for groups "B" and "C".

No significant difference was found in the body weight gain (BWG) between the fish fed diet B and and those fed the reference diet only (A) which were however significantly higher to the BWG of the fish fed diet C. The apparent digestibility coefficients (ADC) of the nutrients and energy of the reference diet in grass carp were 82.3 ± 3.5, 82.3 ± 11.4 and 92.8 ± 1.0%; the ADC of the diet supplemented with cassava leaves were 40.5 ± 10.3, 48.1 ± 9.1 and 60.1 ± 7.0% and the ADC of the diet supplemented with Weed mixture were 49.3 ± 9.7, 47.3 ± 3.8 and 36.4 ± 6.4% for crude protein, lipid and energy respectively. Generally the nutrients and energy contents of the cassava leaves and weed mixture were poorly digestible or even not at all digestible. The fish fed the diet C consumed a significantly higher amount of O_2 per unit of BWG when compared to the fish of other groups. The results of the present study indicated the limitation of the potential of cassava leaves and weeds from northern Vietnam as supplement in fishmeal-based diet for grass carp.

8. General discussion

In the preceding chapters the nutritional potential of plant feed ingredients currently used as feed for stomach-less fish in northern Vietnam has been assessed and discussed. In the first part of this study reported in Chapter 1, the nutrient, energy and antinutrient contents of the different plant materials commonly used as fish feed in Son La (Northern Vietnam) during the course of one year were evaluated. The main plant ingredients used as fish feed in the study region were evaluated in subsequent studies for their suitability as feed for the major fish species cultured in the mountainous regions of Northern Vietnam, namely grass carp. The digestibility and metabolisability of the major nutrients and energy in grass carp of the following leaf material were studied: banana and bamboo leaves in Chapter 2, maize leaves and barnyard grass in Chapter 3, cassava leaves and weed mixture in Chapter 4.

8.1 Potential of the plant leaf materials used as fish feed in Son La

In this study, the analysis of the different feeds fed to fish in Son La was done and grasses, bamboo and rice bran had higher fibre content. Generally, lower digestible energy has been found in feedstuff containing high levels of fibre (Anderson *et al*, 1991). Some of the different feedstuffs analysed in the present work had a relatively high protein and low fibre content. This was the case for banana, cassava, mulberry, peanut and sweet potato leaves. However, for some of them, antinutrient contents were high. The antinutrient contained in the different plant materials analysed in this work were presented and discussed in Chapter 1. It was concluded that the use of these feedstuffs as feed for fish by the small scale fish farmer should be done with caution.

8.2 Reasons for selecting the six plant ingredients tested as feed ingredients in this work

The selected six plant leaf materials tested during the present work were the fish feeds mostly used by the farmers in the project region. The most important criterion of selection was the fact that they constituted the major protein suppliers in the ponds in Son La as listed by Steinbronn *et al*. (2006). All the six selected plant leaf materials tested as feed ingredient for grass carp accounted for a cumulative value of 85.2% of the total nitrogen (protein) input to the ponds in the North-West Vietnam region (Steinbronn et al., 2006). Another criterion of selection was the availability of most of them during most times of the year, tough the application of feed in the ponds was often based on the availability of these plant materials on the farm (Steinbronn *et al*., 2005).

8.3 Plant leaf utilization and fish growth

In the present work, the best partial apparent digestibility coefficients (ADC) of nutrients and gross energy were obtained for banana and fresh maize leaves in grass carp. These ADC values were positive and the fish fed these plant leaves as supplement to the reference diet grew significantly better than those fed only the reference diet. In those two cases our second hypothesis was justified.

However, the ADC of nutrients and energy of some of the plant materials (bamboo and cassava leaves, barnyard grass and mixed weeds) tested in grass carp were found to be all or partially negative (Table 1).

Table 1: Partial digestibility coefficients of nutrients and energy of plant leaf feed ingredients in grass carp (% DM total nutrient or energy of leaf or grass)

Nutrient	Banana leaves	Bamboo leaves	Cassava leaves	Weed mixture	Barnyard grass	Maize leaves (dried)	Maize leaves (fresh)
Crude protein	92.9 ± 2.5	19.2 ± 15.8	-36.1 ± 28.5	-51.8 ± 38.8	-71.3 ± 24.0	28.4 ± 25.4	70.6 ± 5.5
Lipid	52.3 ± 11.4	-83.0 ± 26.6	19.1 ± 17.5	-56.1 ± 15.2	-42.1 ± 24.0	40.3 ± 24.2	35.9 ± 12.0
Gross energy	26.2 ± 0.7	8.7 ± 11.9	19.5 ± 15.9	-46.6 ± 15.8	-21.8 ± 22.5	24.6 ± 17.1	39.5 ± 6.8

Value are mean (n = 5) ± standard deviation.

Such negative values are scarce in the literature; most of them might not have been published up to now, as it has often been recommended to round these value to 0 (Glencross *et al.,* 2007) and the nutrient or the ingredient has only been considered as not digested or not digestible. Zhou *et al.* (2007) also obtained and reported negative apparent digestibility values of protein for feather meal (-5.7%), and of energy (-22.9%) for silkworm manure in bluntnose black bream. If the values obtained for the ADC values are lower than 0 (or higher than 100), the implicit assumption that the digestibility (absorption) of nutrients and energy from the reference (or basal) diet is constant or unaffected by the test ingredients, cannot be justified, and the alternative hypothesis "interaction is present" has to be assumed (Sugiura *et al*., 1998). In these particular practical cases an important part of the nutrients of the reference feed which was a component of the experiment diet might have been washed out by the plant leaves or grass present in the diet and this was reflected in the poor growth of fish groups fed those diets. Thus the negative values obtained for the ADC of these plant materials do not only mean that the nutrients of these materials were not digestible (or digested), but, moreover they also hampered or inhibited the utilization of the nutrients of the reference diet. Glencross et al (2007) already pointed out that the determination of nutrient utilization or interference with nutrient utilization because of incorporation of any one ingredient in a basal diet is perhaps the most complex step in the ingredient evaluation process. The same authors also argued that this complexity is largely related to the wide variety of factors that may impact on nutrient or energy utilization. Thus knowledge of this interactive property of the different feed ingredients can be of high importance in practical feed formulations.

Some of the plant materials tested in this study could be better utilized by grass carp. However, we used, for the experimental purposes, only small fish, due to experimental equipment constrains. A better utilization could be expected in larger fish with a longer adaptation to the consumption and digestion of plant based feed in practical culture ponds systems in which they grow rapidly (Shireman, 1980). It has also been found that in older fish, consumption is twice as high on a pure plant food diet as it is on either an animal food diet or a mixed regime (Chilton II and Muoneke, 1992).

The ADC for crude protein, lipid and gross energy obtained for reference (control) diet in grass carp in the three different feeding experiments conducted in this study were similar and comparable to those reported by Law (1986). Our results, as well as the methods used to determine them were thus sound and reliable. However, the siphon method used in the present study for the faeces collection was found to be inefficient by some authors, like mentioned by Wu *et al*, 1995. The possible errors which could be due to the inefficiency of the faecal collection method have been discussed in the previous chapters (2, 3 and 4). Nutrients content of tested ingredient (such as protein and lipid) seemed to play an important role in the utilization of the tested feedstuffs. Banana and Maize leaves which were better utilized by the fish had not only a relatively higher protein but also higher lipid content which were also relatively good digestible for grass carp (Table 1). This was of major importance for covering the different needs of the experimental fish as Fischer (1973) found out that for grass carp consuming both plant and animal feeds, growth might be covered mainly by animal proteins and by lipids of both animal and plant origin whereas it is most likely that carbohydrates in the diet (mostly in plants) and proteins of plant origin are chiefly used in metabolism processes. It could be observed that not only the protein and lipid content was essential for a good utilization of the leaf material but also other important characteristics such as the fibre and mineral content. In some cases also the antinutrients might have played a detrimental role in the utilization of the leaf material. This was the case for the cassava leaves, which, despite a better nutrient profile with less fibre content, could not be well utilized by the fish.

Barnyard grass, Bamboo leaves and the weed mixture were poorly utilized by the fish and were detrimental to the utilization of the mixed reference diet. It was observed that the higher NDF content of these plant materials negatively influenced their utilization by the grass carp. Previous studies have indicated that grasses were poorly digested in grass carp (Law, 1978; Law and Syed Razlan, 1981), however Venkatesh and Shetty, 1978 reported that grass carp fed with hybrid napier grass achieved interesting weight gain. It has already been settled that the quality of a feed is reflected by its digestibility and the balance of nutrients (Cho and Kaushik, 1985). Low concentrations of dietary fibre can have beneficial effects on fish growth (National Research Council, 1993) and high concentrations of fibre decrease digestibility of dry matter and gross energy in the diet and can reduce the availability of other nutrients in some species (Falge *et al.,* 1978; Spannhof and Plantikow, 1983; Hilton *et al.,* 1983; Steffens, 1989; de Silva *et al*., 1990).

8.4 Why plant leaf material was mixed to a reference feed for the digestibility experiment

Some authors (Hickling (1966), Stanley (1974), Cai and Curtis (1989)) suggested that grass carp, even small fingerlings, could maintain growth when consuming only plant food. Thus according to these results we could test the plant materials alone without mixing them with reference diet. However, these preceding results were in contradiction with that published by Fisher (1972) who found in many cases that plant protein alone without small amounts of animal protein will retard the growth of grass carp. Thus Fisher and Lyakhnovich (1973) suggested that diets (for grass carp) should contain 75% animal food and 25% plant food for optimum growth. Stanley (1974) found that immature grass carp fed an exclusive diet of plant food *(Elodea)* exhibited a negative nitrogen balance. Plant material consumed contained less than half the nitrogen excreted, resulting in a net loss of about 140 mg N day^{-1} kg^{-1} body weight. Besides suggesting a reason why grass carp have been known to consume animal matter, these data indicated the need for sources of protein (nitrogen) additionally to plant material. Stroband (1977) also found that animal food tends to stimulate growth in young grass carp. Later, Law (1986) also suggested that a faster growth rate and a shorter time to harvest may be expected if the grass carp were fed with a nutrient-balanced pelleted diet instead of grass and vegetables only. This affirmation of Law (1986) was already confirmed in the previous finding of Shireman et al., 1978 who showed that the growth rate of grass carp fed only ryegrass was significantly lower than that of grass carp fed a mixture of catfish chow- ryegrass pellets. Thus, we choose to mix these plant leaf materials to be tested with a reference diet according to all these previous works in order to evaluate the nutritive value and the nutrient digestibility of the tested plant leaf materials in grass carp.

The fish of the control group (Group A) received 7 g $kg^{-0.8}$ day^{-1} (which was almost equivalent to 2.5 times maintenance ration for grass carp) reference diet, which was the minimum allowing an acceptable growth of our fish over a short experimental period. The fish of the other two diet groups (B and C) also received 7 g $kg^{-0.8}$ day^{-1} (~2.5 times maintenance) reference diet. From this point of view all the fish groups were comparable. Thus we fed the same amount of reference diet to the fish of all the different experimental groups. Additional to the reference diet, the fish of the groups B and C also received a known supplemental amount (7 g $kg^{-0.8}$ day^{-1}) of plant leaf material, an amount which could be totally consumed by the fish (to avoid feed losses) and which was supposed to result in an additional growth (body weight gain) of the fish, if the supplemented plant leaf material could be well digested and utilized by the fish.

It is also necessary to mention at this point that the protein contribution of the plant leaf material to the total diet protein content was lower than 40% in each case (Table 2).

Table 2: Protein contribution from plant leaf or grass in the mixed feed (in % of total diet protein DM)

Plant leaf ingredient	protein contribution
Bamboo leaves	32.6
Banana leaves	26.8
Cassava leaves	38.1
Weed	26.1
Maize leaves	39.9
Barnyard grass	23.5

We assumed that very low supplementation levels of plant leaf material might not produce any significant additional growth during the short experimental period. Thus we supplemented a rather high amount of plant leaf material that could however be totally consumed by the experimental fish. It has been stated that grass carp should consume an acceptable amount of plant leaf material to sustain a remarkable growth, plant material is generally of low digestibility and herbivorous fish have to consume large quantities to obtain sufficient nutrients for growth (Wiley and Wike, 1986). Thus the diets were formulated to more closely mimic the natural feeding habit of grass carp.

8.5 Energy cost of plant leaf utilization

It was generally observed that the amount of oxygen consumed per g of body weight gained (BWG) by the fish fed only the reference diet (control group "A") in the three digestibility experiments (Chapter 2, 3 and 4) were almost similar, varying from 0.7 ± 0.3 to 1.0 ± 0.4 g. This could be considered as a relative constant parameter to characterize the feed quality. The different experimental diets containing plant leaf materials which were poorly digested and utilized by the grass carp also induced higher oxygen consumption per g of BWG: the metabolic cost of the feed utilization was higher for fish fed poorly digestible diets. Francis et al., (2002) already pointed out that common carp fed diets containing relative high level of saponin had higher oxygen consumption (and metabolic rate) throughout the experiment, indicating continuous higher metabolic activity when compared to fish fed the control diet. This could possibly be a result of physiological stress induced by the higher dietary saponin content and probably also by other antinutrients as in the present work, all the experimental diets supplemented with plant leaf materials contained a relative high amount of saponin (between 0.8 to 4.0% DM of feed). Additionally to saponin, it was also observed in the different chapters of this work that the oxygen uptake per unit of fish weight produced was also related to the NDF content of the different experimental diets and was higher for the fish fed diets containing higher levels of fibre.

8.6 Economical aspects of the use of plant residues as feed for Grass carp in Son La (Northern Vietnam)

Taking into account the fact that grass carp can also consume and successfully utilize some crop residues and terrestrial plants leaves with no economical value, the culture of grass carp can be well integrated into crop farming and animal husbandry, to maximize the utilization of natural resources. Thus there is a possibility, with appropriate feeding management to produce grass carp at low cost. In the present work the protein source of our reference diet consisted basically of fish meal, which is however getting more expensive and scarce (Josupeit, 2007a, b) and difficult to afford for poor farmers. Under culture conditions, grass carp can, however, well accept feeds based on other protein sources, such as the by-products from grain processing and vegetable oil extraction meals which represent cheaper protein sources. Combinations of such by-products with other crop residues, with caution being given to the total feed fibre content, might represent a better way of reducing feed cost in rural aquaculture farming, thus significantly enhancing the economic profitability of this activity and generate an even higher income for the farm households in this poor rural area in Northern Vietnam. Relying on locally available feed ingredients might also ensure the sustainability of the fish farming activity in the area and significantly facilitate the management of the local fish production and therefore boost this sector of activity. Additionally to the increased household economic security, the additional production from aquaculture might also imply an increased availability of protein for household consumption; this could ameliorate the nutritional and health status of the local population. Generally, in situations where aquaculture has been targeted to increase on-farm production of resource-poor households in certain agro-ecological regions, the positive income changes were reportedly more significant (Gupta *et al.,* 1999).

For the pond, in case of polyculture system, grass carp fed plant residues can play an important role as they shred the leaf material, and the high amount of faeces rejected by grass carp can fertilize the pound and increase the biomass production in the pond (Mitchell *et al*., 1984, Maceina *et al.,* 1992) and thus increase the total fish production.

8.7 Conclusion

The key conclusions of the present work can be outlined as follow:

1- The results of the present study indicated that the nutrients of banana (chapter 2) and fresh maize leaves (chapter 3) could meet the growth requirements of grass carp and support a fast growth of these fish. Thus banana and fresh maize leaves have good potential for use as a supplement in fishmeal-based diet for grass carp.

2- The findings (chapter 3) clearly show that grass carp could differently use fresh and dried maize leaf materials. Fresh leaf material based feed and also selected plant ingredients of high nutrient and low fibre content are better suited for supplementing grass carp diets.

3- The study clearly shows the role of dietary plant fibres and some antinutrients on nutrient assimilation in grass carp. Accordingly, caution should be exercised in selecting plant feeds of high nutrient make-up. A low fibre and antinutrient content of the feed could also be an equally important criterion.

4- For the other remaining plant materials analysed in the present study and not tested in feeding experiment in grass carp, some of them might be able to sustain an acceptable growth of fish (grass carp) according to the existing literature. This can be made particularly possible if, they were either treated to reduce their antinutrient content or they were mixed during the feeding, according to their respective antinutrient content, which could help reduce the overall content of the detrimental factors in the so formulated diets. If the fibre content of the plant residues could be reduced by physical or chemical treatments, the utilization of nutrients could potentially be increased. Various chemicals such as sodium hydroxide (Sawar *et al.,* 1992), urea (Sawar *et al*., 1994), ammonia (Williams *et al.,* 1984), and alkaline hydrogen peroxide (Sultan *et al.,* 1992) have been used for upgrading poor quality straws.

It was pointed out that urea, a cheap source of NH_3 after hydrolysis, has given satisfactory results for nutritional enhancement of wheat straw (Ali *et al.,* 1993). Upgrading of straw by urea treatment is caused by swelling cellulose micro fibrils and disrupting of the cell wall structures to a point where enzymes can hydrolyze intracellular components (nutrients) otherwise not accessible (Sarwar *et al.,* 1994). The treatment of plant residues on this way for their use as feed for herbivorous fish has so far not been evaluated. This possibility should be followed, thought the fibre content was found to influence the feed digestibility in the present work (Chapter 2, 3 and 4). However all this treatments should be conducted with consideration of the fact that fresh leaf materials might be better utilized than dried leaf materials as it has been found in the Chapter 3 of this study.

5- The information provided in this thesis could be a good base for further work for the development of feeding strategies using locally available feedstuffs. This could lead to an increase of productivity of fish as well as of other animal species with plant based feeds and enhance the livelihood of the small-scale farmers in the rural areas in Vietnam. Thus, this study has a strong focus on resource-poor households.

Further studies are needed to test the efficiency and elucidate the profitability of using banana and fresh maize leaves as feeds for grass carp under practical production conditions for small-scale farmers in Vietnam in association with different amounts of fish meal based diets or diets based on by-products from grain processing and vegetable oil extraction.

9. References

ADB 2002. Indigenous peoples/ethnic minorities and poverty reduction Vietnam; Environment and Social Safeguard Division, Regional and Sustainable Development Department, Asian Development Bank, Manila, Philippines, pp.57.

Afuang, W., Siddhuraju, P., Becker, K., 2003. Comparative nutritional evaluation of raw, methanol extracted residues and methanol extracts of moringa (*Moringa oleiera* lam.) leaves on growth performance and feed utilisation in Nile tilapia (*Oreochromis niloticus* L.). Aquaculture Research 34, 1147–1159.

Aksnes, A., Hjertnes, T. and Opstvedt, J., 1996. Comparison of two assay methods for determination of nutrient and energy digestibility in fish. Aquaculture 140, 343–359.

Ali, C.S., Sawar, M., Siddiqi, R.H., Khaliq, T., Chaudhry, S.U.R, Barque, A.R., 1993. Effect of Urea treatment of whrat straw on disappearance and rate of passage through reticulo-rumen of buffalo. Pakistan Veterinary Journal 13, 74-81.

Allan, G.L., Booth, M.A., Stone, D.A.J., Rowland, S.J., Frances, J., WarnerSmith, R., 2000. Replacement of fish meal in diets for Australian silver perch, *Bidyanus bidyanus*: I. Digestibility of alternative ingredients. Aquaculture 186, 293–310.

An, Le Van, Hong, Tran Thi Thu and Lindberg, J. E. (2004) Ileal and total tract digestibility in growing pigs fed cassava root meal diets with inclusion of fresh, dry and ensiled sweet potato (*Ipomoea batatas* L. (Lam.)) leaves. Animal Feed Science and Technology 114, 127–139.

Anderson, J., Capper, B.S., Bromage, N.R., 1991. Measurement and prediction of digestible energy values in feedstuffs for the herbivorous fish tilapia (*Oreochromis niloticus* Linn.). British Journal of Nutrition 66, no.1, 37–48 (12).

AOAC, 1980. Official Methods of Analysis, 13th edn., Association of Official Agricultural Chemists, Washington, DC, 125–142.

AOAC, 1990. Official Methods of Analysis, 15th edn. Association of Official Analytical Chemists, Arlington, VA.

Becker, K., Makkar, H.P.S., 1999. Effects of dietary tannic acid and quebracho tannin on growth performance and metabolic rates of common carp (*Cyprinus carpio* L.). Aquaculture 175, 327–335.

Bailey, W.M. and Boyd, R.L., 1971. A preliminary report on spawning and rearing of grass carp *(Ctenopharyngodon idella)* in Arkansas. Proc. Ann. Conf. Southeast. Assoc. Game Fish. Comm. 24, 560-569.

Bassler, r. and Buchholz, H., 1993. Amino acid analysis. In: Methodenbuch, Vol. III, 4.11.1, 1–5. Die ChemischeUntersuchung von Futtermitteln VDLUFA-Verlag, Darmstadt, Germany.

Becker, K. and Makkar, H.P.S. 1999. Effects of dietary tannic acid and quebracho tannin on growth performance and metabolic rates of common carp (*Cyprinus carpio* L.). Aquaculture 175, 327–335.

Belewu, M.A. and Belewu, K.Y., 2005. Cultivation of mushroom *(volvariella volvacea)* on banana leaves. African journal of Biotechnology, vol. 4 (12), 1401–1403.

Ben Salem, H., Abidi, S., Makkar, P.P.S., Nefzaoui, A., 2005*a*. Wood ash treatment, a cost-effective way to deactivate tannins in *Acacia cyanophylla* Lindl. Foliage and to improve digestion by Barbarine sheep. Animal Feed Science and Technology 122, 93–108.

Ben Salem, H., Saghrouni, L., Nefzaoui, A., 2005*b*. Attempt to deactivate tannins in fodder shrubs with physical and chemical treatments. Animal Feed Science and Technology 122, 109–121.

Berg, H., 2001. Pesticide use in rice and rice–fish farms in the Mekong Delta, Vietnam. Crop Protection 20, pp. 897–905.

Blackburn, R.D. and Sutton, D.L., 1971. Growth of the white amur (*Ctenopharyngodon idella* Val.) on selected species of aquatic plants. Proc. Eur. Weed Res. Count. 3rd Ifrt. Symp. Aquatic Weeds, 87–93.

Booth, M.A., Allan, G.L., Frances, J., Parkinson, S., 2001. Replacement of fish meal in diets for Australian silver perch, *Bidyanus bidyanus:* IV. Effects of dehulling and protein concentration on digestibility of grain legumes. Aquaculture 196, 67–85.

Brafield, A.E. and Llewellyn, M.J., 1982. Animal Energetics. Glasgow: Blackie.

Brafield, A.E., 1985. Laboratory studies of energy budgets. In Fish Energetics: New Perspectives (Tytler, P. & Calow, P., eds), pp. 257–282. London: Croom Helm.

Bureau D.P., Harris, A.M., Cho, C.Y., 1999. Apparent digestibility of rendered animal protein ingredients for rainbow trout *(Oncorhynchus mykiss).* Aquaculture 180, 345–358.

Bureau, D.P., Harris, A.M., Cho, C.Y., 1998. The effects of purified alcohol extracts from soy products on feed intake and growth of chinook salmon (*Oncorhynchus tshawytscha*) and rainbow trout (*Oncorhynchus mykiss*). Aquaculture 161, 27–43.

Cai, X., Luo, L., Xue, M., Wu, X. and Zhan W., 2005. Growth performance, body composition and phosphorus availability of juvenile grass carp *(Ctenopharyngodon idellus)* as affected by diet processing and replacement of fishmeal by detoxified castor bean meal. Aquaculture Nutrition 11, 293–299.

Cai, Z. and Curtis, L.R., 1989. Effects of diet on consumption, growth and fatty acid composition in young grass carp. Aquaculture 81, 47-60.

Cai, Z. and Curtis, R., 1990. Effect of diet and temperature on food consumption, growth rate and tissue fatty-acid composition of triploid grass carp. Aquaculture 88, 313–327.

Campaña-Torres, A., Martinez-Cordova, L. R., Villarreal-Colmenares, H., Civera-Cerecedo, R., 2008. Carbohydrate and lipid digestibility of animal and vegetal ingredients and diets for the pre-adult redclaw crayfish, *Cherax quadricarinatus* (von Martens). Aquaculture Research 39, 1115–1121.

Carter C. G. and Bradfield A. E., 1991. The bioenergetic of grass carp, *Ctenopharyngodon idella* (Val.): energy allocation and the planes of nutrition. Journal of Fish Biology 39, 873–887.

Chakraborty, S.C., Chowdhury, S.A. and Chakraborty, S., 1999. Energy budget of Indian Major Carp, *Labeo rohita* fingerlings fed on Diets with Different Protein Levels. Asian Fisheries science 12, 297–308.

Chilton II, E. W. and Muoneke, M.I., 1992. Biology and management of grass carp *(Ctenopharyngodon idella,* Cypfinidae) for vegetation control: a North American perspective. Reviews in Fish Biology and Fisheries, 2, 283–320.

Chin, D.V., 2001. Biology and management of barnyard grass red sprangletop and weedy rice. Weed Biology and Management 1, 37–41.

Chin, D.V., 1995. Weed management in direct-seeded rice in Vietnam. Omonrice 4, 79–82.

Chiou, J.Y., Ogino, C., 1985. Digestibility of starch in carp. Bulletin of the Japanese Society of Scientific Fisheries 41, 465–466.

Cho, C. Y., and S. J. Kaushik, 1985. Effects of protein intake on metabolizable and net energy values of fish diets. Pp. 95-117 in Nutrition and Feeding in Fish, C. B. Cowey, A. M. Mackie, and J. G. Bell, eds. London: Academic Press.

Cho, C.Y. and Slinger, S.J., 1979. Apparent digestibility measurement in feedstuffs for rainbow trout. In: J.E. Halver and K. Tiews (Editors), Proc. World Symp. On Finfish Nutrition and Fish feed Technology, Vol. II. Heenemann, Berlin, 239–247.

Cho, C.Y., Slinger, S.J. and Bayley, H.S. 1982. Bioenergetics of salmonid fishes: energy intake, expenditure and productivity. Comp. Biochem. Physiol. 73B: 25–41.

Cui, L and Liu, J., 1990. Comparison of energy budget among six teleosts-III. Growth rate and energy budget. Comparative Biochemistry and Physiology 97A, 381–384.

Cui, Y., Chen, S. and Wang, S., 1994. Effect of ration size on the growth and energy budget of the grass carp, *Ctenopharyngodon idella* Val. Aquaculture 123, 95–107.

Cui, Y., Chen, S. and Wang, S., 1994. Effect of ration size on the growth and energy budget of the grass carp, *Ctenopharyngodon idella* Val. Aquaculture 123, 95–107.

Cui, Y., Liu, X., Wang, S., and Chen, S. 1992. Growth and energy budget in young grass carp, *Ctenopharyngodon idella* Val., fed plant and animal diets. Journal of Fish Biology 41, 231–238.

Dabrowski, K., 1977. Protein requirements of grass carp fry (*Ctenopharyngodon idella* Val.). Aquaculture 12, 63–73.

DANIDA (Danish International Development Agency), 2002. Current trends in the Vietnamese seafood industry. Hanoi.

Das, K.M., Tripathi, S.D., 1991. Study on the digestive enzymes of grass carp. *Ctenopharyngodon idella* (Val). Aquaculture 92, 21–32.

De la Higuera, M., Garcia-Gallego, M., Cardenete, G., Suarez, M.D., Moyano, F.J., 1988. Evaluation of Lupin seed meal as an alternative protein source in feeding of rainbow trout (*Salmo gairdneri*). Aquaculture 71, 37–50.

De Silva, S.S., Anderson, T.A., 1995. Fish Nutrition in Aquaculture. Aquaculture Series 1. Chapman and Hall, 319 pp.

De Silva, S.S., Shim, K.F. and Khim Gng, A., 1990. An evaluation of the method used in digestibility estimations of a dietary ingredient and comparisons on external and internal markers, and time of faeces collection in digestibility studies in the fish *Oreochromis crurrus* (Steindachner). Reprod. Nutr. Develop., 30, 215–226.

Delgado, C.L., Wada, N., Rosegrant, M.W., Meijer, S. and Mahfuzuddin Ahmed. The future of fish, issues and Trends to 2020. International Food Policy Research Institute and World Fish Center. http://www.fishforall.org/outcomes/pdf/fish2020_brief.pdf; accessed on the 5th of October 2008.

Devendra, C., 1977. Cassava as a feed source for ruminants. In: Nestle, B., Graham, M. (Eds.), Cassava as Animal Feed. IDRC, Canada, pp. 107–119.

DFID, 2000. Poverty and aquatic resources in Vietnam: an assessment of the role and potential of aquatic resource management in poor people's livelihoods. In: Department for International Development (DFID)-SEA Aquatic Resources Management Program; Bangkok, Thailand, pp. 36.

Dongmeza, E., B., Steinbronn, S., Francis, G., Focken, U. and Becker, K., 2008. Investigations on the nutrient and antinutrient content of typical plants used as fish feed in small scale aquaculture in the mountainous regions of Northern Vietnam. Animal Feed Science and Technology 149, 162–178.

Dongmeza, E., Siddhuraju, P., Francis, G., Becker, K., 2006. Effects of dehydrated methanol extracts of moringa (*Moringa oleifera* Lam.) leaves and three of its fractions on growth performance and feed nutrient assimilation in Nile tilapia (*Oreochromis niloticus* (L.). Aquaculture 261, 407–422.

Du Thanh Hang, Preston, T.R., 2005. The effects of simple processing methods of cassava leaves on HCN content and intake by growing pigs. Livestock Research for Rural Development 17 (9).

Duprees, H.K. and Huner, J.V., 1984. Production methods for Chinese carps. In Dupree, H.K. and Huner, J.V., eds. Third Report to the Fish Farmers. Washington, DC: US Dept Interior, Fish and Wildlife Service, 97–105.

Edwards, P., 2000. Aquaculture, poverty impacts and livelihoods. ODI Natural Resource Perspectives 56; ODI, London, UK.

Edwards, P.; Pullin, R.S.V.; Gartner, J.A., 1988. Research and education for the development of integrated crop-livestock-fish farming systems in the tropics, 139-170. ICLARM Studies and reviews 16, 53 p.; International Center for Living Aquatic Resources Management, Manila, Philippines.

Eggum, B.O., 1970. The protein quality of cassava leaves. British Journal of Nutrition 24, 761–768.

Erfanullah, Jafri, A.K., 1998. Growth, feed conversion, body composition and nutrient retention efficiencies in fingerling catfish, *Heterpneustes fossilis* (Bloch), fed different sources of dietary carbohydrate. Aquaculture Research 30, 43–49.

Ewart, A.J., 1931. CSIRO Bulletin No. 50. Fish, B.C., Thompson, L.U., 1991. Lectin-tannin interactions and their influence on pancreatic amylase activity and starch digestibility. Journal of Agricultural and Food Chemistry 39, 727–731.

Falge, R., Schpanof, L. and Jurss, K., 1978. Amylase, esterase and protease activity in the intestine content of rainbow *Salmo guirdneri* Rich., after feeding with feed containing different amounts of starch and protein. J. Ichthyol., 18, 283–287.

FAO Globefish 2007. http://www.infofish.org/marketreports/fishmeal0407.html; accessed on the 20th of November 2008.

FAO, 2001. Fisheries marketing and credit in Viet Nam. Project document. Hanoi.

FAO Fisheries and Aquaculture Department, 2006. THE State of World Fisheries and Aquaculture 2006.

FAO, 2006. FAO Fisheries Department, Fishery Information, Data and Statistics Unit.

FAO. 2006. State of world aquaculture 2006, by R. Subasinghe. FAO Fisheries. Technical Paper No. 500. Rome.

FAO, 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in Vietnam In Hasan, M.R.; Hecht, T.; De Silva, S.S.; Tacon, A.G.J. (eds). Study and analysis of feeds and fertilizers for sustainable aquaculture development. FAO Fisheries Technical Paper. No. 497. Rome, FAO. 2007. pp. 331–357.

FAO, 2007. Fisheries Department, Fishery Information, Data and Statistics Unit. Fish. Fishstat Plus: Universal software for fishery statistical time series. Version 2.3. Capture production: Quantities 1950 – 2005.

FAO, 2007. The State of World fisheries and aquaculture (2007) 2006ftp://ftp.fao.org/docrep/fao/009/a0699e/a0699e.pdf; accessed on the 30th of October 2008.

Fasuyi, A. O., 2005. Nutrient composition and processing effects on cassava leaf (*Manihot esculenta*, Cranz) antinutrients. Pakistant Journal of Nutrition 4 (1), pp. 37–42.

Fischer, Z., 1972*a*. The elements of energy balance in grass carp *(Ctenopharyngodon idella* Val.) Part II. Fish fed with animal food. Pol. Arch. Hydrobiol. 19, pp. 65–82.

Fischer, Z., 1972*b*. The elements of energy balance in grass carp (*Ctenopharyngodon idella* Val.) Part III. Assimilability of proteins, carbohydrates, and lipids by fish fed with plant and animal food. Pol. Arch. Hydrobio119, 83–95.

Fischer, Z. and Lyakhnovich V.P., 1973. Biology and bioenergetic of grass carp (*Ctenopharyngodon idella* Val.). Part 2. Fish fed with animal food. Pol Polskie. Archiwum. Hydrobioligii. 20, 521–557.

Fischer, Z., 1973. The elements of energy balance in grass carp *(Ctenopharyngodon della* Val.). Part IV. Consumption rate of grass carp fed on different types of food. Pol. Arch. Hydrobiol. 20, 309–318.

Fishstat Plus: Universal software for fishery statistical time series. Aquaculture production: quantities 1950-2004, Aquaculture production: values 1984-2004; Capture production: 1950-2004; Commodities production and trade: 1950-2004; Total production: 1970-2004, Version 2.3 (available at www.fao.org/fi/statist/FISOFT/FISHPLUS.asp).

Focken, U., Becker, K. and Lawrence P., 1997. A note on the effects of L-carnitine on the energy metabolism of individually reared carp, C*yprinus carpio* L. Aquaculture Nutriton 3, 261–264.

Focken, U., Schiller, M. and Becker, K., 1994. A computer-controlled system for the continuous determination of metabolic rates of fish. In: P. Kestemont, J. Muir, F. Sevilla and P. Willot (Eds), Measures of success. Contributions presented at the International Conference Bordeau Aquaculture 1994. CEMAGREF edition, Antony, pp. 167–171.

Foulkes, D., Espejo., S., Marie, D., Delpeche, M. and Preston T.R., 1978. The banana plant as cattle feed; composition and biomass production. Tropical Animal Production 3, 45–50.

Francis, G., Makkar, H.P.S. and Becker, K., 2002. Dietary supplementation with a Quillaja saponin mixture improves growth performance and metabolic efficiency in common carp (*cyprinus carpio* L.). Aquaculture 203, pp. 311–320.

Francis, G., Makkar, H.P.S., Becker, K., 2001. Antinutritional factors present in plant-derived alternate fish feed ingredients and their effects in fish. Aquaculture 199, 197–227.

Freeland,W.J., Calcott, P.H., Anderson, L.R., 1985. Tannin and saponin: interaction in herbivore diet. Biochemical Systematics and Ecology 13 (2), 189–193.

Glencross, B.D., Booth, M. and Allan, G.L, 2007. A feed is only as good as its ingredients – a review of ingredient evaluation strategies for aquaculture feeds. Aquaculture Nutrition 13, 17–34.

Glencross, B.D., Hawkins, W.E., Evans, D., McCafferty, P., Dods, K., Maas, R. and Sipsas, S., 2005. Evaluation of the digestible value of lupin and soybean protein concentrates and isolates when fed to rainbow trout, *Oncorhynchus mykiss*, using either stripping or settlement faecal collection methods. Aquaculture 245, 211–220.

Gohl, B., 1981. Tropical Feeds. Feed Information Summaries and Nutritive Values. FAO Animal Production and Health Series 12. FAO, Rome.

Gohl, B., 1993. Tropical Feeds. p.318-320.

Goldstein, W.S., Spencer, K.C., 1985. Inhibition of cyanogenesis by tannins. Journal of Chemical Ecology 11, 847–857.

GSO (General Statistic Office) of Vietnam, 2004.

GSO (General Statistic Office) of Vietnam, 2007. Data available on http://www.gso.gov.vn/default.aspx?tabid=390&idmid=3&ItemID=7393 (in Vietnamese); accessed on the 11th of September 2008.

GSO (General Statistic Office) of Vietnam, 2008. Data available on http://www.gso.gov.vn/default.aspx?tabid=390&idmid=3&ItemID=7400 and on http://www.gso.gov.vn/default.aspx?tabid=390&idmid=3&ItemID=7386 (in Vietnamese); accessed on the 17th of October 2008.

Gupta, M., Mazid, V.M.A., Islam, Md.S., Rahman, M. and Hussain, M.G., 1999. Integration of aquaculture into the farming systems of the floodprone ecosystems of Bangladesh: an evaluation of adoption and impact. ICLARM Technical Report No. 56.

Hajen, W. E., Higgs, D. A., Beames, R. M. and B. S. Dosanjh, 1993. Digestibility of various feedstuffs by post-juvenile chinook salmon *(Oncorhynchus tshawytscha)* in sea water. 2. Measurement of digestibility. Aquaculture, 112, 333–348.

Hajra A., Tripathi, S.D., Nath, D., Chatterjee J.G. and Karmakar. H.C., 1987. Comparative digestibility of dietary plant fibre in grass carp, *Ctenopharyngodon idella* (Val). Proc. Nat. Acad. Sci. India 57 (B), III; 232–236.

Hajra, A. and Tripathi**,** S.D. 1985. Nutritive value of aquatic weed *(Spirodela polyrhiza)* in grass carp (*Ctenopharyngodon idella*). Indian Journal of Animal Sciences 55, 702**–**705.

Hanley, F., 1987. The digestibility of foodstuffs and the effects of feeding selectivity on digestibility determinations in tilapia, Oreochromis niloticus (L). Aquaculture 66, 163–179.

Haque, M.R., Bradbury, J.H., 2002. Total cyanide determination of plants and foods using the picrate and acid hydrolysis methods. Food Chemistry 77, 107–114.

He, X. and Xie, H., 1966. Feeding habits of grass carp *(Ctenopharyngodon idellus)* from the East Lake, Wuchang. In: Collected Papers of the 9th Plenary Congress of the Research Fisheries Committee of the Western Pacific. Science Press, Beijing, 6–l 3.

Hiai, S., Oura, H., Nakajima, T., 1976. Color reaction of some sapogenins and saponins with vanillin sulphuric acid. Planta Medica 29, 116–122.

Hickling, C. F., 1966. On the feeding process in the White Amur, *Ctenopharyngodon idella*. J. Zool. 148, 408–419.

Hilton, J.W., Atkinson, J.L. and Slinger, S.J., 1983. Effect of increased dietary fiber on the growth of rainbow trout *(Oncorhynchus mykiss).* Can. J. Fish. Aquatic Sci. 40, 81–85.

Hossain, M.A., Jauncey, K., 1989. Nutritional evaluation of some Bagladeshi oilseed meals as partial substitutes for fishmeal in the diet of common carp, *Cyprinus carpio* L. Aquacult. Fish. Manage. 20, 255–268.

Hossain, M.A., Jauncey, K. 1993. The effect of varying dietary phytic acid, calcium and magnesium levels on the nutrition of common carp, *Cyprinus carpio*. In: Kaushik, S.J., Luquent, P. (Eds.), Fish Nutrition in Practice. Proceeding of International Conference, Biarritz, France, June 24-27, 1991, 705–715.

Huang, Y.T., and Liu, Y.J., 1989. Studies on the mineral requirement in juvenile grass carp *(Ctenopharyngodon idella C. et V.)*, Acta Hydrobiol. Sinica 13, 134–151 (in Chinese).

Huisman, E.A., 1976*a*. Food conversion efficiencies at maintenance and production levels for carp, *Cyprinids carpio* L., and rainbow trout, *Salmo gairdneri* Richardson. Aquaculture 9, 259–273.

Huisman, E.A. 1976*b*. Sauerstoff als Umweltfaktor für die Fischproduktion. In: H.H. Reichenbach-Klinke (Editor), Fisch und Umwelt, Vol. 2, Gustav Fischer, Stuttgart, 135–144.

Huisman, E.A. and Valentijn, P., 1981. Conversion efficiencies in grass carp *(Ctenopharyngodon idella,* Val.) using a feed for commercial production. Aquaculture 22, 279–88.

Hutagalung, R.I., Phuah, C.H. and Hew, V.F., 1973. The utilization of tapioca *(Manihot utilissima)* in livestock feeding. Paper presented at the 3rd International Symposia on Tropical Root Crops, Ibadan, Nigeria, 2-9 December 1973 (mimeo).

Jackson, A. J., Capper, B. S., Matty, A. J. 1982. Evaluation of some plant proteins in complete diets for tilapia, *Sarotherodn mossambicus*. Aquaculture 27, 97–109.

Jensen, J.W. 1986. Using grass carp for controlling weeds in Alabama ponds. Alabama Cooperative Extension Service, Auburn University, Alabama. Circular ANR-452. 2 pp.

Jeong, K.S., Takeuchi, T., Okamoto, N., Watanabe, T., 1992. The effect of dietary gelatinized rations at different dietary energy levels on growth and characteristics of blood in carp fingerlings. Bulletin of the Japanese Society of Scientific Fisheries 58, 945–951.

Jhingran, V.G., 1975. Fish and Fisheries of India, 1st Ed., Hindustan pulishing Corporation (India), New Dielhi, p. 632.

Johnson, I.T., Gee, J.M., Price, K., Curl, C., Fenwick, G.R., 1986. Influence of Saponins on gut permeability and active nutrient transport in vitro. Journal of Nutrition 116, 2270–2277.

Josupei, H., 2007a. Fishmeal Market Report - April 2007. FAO Globefish 2007. http://www.infofish.org/marketreports/fishmeal0407.html; accessed on the 02nd of June 2008.

Josupei, H., 2007b. Fishmeal Market Report - December 2007 http://www.thefishsite.com/articles/370/fishmeal-market-report-december-2007; accessed on the 02nd of June 2008.

Keir, B., Lai, N.V., Preston, T.R. and Orskov, E.R., 1997. Nutritive value of leaves from tropical trees and shrubs: 1. *in vitro* gas production and *in sacco* rumen degradability. Livestock Research for Rural Development, volume 9, Number 4.

Kent, G., 1997. Fisheries, food security, and the poor. Food Policy 22, No.5; 393–404.

Khiem, N.D.,Van der Poel, P., 1993. Land Use in the Song DaWatershed: SFDP Baseline Study No. 2.Vietnamese German Technical Cooperation, Social Forestry Development Project (SFDP) Song Da, Ministry of Forestry, Hanoi.

Kihara, M., Sakata, T., 1997. Fermentation of dietary carbohydrates to short chain fatty acids by gut microbes and its influence on intestinal morphology of a detritivorous teleost tilapia (*Oreochromis niloticus*). Comp. Biochemistry and Physiology 118A, 1201–1207.

Kilgen, R.H. and Smitherman, R.O., 1971. Food habits of the white amur stocked in ponds alone and in combination with other species. Progressive Fish Cult. 33, 123–127.

Kimambo A.E., and Muya H.M.H., 1991. Rumen degradation of dry matter and organic matter of different parts of the banana plant. Livestock Research for Rural Development Volume 3, Number 3, December 1991.

Kiruiro, E.M., Kihanda, F., Okuro, J.O., 2001. Maize leaves as fodder: the potentials for enhancing feed availability on smallholder farms in Kenya. In: Seventh Eastern and Southern Africa Regional Maize Conference, 11–15 February 2001, pp. 457–462.

Kitahara, N., Shibata, S., Nishida, T., 2000. Management and Utilisation of Mulberry for Forage in Japan. 1: Productivity of mulberry-pasture association and nutritive value of mulberry. In: FAO Electronic Conference on Mulberry for Animal Production.

Konradt, A.G., 1968. Methods of breeding the grass carp, *Ctenopharyngodon idella* and the silver carp, *Hypophthalmichthys molitrix*. F.A. O. Fish. Rep. (44) 4, 195–204.

Krogdahl, A., Hemre, G.-I., Mommsen, T.P., 2005. Carbohydrates in fish nutrition: digestion and absorption in postlarval stages. Aquaculture Nutrition 11, 103–122.

Law, A.T. 1978. Digestibility of napier grass (*Pennisetum purpureum*) in grass carp *Ctenopharyngodon idella*). Pertanika, 1(1), 51–54.

Law, A.T. and Syed Razlan B. Syed Putra Jamalullail, 1981. Digestibility of carpet grass *(Axonopus compressus)* in grass carp (*Ctenopharyngodon idella).* Pertanika, 4 (1), 91-93.

Law, A.T. 1986. Digestibility of low-cost ingredients in pelleted feed by grass carp *(Ctenopharyngodon idella C. et V).* Aquaculture 51, 97–103.

Li, A., 1996. Aquaculture Animal's Feed and Nutrition. Chinese Agriculture Press Inc., Beijing, P. R. China, p. 35.

Liao, C. and Wang, Z., 1987. Studies on the requirements of dietary protein by grass carp fingerlings (*Ctenopharyngodon idella* C. et V.) in varied growth periods. Freshwater Fish. 1, 1.

Liao, X., Lin, D., Mao, Y., and Cai. F., 1980. Experiment on enzymatic fiber pellets used as fish feed and protein requirements of grass carp (*Ctenopharyngodon idella* C. et V.). Journal of Fish China 4, 217.

Lied, E., Julshamn, K. and Braekkan, O.R., 1982. Determination of protein digestibility in Atlantic cod *(Gadus morhua)* with internal and external indicators. Canadian Journal of Fisheries and Aquatic Science 39, 854–861.

Lin, D., Mao, Y., and Cai, F., 1980. Experiment on the protein requirements of grass carp (*Ctenopharyngodon idella* C. et V.) juveniles. Acta Hydrobiol. Sinica, 7, 207.

Lin, S.Y., 1935. Life-history of Waan Ue, *Ctenopharyngodon idellus* (Cuv, & Val.). Lingnan Sci. J. 14, 129–135.

Lopinot, A. (1972) White amur *Ctenopharyngodon idella.* Illinois Dept Conservation, Division of Fisheries. Fish Management Mimeo No. 37, 2.

Luo Chen and Liu Yun, 1993. Disease resistance gene transfer in grass carp by sperm chromosome fragmentation and gynogenesis. Aquaculture 111, 311.

Luu, L.T.; Trang, P.V.; Cuong, N.X.; Demaine, H.; Edwards, P.; Pant, J., 2002. Promotion of small-scale pond aquaculture in the Red River Delta, Vietnam. In "Rural Aquaculture", 55-75, eds. Edwards, P., Little, D.C., Demaine, H.; CABI Publishing Oxon, UK and New York, USA, pp. 368

Maceina, M.J., Cichra, M.F., Betsill, R.K. and Bettoli, P.W., 1992. Limnological changes in a large reservoir following vegetation removal by grass carp. J. Freshwat. Ecol. 7, 81–95.

Makkar, H.P.S., 2003. Effects and fate of tannins in ruminant animals, adaptation to tannins, and strategies to overcome detrimental effects of feeding tannin-rich feeds. Small Ruminant Research 49, 241–256.

Makkar, H. P. S., 2007. Plant secondary metabolites as antinutrients in monogastric nutrition. In: Fodder banks for sustainable pig production systems (Leterme P., Buldgen, A., Murgueitio, E. and Cuartas, C., eds.) pp. 67–84, CIPAV foundation. Cali, Colombia.

Makkar, H.P.S., Becker, K., 1996. Nutritional value and antinutritional components of whole and ethanol extracted *Moringa oleifera* leaves. Animal Feed Science and Technology 63, 211–228.

Makkar, H. P. S. and Becker K., 1997. Nutrient and antiquality factors in different morphological parts of *Moringa oleifera* tree. Journal of Agriculture Science, Cambridge 128, 311–322.

Makkar, H.P.S., Becker, K., 1998. Adaptation of cattle to tannins: role of proline-rich proteins in oak-fed cattle. Animal Science 67, 277–281.

Makkar, H.P.S., Blummel, M., Becker, K., 1995. In vitro effects of and interactions between tannins and saponins and fate of tannins in the rumen. Journal of the Science of Food and Agriculture 69, 481–493.

Makkar, H.P.S., Bluemmel, M., Borowy, N.K. and Becker, K., 1993. Gravimetric determination of tannins and their correlations with chemical and protein precipitation methods. Journal of the Science of Food and Agriculture 61, 161–165.

Mamun, S. M., Focken, U., Becker, K., 2007. Comparative digestion efficiencies in conventional, genetically improved and genetically male Nile tilapia, *Oreochromis niloticus* (L.). Aquaculture Research, 38, 381–387.

Mamun, S. M., Focken, U., Becker, K.; 2007. Comparative digestion efficiencies in conventional, genetically improved and genetically male Nile tilapia, *Oreochromis niloticus* (L.). Aquaculture Research, 38, 381–387.

Mao Weifeng, Wang Yaping, Wang Wenbo, Wu Bo, Feng Jianxin and Zhu Zuoyan, 2004. Enhanced resistance to Aeromonas hydrophila infection and enhanced phagocytic activities in human lactoferrin-transgenic grass carp (*Ctenopharyngodon idellus*). Aquaculture 242, 93–103.

Mao, Y., Cai, F., Lin, D., 1985. Studies on the daily requirements of protein, carbohydrates, fat, minerals and fiber of juvenile gras carp (*Ctenopharyngodon idella* C. *et* V.). Transactions of the Chinese Ichthyol Society 4, 81.

MARD (Ministry of Agriculture and Rural development) 2002. http://www.agroviet.gov.vn; http://mard.gov.vn; accessed on the 10th of September 2008.

MARD (Ministry of Agriculture and Rural Development) of Vietnam, 2006. http://www.fas.usda.gov/gainfiles/200704/146280974.pdf; accessed on the 07th of August 2008.

Maynard, L.A. and Loosli, J.K. (1969) Animal Nutrition, 6th edition. McGraw-Hill Book Company, London, p. 613.

Meyreles, L. and Preston, T.R., 1979. Studies on leaf production in the banana plant. Tropical Animal Production 4, 302.

Mgbenka, B.O. and Lovell, R.T., 1986. Intensive feeding of grass carp in ponds. Prog. Fish-Cult. 48, 238–241.

Miller, D.F., 1958. Composition of Cereal Grains and Forages. National Academy of Sciences, National Research of Sciences, National Research Council, Washinton, DC (Publ. 585).

Minot, N.; Baulch, B.; Epprecht, M. in collaboration with the Inter-Ministerial Poverty Mapping Task Force, 2003. Poverty and inequality in Vietnam: Spatial patterns and geographic determinants; International Food Policy Research Institute and Institute of Development Studies, Washington; pp. 86.

Mitchell, C.P., Fish, G.R. and Burnett, A.M.R., 1984. Limnological changes in a small lake stocked with grass carp. N.Z.J. mar. freshwat. Res. 18, 103–114.

MoFI (Ministry of Fisheries), 2004. Planning and management issues for the development of Pangasius production to year 2010. Workshop on Viet Nam Tra-Basa trade name and quality held in An Giang province, 14 – 16 December 2004, Hanoi, Ministry of Fisheries. (Vietnamese).

MoFI. 2005. Annual report on the state achievements of 2004 and action plan of 2005 of the fisheries sector. 25 pp. (in Vietnamese).

Moody, K., 1996. Sustainability in rice weed management. In: Innovative Weed Management Strategy for Sustainable Agriculture. JIRCAS International Symposium Series, Vol. 4, 48–56.

National Research Council (NRC), 1993. Nutrient Requirements of Fish. National Academy Press, Washington, DC, p 114.

National Research Council (NRC), 1983. Nutrient requirement of Warm water Fishes and Shellfish, National Academy Press, Washinton, D.C.

Naumann, C., Bassler, R., Seilbold, R. and Barth, C., 1988. Methodenhandbuch III - Die chemische Untersuchung von Futtermitteln. VDLUFA-Verlag, Darmstadt.

Ng, W.K. and Wee, K.L., 1989. The nutritive value of cassava leaf meal in pelleted feed for Nile tilapia. Aquaculture 83, 45–58.

Nguyen, S.H., Bui, A.T., Le, L.T., Nguyen, T.T.T., De Silva, S.S., 2001. The culture-based fisheries in small, farmer-managed reservoirs in two Provinces of northern Vietnam: an evaluation based on three production cycles. Aquaculture Research 32, 975–990.

NRC (National Research Council), 1993. Nutrient Requirements of Fish. National Academy Press, Washington, DC, p 114.

Oduro, I., Ellis, W.O., Owusu, D., 2008. Nutritional potential of two leafy vegetables: *Moringa oleifera* and *Ipomoea batatas* leaves. Scientific Research and Essay 3 (2), 057–060.

Opuszynski, K., 1968. Carp polyculture with plant-feeding fish: grass carp (*Ctenopharyngodon idella* Val.) and silver carp *(Hypophthalmichthys molitrix* Val.). Bull. Acad. pol. Sci. Ser. Sci. Biol. 16, 677–81.

Opuszynski, K., 1972. Use of phytophagous fish to control aquatic plants. Aquaculture 1, 61–74.

Osborne, J.A. and Sassic, N.M., 1981. The size of grass carp as a factor in the control of hydrilla. Aquat. Bot. 11, 129–136.

Oxfam. 2000. Finding a balance between riches and ruin, by Martinelli, Anne. Hong Kong.

Peres, H., Oliva-Teles, A., 2002. Utilization of raw and gelatinized starch by European sea bass (*Dichentracus labrax*) juveniles. Aquaculture 205, 287–299.

Pintér-Szakács, M., Molnár-Perl, H., 1990. Determination of tryptophan in unhydrolysed food and feedstuffs by the acid ninhydrin method. Journal of Agricultural and Food Chemistry 38, 720–726.

Plakas, S.M., Katayama, T., 1981. Apparent digestibility of amino acids from three regions of gastro-intestinal tract of carp (*Cyprinus carpio*) after ingestion of a protein and a corresponding free amino acid diet. Aquaculture 24, 309–314.

Porter, L.J., Hrstich, L.N. and Chan, B.G., 1986. The conversion of procyanidins and prodelphinidins to cyaniding and delphinidin. Phytochemistry 25, 223–230.

Prein, M.; Ahmed, M., 2000. Integration of aquaculture into smallholder farming systems for improved food security and household nutrition. Food and Nutrition Bulletin Vol. 21 (4), 466–471.

Preston, T.R. and Leng, R.A., 1991. Matching ruminant production systems with available resources in the tropics and sub- tropics. p. 165-185.

Prowse, G.A., 1966. Some aspects of tropical fish culture. Verh. int. Verein Limnol. 16, 1405-1407.

Qiu, T., Lu, R. H., Zhang, J. and Zhu, Z. Y., 2001. The molecular characterization of RNA segment S9 of grass carp hemorrhage virus (GCHV), an aquareovirus. Aquaculture 203, 1–7.

Richter, H., Lückstädt, C., Focken, U., Becker, K., 2003. Evacuation of pelleted feed and the suitability of titanium (IV) oxide as a feed marker for gut kinetics in Nile tilapia. Journal of fish Biology 63, 1080–1099.

Richter, N., Siddhuraju, P. and Becker, K., 2003. Evaluation of the quality of (*Moringa oleifera* Lam.) leaves as an alternative protein source for Nile tilapia (*Oreochromis niloliticus* L.). Aquaculture 217, 599–611.

Rogers, D.J. and Milner, M., 1963. Amino acid profile of maniac leaf protein in relation to nutritive value. Econ. Bot., 17, 211–216.

Rogers, D.J., 1959. Cassava leaf protein. Economic Botany 13, 261.

Rothuis, A.J., Nhan, D.K., Richter, C.J.J., Ollevier, F., 1998. Rice with fish culture in the semi-deep waters of the Mekong Delta Vietnam: a socio-economical survey. Aquacult. Res. 29, 47–57.

Santiago, C.B., Focken, U. and Becker, K., 2001. Voluntary feed intake and energy partitioning in tilapia (*Oreochromis niloticus*) fed diets with different protein/energy levels. 15th symposium on energy metabolism in animals, 11.-16. September 2000, Snekkersten, Denmark. Chwaligbog, A., Jakobsen, K., (Eds), EAAP publication 103: 181 –184.

Satoh, S., 1991. Common carp, *cyprinus carpio*. In: Wilson, R.P. (Ed.), Handbook of Nutrient Requirements of Finfish. CRC Press, Boca Raton, FL, pp. 55–67.

Sawar, M., Firkins, J.L., Estridge, M.L, 1992. Effects of varying forage and concentrate carbohydrates on nutrient digestibilities and milk production by dairy cows. Journal of dairy Science 75, 1533–1541.

Sawar, M., Iqbal, M.A, Ali, C.S., Khalq, T., 1994. Growth performance of buffalo male calves as affected by using cowpeas and soybean seeds as a source of urease during UTWS ensiling process. Egyptian Journal of Animal Production 2, 179–185.

Schlechtriem, C., Focken, U., Becker, K., 2003. Effect of different lipid extraction methods on $\delta^{13}C$ of lipid and lipid-free fractions of fish and different fish feeds. Isotopes Environ. Health Stud. 39, 135–140.

Schneeman, B. O., 1978. Effect of plant fiber on lipase, trypsin and chymotrypsin activity. J. Food Sci. 43, 634–635.

Schneeman, B. O. &. Gallaher, D., 1980. Changes in small intestinal digestive enzyme activity and bile acids with dietary celluloses in rats. J. Nutr. 110, 584–590.

Shearer, K.D., 1994. Factors affecting the proximate composition of cultured fishes with emphasis on Salmonids. Aquaculture 119, 63–88.

Shelton, W.L., Smitherman, R.O. and Jensen, G.L., 1981. Density-related growth of grass carp, *Ctenopharyngodon idella* (Val.) in managed small impoundments in Alabama. J. Fish Biol. 18, 45–51.

Shiau, S.-Y., Yu, Hu.-L., Hwa, S., Chen, S. and Hsu, S.-I., 1988. The influence of carboxymethylcellulose on growth, digestion, gastric emptying time and body composition of tilapia. Aquaculture 70, 63–88.

Shimoyamada, M., Ikedo, S., Ootsubo, R., Watanabe, K., 1998. Effects of soybean saponins on chymotryptic hydrolyses of soybean proteins. Journal of Agricultural and Food Chemistry 46, 4793–4797.

Shireman, J.V. and Maceina, M.J. 1981. The utilization of grass carp, *Ctenopharyngodon idella* Val., for hydrilla control in Lake Baldwin, Horida. J. Fish Biol. 19, 629–636.

Shireman, J.V., Colle, D.E. and Maceina, M.J., 1980. Grass carp growth rates in lakes Wales, Florida. Aquaculture, 19, 379–382.

Shireman, J.V., Colle, D.E. and Rottmann, R.W., 1977. Intensive culture of grass carp, *Ctenophmyngodon idella,* in circular tanks. J. Fish. Biol. 11, 267–272.

Shireman, J.V., Colle, D.E. and Rottmann, R.W., 1978. Growth of grass carp fed natural and prepared diets under intensive culture. Journal of Fish Biology 12, 457–463.

Sibbing, F.A., 1991. Food processing by mastication in fish. In: Vincent, J.F.V., Lillford, P.J. (Eds.), Feeding and the Texture of Food. Society of Experiments in Biology Seminar Series, vol. 33. Cambridge University Press, Cambridge, pp. 57–92.

Siddhuraju, P., Becker, K., Makkar, H.P.S., 2001. Chemical composition, protein fractionation, essential amino acid potential and antimetabolic constituents of an unconventional legume, Gila bean (*Entada phaseoloides* Merrill) seed kernel. Journal of the Science of Food and Agriculture 82 (2), 192–202.

Siddhuraju, P., Becker, K., 2002. Effect of phenolic non-protein amino acid, l-Dopa (l-3,4-dihydroxyphenylalanine), on growth performance, metabolic rates and nutrient utilisation in common carp (*Cyprinus carpio* L.). Aquaculture Nutrition 8, 69–77.

Siddhuraju, P., Becker, K., 2003. Antioxydant properties of various solvent extracts of total phenolic constituents from three different agroclimatic origins of drumstick tree (*Moringa oleifera* Lam.) leaves. Journal of Agricultural and Food Chemistry 51, 2144–2155.

Singh, S.B., Sukumaran, K.K., Pillai, K.K. & Chakrabarti, F.C., 1966. Observations on the efficacy of grass carp *Ctenopharyngodon idella* Val. in controlling and utilising aquatic weeds in ponds in India. Proceedings of the Indo-Paciftc Fishery Council 12, 220–235.

Smedes, F., 1999, Determination of total lipid using non-chlorinated solvents. Analysts 124, 1711–1718.

Smith, L.S., 1989. Digestive functions in teleost fishes. In: Halver, J.E. (Ed.), Fish Nutrition, second ed. Academic Press, London, p. 593.

Smith, R.R., Peterson, M.C. and Allred, A.C., 1980. Effect of leaching on apparent digestion co-efficients of feedstuff for salmonids. Progressive Fish-Culturist 42, 195–199.

Spannhof, L. and Plantikow, H., 1983. Studies on carbohydrate digestion in rainbow trout. Aquaculture 30, 95–108.

Stanley, J.G., 1974*a*. Nitrogen and phosphorus balance of grass carp, *Ctenopharyngodon idella,* fed elodea, *Egeria densa*. Trans. Am. Fish. Soc. 103, 587–592.

Stanley, J.G., 1974*b*. Energy balance of white armur fed *Egeria*. Water Hyacinth Control J. 12, 62– 66.

Steffens, W., 1989. Principles of Fish Nutrition. Ellis Harwood Ltd., Chichester, UK, 384 pp.

Steinbronn, S., Dongmeza, E.B., Tuan, N.N., Hong, N.T.L., Focken, U., Becker, K., 2006. Livelihood from weeds and leaves – Nutrient flows in the crop/aquaculture system of Black Thai farmers in Yen Chau/ Son La Province/Northern Vietnam; presented at symposium "Towards sustainable livelihoods and ecosystems in mountainous regions", Chiang Mai, Thailand, March 2006.

Steinbronn, S., Tuan, N.N., Focken, U., and Becker, K., 2005. Limitations in fish production in Yen Chau/Son La Province/Northern Vietnam; presented at Deutscher Tropentag, Stuttgart, Germany, October 2005.

Stevenson, M.H., Graham,W.D., 1983. The chemical composition and true metabolisable energy content of cassava root meal imported into Northern Ireland. Journal of the Science of Food and Agriculture 34, 1105–1106.

Storebakken, T., Shearer K.D and Roem, A.J., 1998. Availability of protein, phosphorus and other elements in fishmeal, soy protein concentrate and phytase-treated soy protein-concentrate-based diets to atlantic salmon, *Salmo salar*, Aquaculture 161, 365–379.

Stott, B. and Orr, L.D., 1970. Estimating the amount of aquatic weed consumed by grass carp. Progve Fish Cult. 32, 51–54.

Stroband, H.W.J., 1977. Growth and diet dependent structural adaptations of the digestive ract in juvenile grass carp (*Ctenopharyngodon idella,* Val.). J. Fish Biol. 11, 167–74.

Stroganov, N. S., 1963. The food selectivity of the amur fishes. Problems of the Fisheries Akad. Nauk Turkmensk. SSR., Ashkhabad p. 181-191 from Ref. Zh. Biol. 1964, No. 3132 (Transl. from Russian).

Stroganov, N.S., CTporaHOB, H.C., 1963. The food preference ability in grass carp. In: Materialy vsesoyuz. Soveshchaniya po rybokhozyajstvennomu osvoenyu rastitel'noyadnykh ryb – amura *(Ctenopharyngodon idella)* I tolstolobika (Hypothalmichthys molitrix) vodoemakh SSSR. Ashkhabad 1961. 181–191, Ashkhabad, Izdat. Akad. Nauk Turkmenskoj SSR.

Sugiura, S.H., Dong, F.M., Rathbone, C.K., Hardy, R.W., 1998. Apparent protein digestibility and mineral availabilities in various feed ingredients for salmonid feeds. Aquaculture 159, 177–202.

Sultan, J.L., Fluharty, F.L., Firkins, J.L., Loerch, S.C., 1992. Effect of supplemental protein source and alkaline hydrogen peroxide treatment of wheat straw on site of nutrient digestion and flow of nitrogenous compounds to the duodenum of steers. Journal of Animal Science 70, 3909–3918.

Sutton, D.L. and Blackburn, R.D., 1972. Feasibility of the Amur *(Ctenopharyngodon idella* Val.) as a biocontrol of aquatic weeds. Progress report for fiscal year 1972. US Dep Agric. and US Army Corps of Engineers. Ft. Lauderdale, FI. 43 pp.

Tacon, A.G.J., 1997. Contribution to food fish supplies. In: Review of the State of World Aquaculture; FAO Fisheries Circular No. 886; FAO Fisheries Department, FAO, Rome, 17–21.

Tan, Y.T., 1970. Composition and nutritive value of some grasses, plants and aquatic weeds tested as diets. J. Fish Biol. 2, 253–7.

Tang, Y.A., 1970. Evaluation of balance between fishes and available fish foods in multispecies fish culture ponds in Taiwan. Trans. Am. Fish. Soc. 99, 708–18.

Tuan, D., 2003. Son La – Potentials, chances of investment and development (Ed: Ha Hung); published by Department of Culture and Communication of Son La; Vietnam.

Tucker, C.S., Robinson, E.H., 1990. Channel Catfish Farming Handbook. Van Nostrand Reinhold, New York, NY, p. 454.

Ufodike, E.B.C., Matty, A.J., 1983. Growth responses and nutrient digestibility in mirror carp *Cyprinus Carpio* fed different levels of cassava and rice. Aquaculture 31, 41–50.

Vaintraub, I.A. and Lepteva N.A., 1988. Colorimetric determination of phytate in unpurified extracts of. seeds and the products of their processing. Analytical Biochemistry 175, 227–230.

van Anrooy, R. and Evans, B., 2001. FAO Aquaculture activities: an example from Vietnam. FAO Aquaculture Newsletter - 2001 - No.27.

http://www.fao.org/docrep/004/y2419e/y2419e01.htm; accessed on the 16th of August 2008.

Van Chinh, B. and Viet Ly, L., 2001. The use of some agro-byproducts for ruminants. Proceedings of the national workshop on nutrition and feeds for ruminants in Vietnam; pp. 31–41.

Van Chinh, B; Le Viet L.; Nguyen Huu Tao and Do Viet Minh, 1994. The use of sugarcane juice, "C" molasses and ensiled cassava leaves for fattening pigs. In: Annual scientific report on animal production, NIAH, Hanoi, pp. 27–31.

Van Keulen, J., Young, B.A., 1977. Evaluation of acid-insoluble ash as natural marker in ruminant digestibility. Journal of Animal Science 44, 262–266.

Van Soest, P.J., Robertson, J.B., Lewis, B.A., 1991. Methods of dietary fiber, neutral detergent fiber and non starch polysaccharides in relation to animal nutrition. Journal of Dairy Science 74, 3583–3597.

Venkatesh, B. and Shetty, H.P.C., 1978. Studies on the growth rate of the grass carp *Ctenopharyngodon idella* (Valenciennes) fed on two aquatic weeds and a terrestrial grass. Aquaculture 13, 45–53.

Vincent, J.F.V., 1991. Plants as food. In: Vincent, J.F.V., Lillford, P.J. (Eds.), Feeding and the Texture of Food. Society of Experiments in Biology Seminar Series, vol. 44. Cambridge University Press, Cambridge, pp. 19–33.

Vincent, J.F.V., Sibbing, F.A., 1992. How the grass carp (*Ctenopharyngodon idella*) chooses and chews its food–some clues. Journal of Zoology (London) 226, 435–444.

Wanapat, M., 1999. Feeding of ruminants in the tropics based on local feed resources, p. 229–234.

Wanapat, M.; Pimpa, O.; Petlum, A. and Booata, U., 1997. Cassava hay: a new strategic feed for ruminants during the dry season. Livestock Research for Rural Development, Volume 9, Number 2.

Wang, S., Liu, Y.-J., Tian, L.-X., Xie, M.-Q., Yang,H.-J., Wang, Y., and Liang, G.-Y., 2005. Quantitative dietary lysine requirement of juvenile grass carp *(Ctenopharyngodon idella)*. Aquaculture 249, 419–429.

Watkins, C.E., Shireman, J.V., Rottmann, R.W. and Colle, D.E., 1981. Food habits of fingerling grass carp. Progressive Fish-Culturist 43, 95–97.

Wattendoff, R.J. and Anderson, R.S., 1987. Hydrilla consumption by triploid grass carp. Proc. Ann. Conf. Southeast. Assoc. Fish. Wildl. Agencies 38(1984), 319–326.

Wee, K.L., Wang, S.S., 1987. Nutritive value of *Leucaena* leaf meal in pelleted feed for Nile tilapia. Aquaculture 62, 97–108.

Wen, Z., 1990. Studies on aquatic vegetation and ration carrying capacity of grass carp, *Ctenopharyngodon idella* Val., in Lake Niushanhu. M. Sc. Thesis, Institute of Hydrobiology, Academia Sinica.

Wiley, M. J. and Wilke, L. D., 1986. Energy balances of diploid, triploid and hybrid grass carp. Transactions of the American Fisheries Society 115, 853–861.

Williams, M.J. 1996. The transition in the contribution of living aquatic resources to food security. Food, agriculture, and the environment Disc. Pap. 13, 41 p. International Food Policy Research Institute, Washington, D.C.

Williams, M.J., 1999. The role of fisheries and aquaculture in the future supply of animal protein. Sustainable Aquaculture: food for the future? (eds N. Svennevig, H. Reinertsen & M. New), pp. 5–18. Balkerma, Rotterdam.

William, P.E.V, Innes, G.M, Brewer, A., 1984. Ammonia treatment of straw via the hydrolysis of urea. Effect of dry matter and urea concentrations on the rate of hydrolysis of urea. Animal Feed Science and technology 11, 103–111.

Wilson, R.P. and Cowey, C.B., 1985. Amino acid composition of whole body tissue of rainbow trout and atlantic salmon. Aquaculture 48, 373–376.

Windell, J.T., Foltz, J.W. and Sarokon, J.A., 1978. Methods of feed collection and nutrient leaching in digestibilities studies. Progressive Fish-Culturist 40, 51–55.

Wing Keong N.G. and Kok Leong Wee, 1989. The nutritive value of cassava leaf meal in pelleted feed for Nile tilapia. Aquaculture 83, 45–58.

Wu, J., Yong, W., You, W., Wen, H., Liao, C. and Wu, D., 1995. Apparent digestibility and digestible energy of 12 feedstuffs for bluntnose black bream (*Megalobram amblycephala* Yih). J. Fish Sci. China, 2, 55–62 (In Chinese with English abstract).

Zhong, J., Wang, Y. and Zhu, Z., 2002. Introduction of the human lactoferrin gene into grass carp (*Ctenopharyngodon idellus*) to increase resistance against GCH virus. Aquaculture 214, 93–101.

Zhou, Z., Ren, Z., Zeng, H. and Yao, B., 2007. Apparent digestibility of various feedstuffs for bluntnose black bream *Megalobrama amblycephala* Yih. Aquaculture Nutrition 13, 1–13.

Zoology Division Isotopes Laboratory, 1978. Studies on the nutritional physiology of grass carp III. On the application of ^{14}C to study the digestion and absorption of grass carpto crude cellulose. Acta Scientarum Naturlium Universitatis Sunyatsine 4, 106.