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Modelling Digestibility Coefficients of Plant Protein Sources and Levels in Tilapia Diets

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ABSTRACT

The objective of this study was to compile database of apparent digestibility coefficients of the nutrients and energy (ADCs) for plant protein sources fed by Nile tiplapia, and select linear model procedures as the statistical framework to model the relationships between ADCs and dietary plant protein level. A database containing plant protein sources digestibility coefficients were collected from 21 studies. The models obtained to predict the ADC*s* of nutrients and energy based on dietary plant protein sources (PPS) level of the ingredients were as follow:

- Apparent protein digestibility coefficient= -0.233*(Incorporation level of PPS) + 97.778
- Apparent lipid digestibility coefficient = -0.3898*(Incorporation level of PPS) + 100.93
- Apparent energy digestibility coefficient= -0.2965*(Incorporation level of PPS) + 87.865
- Apparent dry matter digestibility coefficient= 0.0972*(Incorporation level of PPS) + 61.031.

Using dietary plant protein sources level as indicators to predict ADCs in tilapia diets, most of the error was attributed to random disturbance (99.9%), indicating a lack of either slope or mean bias errors and high accuracy model. The results suggest that increasing the incorporation level of plant protein ingredient in tilapia diets have negative effect on the ADC of protein (R^2=0.74).

Keywords:

INTRODUCTION

Fish meal (FM) is one of the best protein sources for fish feeds because of its nutritional value and high palatability to fish. FM contains high levels of dietary essential amino acids and essential fatty acids (omega-6 and omega-3 highly unsaturated fatty acids). However, FM is a restricted resource and is expensive (Muirhead, 2011) relative to other protein supplements in the ingredient market. Height FM prices worldwide will continue to increase feed prices unless more economical alternatives are developed and utilized. Several ingredients have the possibility to replace FM in marine-fish diets. Plant ingredients are likable replacements for FM because of their lower cost and widespread availability (Suloma and Ogata, 2001). The reduction or cancellation of FM use in commercial diets can greatly reduce feed costs for aquaculturists (Gregory, 2011).

Nutritional value of plant protein sources products for sea bass and tilapia has been evaluated in a number of works by either measuring their digestibilities or by including different levels of the product in the diet and following the performance of the fish. Accurate estimation of digestible plant protein content feed could be achieved through a modeling approach taking into account the digestibility of the different plant protein sources composition and the effect of their inclusion levels. As the aquaculture industry moves towards increased cost efficiencies, feed formulations must become more precise thus making the need for digestibility values of plant protein sources for many aquatic animal species even more critical (Suloma et al, 2013; Nguyen, 2008).

Meta-analysis, the review of scientific literature with the emphasis on providing a quantitative synthesis of data, allows the evaluation and integration of results from a group of studies, even those with seemingly contradictory results (Fernandez-Duque, 1997). The objective of the present study was to analyse, with the use of linear model, available published digestibility studies results obtained on Nile tilapia due to the replacement of dietary FM by plant products, to develop mathematical models to estimate the digestible nutrients for plant protein ingredients in tilapia diets.

MATERIALS AND METHODS

1- Modelling digestibility coefficients of plant protein ingredients in tilapia diets

a. Dataset tilapia

A database containing plant protein sources digestibility coefficients was collected from the following studies (Table 1):

Appler, 1985; Shiau *et al.*, 1987; Shiau *et al.*, 1989; Shiau *et al.*, 1990; Sintayehu *et al.*, 1996; Falaye and Jauncey, 1999; Fernandes *et al.*, 1999; Mbahinzireki *et al.*, 2001; El-Saidy and Gaber, 2002; Ng *et al.*, 2002; El-Saidy and Gaber, 2003; El-Shafai *et al.*, 2004; Gaber, 2005; Koprucu and Özdemir, 2005; Gaber, 2006; Ogunji *et al.*, 2008; Soltan *et al.*, 2008; Yue and Zhou, 2008; Wee and Shu 1989 and Azaza *et al.*, 2009.

b. Calculated and statistic

The incorporation level of the plant protein sources was calculated for each treatment. Despite the absence of information on moisture status of diets in some studies, values were converted to a dry matter basis if presented as wet weight. Simple linear regression analysis was carried out to evaluate the relation between predicted (y) and observed (x) values of ADCs of the nutrient performed with the use of the software SPSS (data analysis software system, Version 17), as described by Sales (2008). With linear regression the coefficient of determination (R^2) illustrates how well the regression line represents the data, whereas the root mean square error (RMSE) indicates the magnitude of variation.

Mean square prediction error (MSPE) analysis, as described by Sales (2009), was included to identify the error of predicted relative to observed values (Theil, 1966):

$$MSPE = \sum (O_i - P_i)^2/n \quad i=1$$

where: n = the number of experimental observations.

O_i, P_i = the observed and predicted values, respectively.

The mean prediction error (MPE) was calculated by presenting the root MSPE (√ MSPE), which can be expressed in the same units as the output, as a fraction of the observed mean (O)

$$MPE = \frac{\sqrt{MSPE}}{O}$$

The MSPE was divided into: (1) error in central tendency (ECT) or mean bias, (2) error due to regression (ER) or line bias, and (3) error due to disturbance (ED) or random bias:

$$ECT = (\bar{X}_P - \bar{X}_O)^2$$
$$ER = (s_P - r \times s_O)^2$$
$$ED = ((1 - r^2) \times s_O)^2$$

Table 1. ***Input data used for modelling digestibility coefficients of plant protein ingredients in tilapia diets.***

No.	Protein source	Temp. (⁰C)	Period	Size g.	Marker	Reference
1	Wheat, feba beans, chick peas, field peas and FM 70	27		15	Chromic oxide	Koprucu and Ozdemir, (2005)
2	Corn gluten meal, sorghum m,wheat meal ,soy bean meal, FM,poultry by product, blood meal and meat meal	25	12 weeks	6.7	Chromic oxide	Fernandes *et al.* (1999)
3	Pea seed meal and FM	24.5 – 31	70 days	10.54 – 12.20	chromic oxide	Wee and Shu (1989)
4	Faba bean meal, Maize meal, Dehulled SBM and FM	28.5– 30.6 °C	75 days	17.27g	chromic oxide	Azaza *et al.*, (2009)
5	Defatted soybean meal, soy bean meal and FM	26	9 weeks	5.13 – 5.16	chromic oxide	Shiau *et al.* (1990)
6	SBM, cottonseed meal and FM	28- 30	8 weeks	6.27g	Chromic oxide	Yue and Zhou (2008)
7	FM and Plant Protein Mixture(cottonseed, sunflower, canola, seasme and linseed meals)	23.15 - 30.16	12 weeks	(2.61- 2.71) (5.6- 5.7)	chromic oxide	Soltan *et al.* (2008)
8	Fishmeal and magmeal	28	56 days	2.85	Chromic oxide	Ogunji *et al.* (2008)
9	Fishmeal and Soybean meal	26	9 weeks	1.24	chromic oxide	Shiau *et al.* (1987)
10	Fishmeal and Algal meal	26	50 days	0. 1 g	Chromic oxide	Appler (1985)
11	Cocoa husk and FM	27 – 28	49 days	0.97	chromic oxide	Falaye and Jauncey (1999)
12	Cottonseed meal and FM	27	16 weeks	11.8	chromic oxide	Mbahinzireki *et al.* (2001)
13	Danish FM soy bean meal and palm kernel meal		10 weeks	5.1	chromic oxide	Ng *et al*. (2002)
14	FM and Plant protein mixture(SBM, 25% cottonseed meal, 25% sun£ower meal and 25% linseed meal)	27.5- 28.5	16 weeks	3.77	chromic oxide	El-Saidy and Gaber (2003)
15	Fishmeal, corn, wheat and wheat bran	27.4 – 29	49 days	90	Chromic oxide	El-Shafai *et al.* (2004)
16	FM, Broad bean meal, Corn meal and Wheat bran	28.1	16 weeks	1.9	Chromic oxide	Gaber (2006)
17	Soybean meal, cottonseed meal, sun- flower seed meal and fishmeal	26.5		93 - 64	HCI-insoluble ash	Sintayehu *et al.* (1996)
18	FM, SBM, Wheat bran and Corn meal	27.3	10 weeks	1.93		El-Saidy and Gaber (2002)
19	FM, SBM, Wheat bran and Corn meal	27.5	20 weeks	0.8	Chromic oxide	Gaber (2005)
20	FM, SBM, cottonseed meal, sunflower meal, and linseed meal	26.5- 28.8	6 months	14.2	Chromic oxide	Gaber (2006)

Where:

$\bar{X}_P$, $\bar{X}_O$ = the mean predicted and observed values, respectively.

s_P, s_O = the standard deviations of the predicted and observed values, respectively.

r = the correlation coefficient between predicted and observed values

RESULTS AND DISCUSSION

The data collected for this modeling were included fish size ranged from 0.1 (Appler, 1985) to 90 g (El-Shafai *et al.*, 2004). All studies kept fish in fresh water with temperature varying from 23.15 (Soltan *et al.*, 2008) to 30.6°C (Azaza *et al.*, 2009). All studies used chromic oxide as indigestible marker, except Sintayehu *et al.* (1996) who used HCl-insoluble ash.

The models obtained to predict the ADC*s* of nutrients and energy based on dietary plant protein sources (PPS) level of the ingredients were as follow:

Apparent protein digestibility coefficient= -0.233*(Incorporation level of PPS) + 97.778 (Fig.1 and 2)

Apparent lipid digestibility coefficient = -0.3898*(Incorporation level of PPS) + 100.93 (Fig.3 and 4)

Apparent energy digestibility coefficient= -0.2965*(Incorporation level of PPS) + 87.865 (Fig. 5 and 6)

Apparent dry matter digestibility coefficient= 0.0972*(Incorporation level of PPS) + 61.031 (Fig. 7 and 8).

Using dietary plant protein sources level as indicators to predict ADCs in tilapia diets, most of the error was attributed to random disturbance (99.9%) (Table 2), indicating a lack of either slope or mean bias errors.

Generally, the majority of studies that recommended only partial replacements of alternative protein sources to fishmeal implicate antinutritional factors, an incomplete amino acid profile, P deficiency or reduced digestibility utilization as the reasons (El-Husseiny et al., 2002a&b; Goda et al., 2002: El-Sayed *et al.*, 2000; El-Saidy and Gaber, 2004; Garcia-Abiado *et al.*, 2004; Yue and Zhou, 2008 and Zhao *et al.*, 2010).

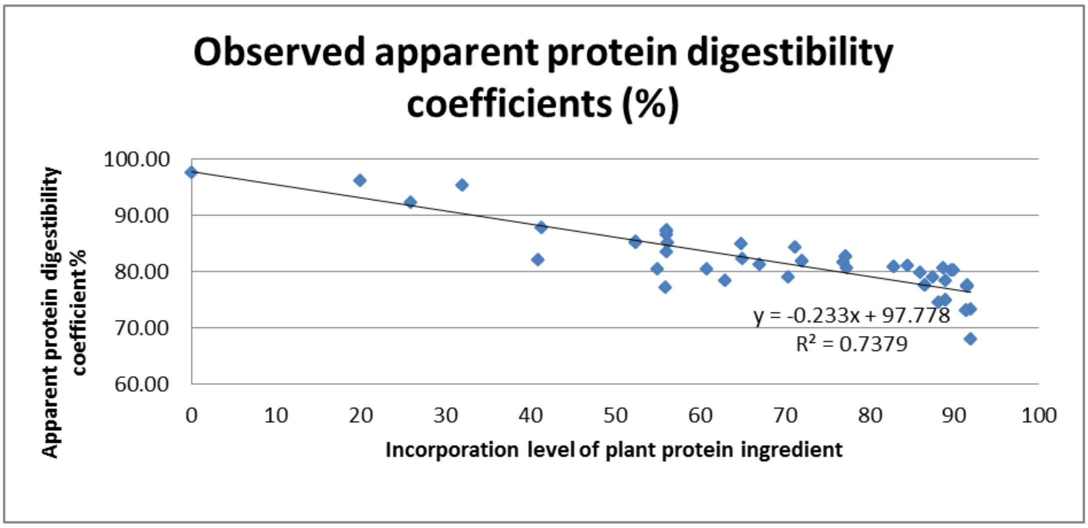

Fig.1. ***Linear equation to estimate apparent digestible protein content in Nile tilapia diets.***

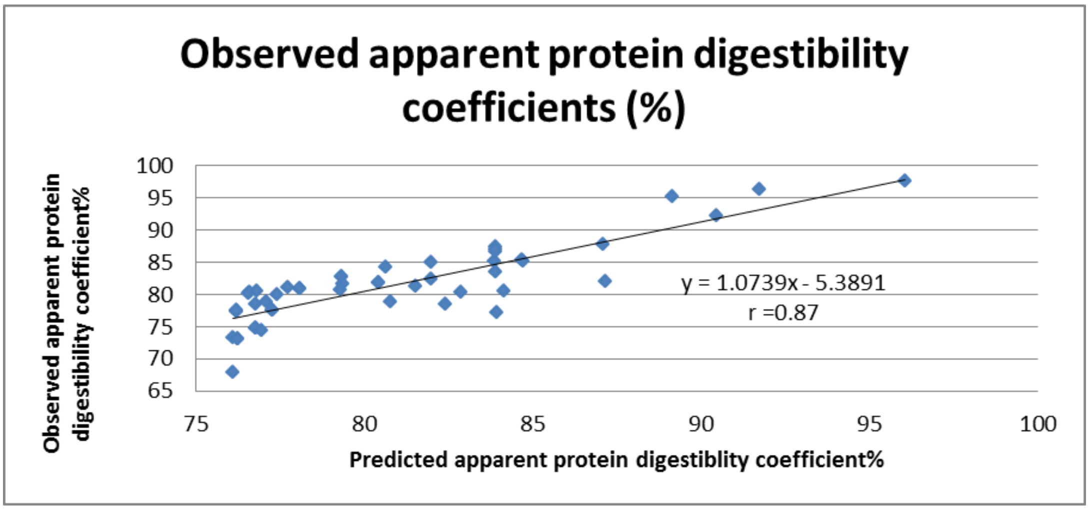

Fig.2. *Comparison of observed and model estimated apparent digestible protein content % in tilapia diets.*

Table 2. *Decomposition of mean square prediction errors (MSPEs) between predicted and observed protein values for sea bass data.*

ADCs	MSPE root	Proportion MSPE		
		Error in central tendency	Error due to regression	Error due to disturbance
CP	3.74	3.75	1.29	94.95
CL	12.16	2.28×10^{-5}	3.31×10^{-7}	99.90
GE	7.51	2.43	.001	97.57
DM	9.75	$3.71 \times 1\ 0^{-6}$	2.43×10^{-7}	99.90

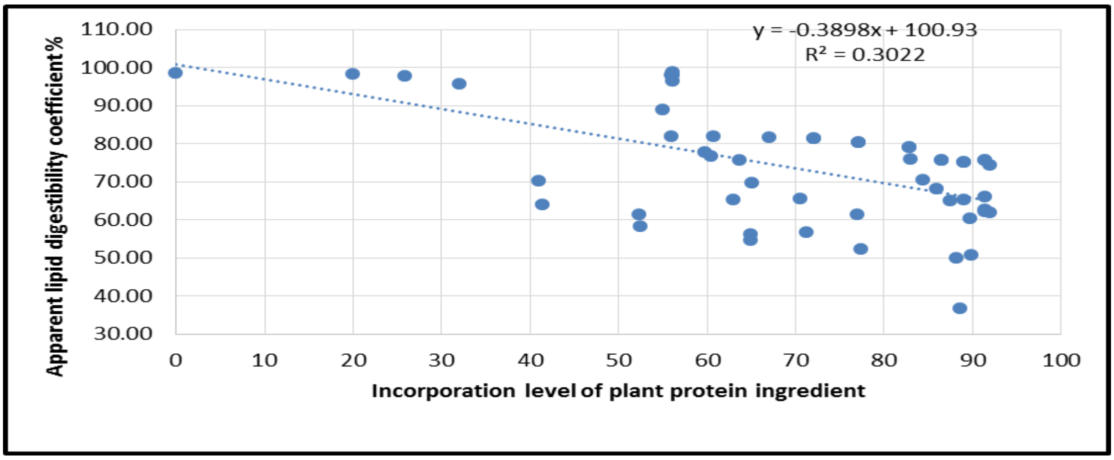

Fig.3. *Linear equation to estimate apparent digestible lipid content in Nile tilapia diets.*

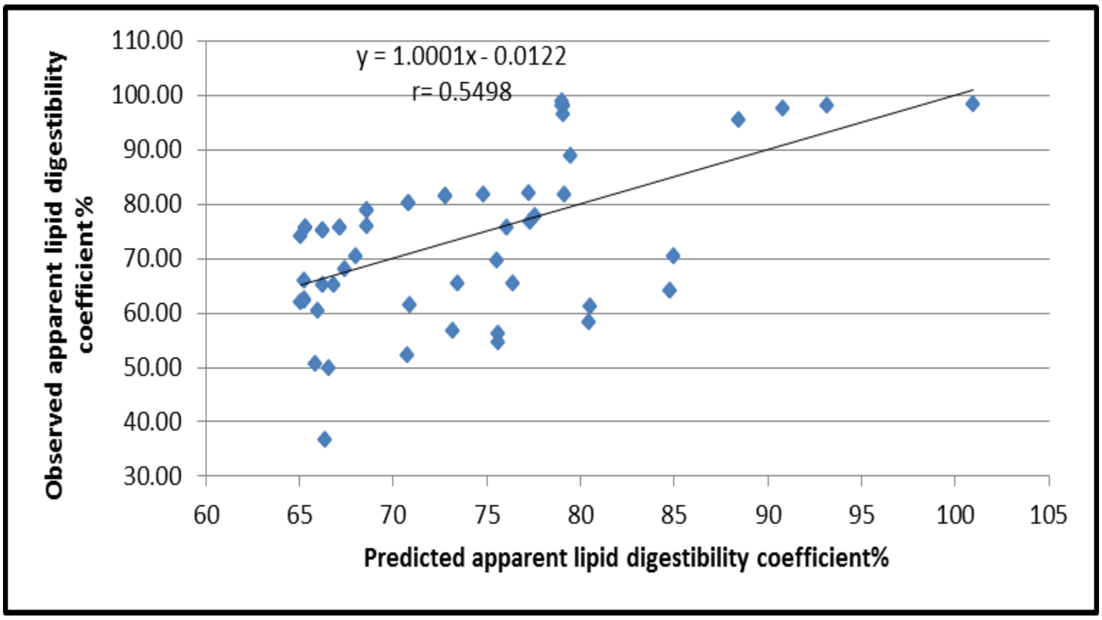

Fig.4.*Comparison of observed and model estimated apparent digestible lipid content % in tilapia diets*.

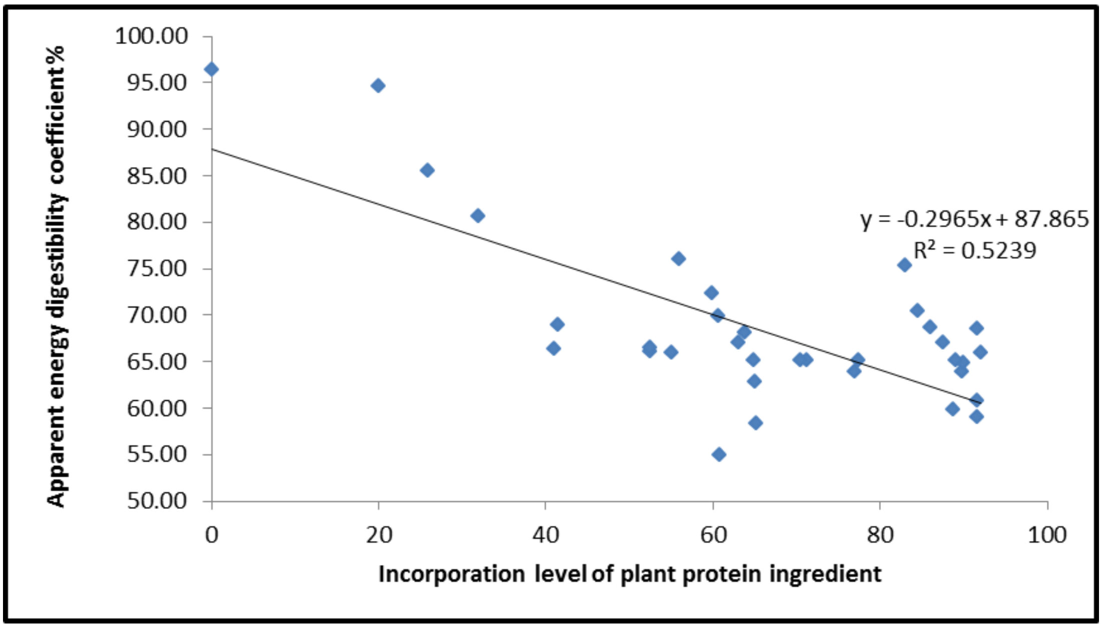

Fig.5. *Linear equation to estimate apparent digestible energy content in Nile tilapia diets*

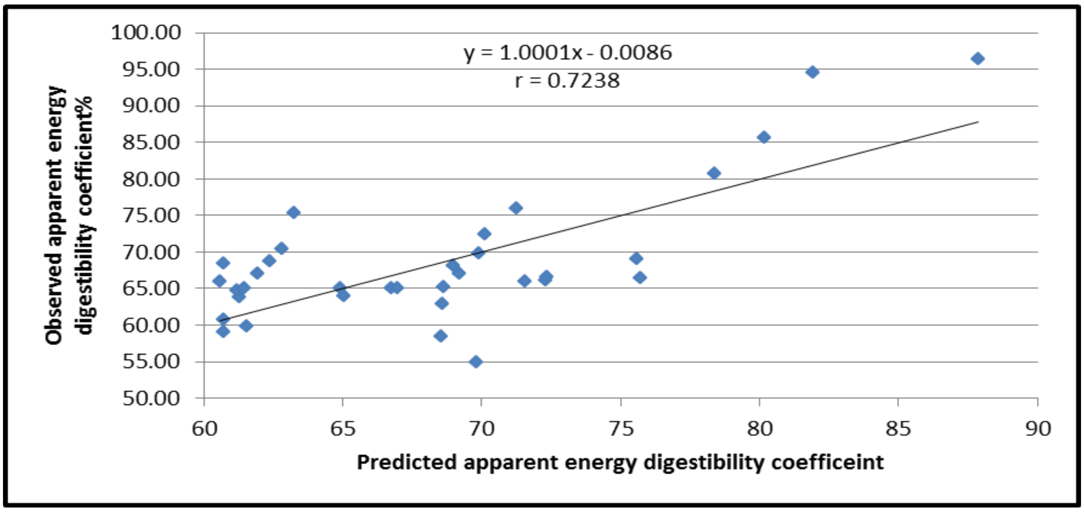

Fig.6. Comparison of observed and model estimated apparent digestible energy content % in tilapia diets.

The data collected for the modelling showed that ADCs of dry matter, protein, lipid, and energy in Nile tilapia diets were affected by increasing of plant protein inclusion levels ($P < 0.05$).

The results suggest that increasing the incorporation level of plant protein ingredient in tilapia diets have negative effect on the ADC of protein (R^2=0.74) (Fig. 1). Proteins in most feedstuffs that have been properly processed are highly digestible to fish. The digestion coefficients for protein-rich feedstuffs are usually in the range of 75 to 95% (NRC, 1993). APDs of SBM for tilapia reported by different authors were 94.0% (NRC, 1993); 91.6% (Jauncey, 1998); 96.2% (Sklan *et al.*, 2004), 87.4% (Koprucu and Ozdemir, 2005) and 92.4% (Guimaraes *et al.*, 2007), defatted SBM 94.4% and fullfat soybean 90.0% (Fontainhas-Fernandes *et al.*, 1999); cottonseed meal 31.0% and groundnut meal 79.0% (Luquet, 1989) and cottonseed meal 78.5% (Guimaraes *et al.*, 2007). Part of the variability in APDs may be explained by differences in chemical composition, origin and processing of these various feed ingredients, methods of faeces collection and calculation of ADCs (Bureau *et al.*, 1999; Forster, 1999 and Bureau and Hua, 2006).

Generally, the protein quality of dietary ingredients is one of the leading factors affecting fish performance and protein digestibility (digestible protein) is the first measure of its availability to fish. Protein quality of dietary protein sources depends on the amino acid composition and their digestibility. APD of the plant protein sources used in this study tends to be depressed as the concentration of dietary fiber increases (NRC, 1993).

Plant protein sources used in the modling of this study contain high level of fibre compared with animal protein sources (NRC, 1993). Fibre refers to indigestible plant matter such as lignin, cellulose, hemicellulose, pentosans, and other complex carbohydrates found in feedstuffs (NRC, 1993). Monogastric animals including fish are generally unable to digest fibre because they do not secrete cellulase (Bureau *et al.*, 1999). Fibre provides physical bulk to feed and may improve pelletability (NRC, 1993). Cellulose and hemicellulose have

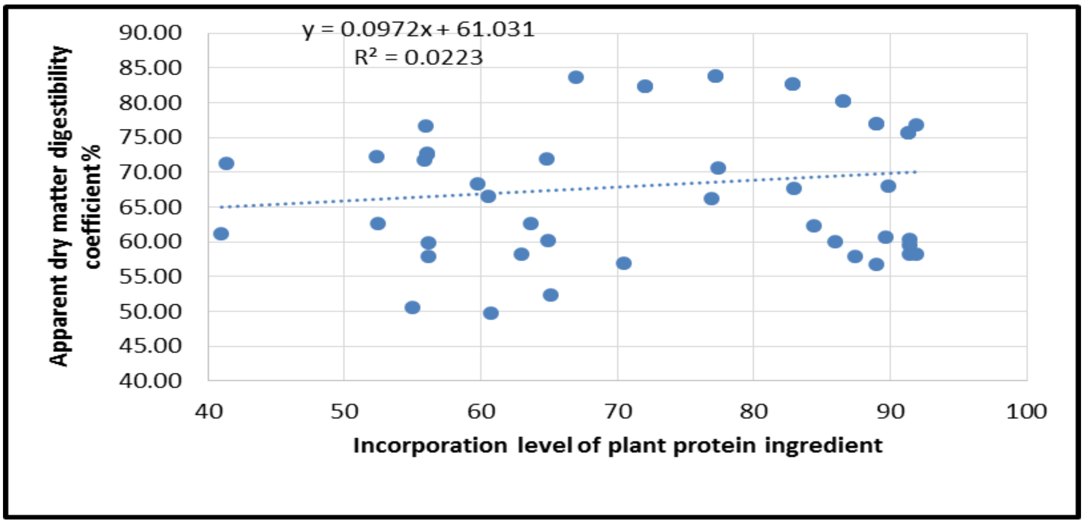

Fig.7.***Linear equation to estimate apparent digestible dry matter content in Nile tilapia diets.***

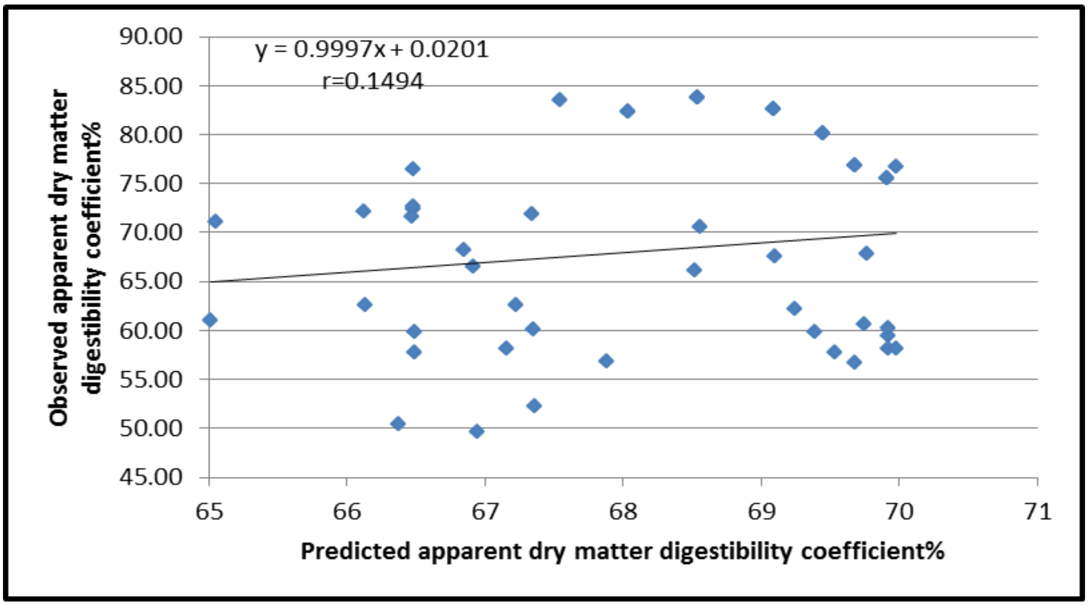

Fig.8. ***Comparison of observed and model estimated apparent digestible dry matter content % in tilapia diets***.

been used as diluting agents and fillers especially in experimental fish diets (De Silva and Anderson, 1995 and Jauncey, 1998). Small amounts of dietary fibre have been reported to improve efficiency of protein utilization in laboratory diets (Buhler and Halver, 1961) and gastric evacuation time of rainbow trout (Hilton *et al.*, 1983). However, it is not desirable to have a fibre content exceeding 8-12% in diets for fish, as increase in fibre content would consequently lead to the decrease of the quantity of a usable nutrient in the diet. Excessive fibre content could also result in decrease in total dry matter and nutrient digestibility of the diet resulting in poor performance (De Silva and Anderson, 1995). Because fibre is indigestible, it adds to the faecal waste which affects the water quality and hence fish performance (Lovell, 1998).

Phytic acid in most plant protein sources used in the modling of this study is associated with specific parts of the seed such as the endosperm, germ and hull. Phytate (Ca-Mg salt of phytic acid) chelates with mineral cations like potassium (K), magnesium (Mg), calcium (Ca), zinc (Zn), iron (Fe), copper (Cu) and forms poorly soluble complexes (Papatryphon *et al*., 1999; Rackis, 1974 and Smith, 1977). These salts of phytic acid are known as phytins and their availability/digestibility to monogastric animals including fish is very limited due to lack of digestive enzyme phytase for efficient phytate hydrolysis during digestion (NRC, 1993; Jackson *et al*., 1996 and Hughes and Soares, 1998). The majority of phosphorus in most proteinrich plant ingredients is bound in phytate, therefore, limits its bioavailability to most fish because they lack the digestive enzyme phytase (Jobling *et al*., 2001). Similarly, phytate forms complexes with proteins and amino acids (Spinelli *et al*., 1983; Liu *et al*., 1998 and Sugiura *et al*., 2001) and their availability/digestibility to monogastric animals including fish such as tilapias become very limited (NRC, 1993). The inclusion of phytate containing ingredients in the diet has been reported to negatively affect growth and feed efficiency in commonly cultured fish species, such as carp, tilapia, trout and salmon (Francis *et al*., 2001 and Portz and Liebert, 2004). Salmonids seem to be able to tolerate dietary levels of phytate in the range of 5 – 6 $g.kg^{-1}$, while carp appears to be sensitive to these levels. It seems to be advisable to maintain the level of phytates below 5 .0 $g.kg^{-1}$ in fish feeds (Francis *et al.*, 2001).

Saponins in various legume seeds range between 18 and 41 $mg.kg^{-1}$ and defatted roasted soybean flour contain 67 $mg.kg^{-1}$ (Fenwick *et al*., 1991). Dietary saponins are known to have several adverse effects on fish performance, including reduction of feed intake due to their astringent taste (Guillaume and Metailler, 1999) and interference with digestibility and absorption of nutrients due to formation of sparingly digestible saponin-nutrient complexes (Potter *et al*., 1993 and Ikedo *et al*., 1996). Saponins may also damage intestinal epithelium mucosa and repiratory epithelium (Hostettmann and Marston, 1995 and Bureau *et al*., 1998).

CONCLUSION

Most of the model errors were attributed to random distuebance indicating a high accuracy of model. Also, efforts should ideally be a lot more logical and no longer be focused on the " substitution" of one plant protein source by other but rather on "how can we cost-effectively and safely meet the requirements of the animals by selecting blends of highly digested ingredients".

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نمذجة معاملات هضم مصادر البروتين النباتية فى علائق البلطى النيلى

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تهدف هذه الدراسة الى تطوير نموذج احصائى للتنبؤ بمعاملات هضم المركبات الغذائية فى علائق البلطى ذات محتوى عالى من مصادر البروتين النباتية. لتحقيق هذا الهدف تم تجميع البيانات المتعلقة بمعاملات الهضم الظاهرية للمركبات الغذائية و الطاقة لمواد العلف ذات الاصل النباتى من الدراسات السابقة (٢١ دراسة علمية منشورة فى مجالات ذات معامل تأثير)، و تم اختبار النموذج الخطى لدراسة العلاقات ما بين زيادة نسب مواد العلف النباتية فى العلائق (صفر الى ١٠٠%) على معاملات هضم المركبات الغذائية و الطاقة و قد تم حساب نسبة مدى احتواء العليقة من مواد العلف النباتية لكل معاملة داخل الدراسات المختلفة و قد تم استخدام متوسط مربعات خطأ التنبؤ (MSPE (Mean square prediction error كمعيار لتحديد مدى دقة النموذج على التنبؤ بمعاملات الهضم.

وكانت النماذج المتحصلة عليها كالأتى:

معامل الهضم الظاهرى للبروتين % =(- 0.233× نسبة إضافة مواد العلف النباتية فى العليقة) + 97.778
معامل الهضم الظاهرى للدهون % = (- ٠,٣٨٩٨× نسبة إضافة مواد العلف النباتية فى العليقة) + ١٠٠,٩٣
معامل الهضم الظاهرى للطاقة % = (- ٠,٢٩٦٥ × نسبة إضافة مواد العلف النباتية فى العليقة) + ٨٧,٨٦٥
معامل الهضم الظاهرى للمادة الجافة % = (٠,٠٩٧٢× نسبة إضافة مواد العلف النباتية فى العليقة) + ٦١,٠٣١

وقد وجد أن معظم الخطأ راجع إلى الخطأ العشوائي (Disturbance error) بما يعادل ٩٩% لكل النماذج مما يدل على عدم وجود خطأ التحيز Pais أو لخطأ الإنحدار Slope error.مما يدل على صلاحية النموذج للاستخدام فى عملية التنبؤ. كما دلت الدراسة على ان زيادة نسبة إضافة مصادر البروتين النباتى فى علائق البلطى النيلى تؤثر سلبيا على معامل الهضم الظاهرى للبروتين (R^2= 0.74).