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Water spinach (*Ipomoea aquatica*) as a feed resource for growing rabbits

Pok Samkol

Center for Livestock and Agriculture Development
(CelAgrid-UTA Cambodia), Cambodia
samkol@mekarn.org, samkolpok@yahoo.com

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1. Introduction

Rabbits are herbivores which efficiently convert forages to food. The whole point of sustainable systems of meat production is to convert plant proteins into animal protein of superior nutritive value for people, especially pregnant women and children (Waterlow, 1998). According to Lebas *et al.* (1997), rabbits in efficient production systems can turn 20 percent of the proteins they eat into edible meat. Comparable figures for other species were quoted as 22 to 23 percent for broiler chickens, 16 to 18 percent for pigs and 8 to 12 percent for beef. Rabbits can also utilize the available proteins in cellulose-rich plants, whereas it is not economical to feed these to chickens and turkeys, the only animals with higher energy and protein efficiency. The traditional grain and soybean meals fed to these domestic poultry put them in direct competition with humans for food. For countries with no cereal surpluses, rabbit meat production is thus especially interesting (Lebas *et al.*, 1997).

In the view of the worldwide demand for additional sources of food, the exploitation of plants of low economic importance would be a step towards better resource utilization (Telek, 1983). This is in line with the strategy to achieve sustainable animal production systems by matching them with the locally available feed resources (Preston and Sansoucy, 1987).

Water spinach is used traditionally in Cambodia as a vegetable for consumption by people and animals. It has a short growth period and is resistant to common insect pests. However, there appears to be no information in the literature on its response to fertilizer especially fertilizer of organic origin as is produced by the anaerobic digestion of livestock manure (Kean Sophea and Preston, 2001). It does not appear to contain anti-nutritional compounds and has been used successfully for growing pigs as the only source of supplementary protein in a diet based on broken rice (Ly, 2002; Chhay Ty and Preston, 2005). Prak Kea *et al.* (2003) reported a linear increase in growth rates in pigs fed water spinach, palm oil and broken rice when up to 6% fish meal replaced equivalent amounts of water spinach, which they attributed to an improved amino acid balance, especially in terms of the sulphur-rich amino acids.

Recent research has explored the feasibility of using water spinach in combination with broken rice as a readily digestible feed for growing rabbits (Miech Phalla, 2002, unpublished data; Hongthong Phimmasan *et al.*, 2004; Vo Thi Tuyet Nga, 2004). However, most of these reports are of a preliminary nature.

2. Objectives

- To confirm the observations of Hongthong Phimmasan *et al.* (2004), concerning the nutritive value of water spinach for growing rabbits, but using the direct method for determining digestibility.
- To determine performance traits of young rabbits fed water spinach *ad libitum* and graded levels of broken rice.
- To measure the response of water spinach to fertilization with biodigester effluent and to study the effect of different offer levels of water spinach on performance traits and digestibility coefficient of rabbits.

3. General discussion

3.1. Rabbit production in the world

Lebas and Colin (1992) suggest that world production of rabbit meat is of the order of 1.5 million tonnes. This would mean a per caput annual consumption of roughly 280 g of rabbit meat; however, most inhabitants in a great many countries consume no rabbit meat whatsoever as compared with the 10 kg/year consumed by French farmers and 15 kg/year per caput in Naples, and Italy (Lebas and Colin, 1992). Europe is indeed the centre of world rabbit production. The foremost world producers, far surpassing all other countries, are Italy, the Commonwealth of Independent States countries (particularly Russia and the Ukraine), France, China and Spain. Europe accounts for 75 percent of world production. China is second, specifically certain central Chinese provinces such as Szechuan. Production areas are also found in some regions of Africa, Central America and

Southeast Asia, particularly Indonesia. Rabbits are not reared in most countries of the Near East. The annual consumption of rabbit meats is shown in table 1.

Table 1. Estimated annual rabbit meat consumption in selected countries, per caput (kg of carcass per person per year).

Country	Carcass weight	Country	Carcass weight
Japan	0.03	Thailand	0.31
Benin	0.04	Ghana	0.32
Congo	0.04	Bulgaria	0.39
China	0.07	Germany	0.44
Brazil	0.08	Nigeria	0.45
Hungary	0.10	Tunisia	0.48
South Africa	0.11	Malaysia	0.50
Argentina	0.12	Poland	0.50
Peru	0.13	Netherlands	0.63
United States	0.14	Romania	0.64
Mexico	0.18	Greece	0.70
Jamaica	0.20	CIS (former USSR)	0.75
Canada	0.23	Slovenia	0.77
Colombia	0.24	Morocco	0.78
Syrian Arabic Republic	0.25	Czechoslovakia	1.72
Algeria	0.27	Portugal	1.94
Egypt	0.27	Spain	2.61
Indonesia	0.27	Belgium	2.61
United Kingdom	0.27	France	2.76
Vietnam	0.27	Cyprus	4.37
Philippines	0.29	Italy	5.71
Venezuela	0.30	Malta	8.89

Sources: from Lebas et al. (1986); Lebas and Colin (1992); Colin and Lebas (1994).

3.2. Feed preferences and feeding behaviour of rabbits

Rabbits are very selective in their feeding behaviour and in the wild will nibble and select specific plant parts. They generally select leaves rather than stems, young plant materials rather than old and green rather than dry materials, resulting in a diet that is higher in protein and digestible energy and lower in fiber than the total plant material available. They are much more sensitive to slight changes in the feed than other livestock. Sometimes they will refuse to accept a new diet and will starve rather than even taste the new feed for several days (McNitt *et al.*, 1996).

Lukefahr (1992) presented information on suitable feed sources and basic primary dietary requirements and concluded that feeds for rabbits could be obtained from a variety of sources. These included: wild, indigenous plant stands, cultivated forage plots, farm crop residues, farm surplus foods, agricultural by-products, kitchen wastes, and market sources. However, the wild plants may be poor in palatability and some forage may only seasonally available. He suggested cultivating forage plots on the farm with recommended species, managing the plots for the best yields, finally making the harvest and feeding the forage at the proper time. Ryan (1988) included sixteen feedstuffs that could be recommended to be grown without much care and regular watering such as: *Desmanthus virgatus*, *Sesbania grandiflora*, *Euphorbia hirta*, *Cicca acida*, *Ocimum sanctum*, *Erythrina variegata*, *Cyperus rotumdus*, *Acalypha indica*, *Solanun nigrum*, *Raphanus sativus*, *Moringa concanensis*, *Solanum torvum*, *Kydia calycina*, *Leucas aspera*, *Manihot esculenta* and *Kirganelia reticulata*. He recommended that two thirds of the ration must be given at night and a third stored for the next morning.

3.3. The digestion process

The feed taken by rabbits is first mashed up by the teeth and mixed with saliva, which contains enzymes to begin breaking down the food. When the food is swallowed it enters the stomach where it is mixed with stomach acid and digestive enzymes, which continue the digestion process (Tessmer and Smith, 1998). The following description of the digestion process is given by Lebas *et al.* (1997):

"Feed eaten by the rabbit quickly reaches the stomach. There it finds an acid environment. It remains in the stomach for three to six hours, undergoing little chemical change. The contents of the stomach are gradually injected into the small intestine in short bursts, by strong stomach contractions. As the contents enter the small intestine they are diluted by the flow of bile, the first intestinal secretions and finally the pancreatic juice.

After enzymatic action from these last two secretions the elements that can easily be broken down are freed and pass through the intestinal wall to be carried by the blood to the cells. The particles that are not broken down after a total stay of about one and a half hours in the small intestine enter the caecum. There they have to stay for a certain time, from two to 12 hours, while they are attacked by bacterial enzymes. Elements which can be broken down by this new attack (to produce mainly volatile fatty acids) are freed and in turn pass through the wall of the digestive tract and into the bloodstream.

The contents of the caecum are then evacuated into the colon. Approximately half consists of both large and small feed particles not already broken down, while the other half consists of bacteria that have developed in the caecum, fed on matter from the small intestine.

So far, the functioning of the rabbit's digestive tract is virtually the same as that of other monogastric animals. Its uniqueness lies in the dual function of the proximal colon. If the caecum contents enter the colon in the early part of the morning they undergo few biochemical changes. The colon wall secretes mucus which gradually envelops the pellets formed by the wall contractions. These pellets gather in elongated clusters and are called soft or night pellets. If the caecal contents enter the colon at another time of day the reaction of the proximal colon is entirely different.

Successive waves of contractions in alternating directions begin to act; the first to evacuate the contents normally and the second to push them back into the caecum. Under the varying pressure and rhythm of these contractions the contents are squeezed like a sponge. Most of the liquid part, containing soluble products and small particles of less than 0.1 mm, is forced back into the caecum. The solid part, containing mainly large particles over 0.3 mm long, forms hard pellets which are then expelled. In fact, as a result of this dual action, the colon produces two types of excrement: hard and soft. The hard pellets are expelled, but the soft pellets are recovered by the rabbit directly upon being expelled from the anus. To do this the rabbit twists itself round, sucks in the soft faeces as they emerge from the anus, then swallows without chewing them. The rabbit can retrieve the soft pellets easily, even from a mesh floor. By the end of the morning there are large numbers of these pellets inside the stomach, where they may comprise three quarters of the total contents.

From then on the soft pellets follow the same digestive process as normal feed. Considering the fact that some parts of the intake may be recycled once, twice and even three or four times, and depending on the type of feed, the rabbit's digestive process lasts from 18 to 30 hours in all, averaging 20 hours.

The soft pellets consist half of imperfectly broken down food residues and what is left of the gastric secretions and half of bacteria. The latter contain an appreciable amount of high-value proteins and water-soluble vitamins. The practice of coprophagy therefore has a certain nutritional value.

The composition of the soft pellets and the quantity expelled daily are relatively independent of the type of feed ingested, since the bacteria remain constant. In particular, the amount of dry matter recycled daily through coprophagy is independent of the fiber content of the feed. The higher the crude fiber contents of the feed and/or the coarser the particles, the sooner it passes through the digestive tract.

On the other hand, this particular function requires roughage. If the feed contains few large particles and/or it is highly digestible, most of the caecal contents are pushed back to the caecum and lose elements which nourish the normal bacteria living in the caecum. This would appear to increase the risk of undesirable bacteria developing in this impoverished environment, some of which might be harmful.

It is thus advisable to include a minimum of roughage in the feed, enabling the rabbit's digestive process to be completed fairly rapidly. In theory, roughage is provided by the crude-fiber content of the feed, as this is normally rather hard to digest. However, certain fiber sources (beetroot pulp, fruit pulp in general) are highly digestible (digestibility of crude fiber varies from 60 to 80 percent)".

3.4. Utilization of fiber

In general, the fiber fraction of feeds is poorly utilized by rabbits (Table 2). If the rabbits digest fiber so poorly, how do they make efficient use of fibrous feeds? This apparent contradiction can be explained by recognizing that fiber makes up only 20 to 25% of forages. Thus, a foliage like alfalfa meal is 75 to 80% of non-fiber. The rabbit efficiently digest the non-fiber fraction, such as the protein and soluble carbohydrates, and excretes the fiber fraction (McNitt *et al.*, 1996). Despite the favorable digestibility of the crude protein of Leucaena leaf meal for rabbits (Raharjo *et al.*, 1986), graded additions of this legume to a control diet precipitated progressive depressions in growth such that, at the 400g/kg inclusion, weight gain was less than 40% of control values (Tangendjaja *et al.*, 1990).

Table 2. Digestibility of the fiber of alfalfa hay by various animals (McNitt *et al.*, 1996).

Animals	Fiber digestibility, %
Cattle	44
Sheep	45
Goats	41
Horses	41
Pigs	22
Rabbits	14

According to Lebas *et al.* (1997), the poor digestibility of the fibrous parts of raw materials such as alfalfa and straw makes them secondary to starch in covering energy needs. However, the fibrous components from tender, usually young plants are much more digestible. They can then provide 10 to 30 percent of energy requirements in favourable conditions. The fibrous parts have another function as providing bulk, which is generally evaluated on the basis of crude fiber content. In term of receiving enough bulk for growing rabbits, 13 to 14 percent crude fiber content seems to be satisfactory. The more digestible the fibrous parts the higher the total input needed to supply at least 10 percent indigestible crude fiber. Feeds with too low fiber content may cause diarrhea.

3.5. Utilization of coprophagy by rabbits and its chemical composition

The principle nutritional consequence of coprophagy in the rabbits is that this is a means to provide the requirements for B vitamins. All the members of the B complex group are synthesized by bacteria in the rabbit hindgut and made available to the rabbits after they consume the soft faeces. As a result, rabbits do not require B vitamins in their diets. Another consequence of coprophagy is that it provides a small amount of bacterial protein. Rabbits excrete two types of faeces. The hard faeces, which are produced in the large intestine, are the faecal pellets commonly seen. The faeces that are consumed via coprophagy are the soft faeces, produced in the caecum (McNitt *et al.*, 1996). Lukefahr (1992) reported that the consumption of soft faeces of rabbits was a means of providing nutrients that could be recycled for digestion and absorption purposes. As a result, vitamin K and B vitamins are not required in the diets, since they are synthesized through coprophagy and fermentation in the caecum and hindgut.

Proto (1980) offered rabbits with ten different feed sources, which were either balanced concentrate feeds, or green and dry forages, and measured the nutrients in the hard and soft faeces (Table 3). The major difference in composition was in the DM content (lower in soft faeces) and crude protein (much higher in the soft faeces).

Table 3. Composition of hard and soft faeces from ten different feed sources, % in dry matter basis except for DM which is in fresh basis (Proto, 1980).

Components	Hard faeces	Soft faeces
Dry matter, %	48-66	18-37
As % in DM		
Crude protein	9-25	21-37
Crude fiber	22-54	14-33
Ether extract	1.3-5.3	1.0-4.6
Minerals	3.1-14.4	6.4-10.8
Nitrogen-free extract	28-49	29-43

3.6. Protein and amino acid requirements for rabbits

Rabbits digest the protein in the forages efficiently compared with other monogastric animals. Due to the coprophagy, the rabbits have the ability to digest protein more than swine, for example: pigs fed alfalfa will digest less than 50% while 75 to 80% is digested by rabbits, in spite of the fact that they do not digest the fiber fraction more efficiently than swine do (McNitt *et al.*, 1996).

Many researchers have studied the effect of crude protein levels in the diets on the performance traits of growing rabbits. The general conclusion was that low dietary crude protein levels reduced production performance and high dietary crude protein increased economic profit, weight gain, slaughter performance and nutrient digestibility (Lei *et al.*, 2004). Lei *et al.* (2004) also reported that daily weight gain increased as crude protein level was raised from 14% to 20%, then decreased at the 22% crude protein level, with a similar trend for feed conversion. Daily weight gain and feed conversion were 19.4 g/day and 3.8 when crude protein in the diet was 19.5%, which were better than was achieved with 16.7% or 12% crude protein in the diet (Tang, 1987).

Wang (1999) showed that the daily weight gain was 29 g/day when the dietary crude protein was 16.5%, which was higher than for the 13.5%, 15%, 18%, 19.5% and 21% crude protein groups. Feed conversion was 3.5 when the dietary crude protein was 18%, which was better than in the 13.5%, 15%, 16.5%, 19.5%and 21% crude protein groups.

The recommended amounts of the essential amino acids in the diet of young and fattening rabbits are shown in Table 4. These recommended amounts have been estimated simply on the basis of the composition of regular satisfactory diets. When these essential amino acids are supplied by a well balanced protein, then 15 to 16% crude protein in the diet DM should be enough for fattening rabbits. Rabbits will always eat more of a balanced feed containing essential amino acids than the same feed without amino acids. Amino acid balance can easily be achieved with plant protein alone as is the case in almost all balanced feeds used in Europe. Proteins of animal origin can be used by rabbits but are absolutely unnecessary: all that counts is the amino acid intake, not the origin.

Table 4. Recommended chemical composition (%) of feeds (usually pelleted feeds containing cereal grain and alfalfa) for intensively reared rabbits of different categories (Lebas, 1989).

Components	Young rabbits	Mixed

	(4-12 weeks)	(maturity+fattening)
Crude protein	16	17
Digestible protein	11.5	12.4
Amino acids		
Methionine + cystine	0.60	0.60
Lysine	0.70	0.70
Arginine	0.90	0.90
Threonine	0.55	0.60
Tryptophane	0.13	0.13
Histidine	0.35	0.40
Isoleucine	0.60	0.65
Phenylalanine + tyrosine	1.20	1.25
Valine	0.70	0.80
Leucine	1.05	1.20

3.7. Water spinach foliage as a feed source for rabbits

3.7.1. The role of water spinach in integrated farming system

Two common types of water spinach are normally cultivated in Cambodia, for growing either on the soil or in the water. Water spinach grown on the soil has long, narrow leaves with pointed ends. The succulent foliage and stem tips are light green in colour. In order to obtain seeds, water spinach is allowed to develop the mature flowers, from which seed bearing pods are formed. Two main cultivar groups can be distinguished: var. *aquatica* and var. *replans*. The first is an aquatic plant or paddy vegetable in Southern part of India and Southeast Asia, propagated by cuttings and growing in the wild or cultivated in the fish ponds and water courses. The second is an upland vegetable, cultivated on dry or marshy land and propagated by seeds or cuttings (Palada and Crossman, 1999).

Water spinach grows well at high ambient temperatures and is commonly cultivated in Southeast Asia for humans and animals. It is an important feed source for pigs in Cambodia as well as in Vietnam, because it is easy to grow and is readily available. In Malaysia and Fiji, it was reported that water spinach is used to feed dairy cattle in combination with elephant grass (*Pennicetum purpureum*) (Göhl, 1981).

Among aquatic weeds, water spinach has great potential for use as feed foliage and is effective in waste water treatment systems. Average annual fresh weight production of 90, 70 and 100 tonnes/ha have been reported in Hong Kong, Fiji and the Netherlands, respectively, and the dry weight production during an eight months period exceeded 20 tonnes/ha when grown in a culture solution (Jain *et al.*, 1987). Kean Sophea and Preston (2001) reported high yields of water spinach of over 20 tonnes/ha in a 28 day period; the equivalent of 90 to 120 tonnes/ha/year was recorded by Sath Sonetra (2002). Biomass yield of water spinach after 28 days of cultivation was higher (2.85 tonnes DM/ha) when fertilized with worm casts than with urea (2.49 tonnes DM/ha), each applied at up to 60 kg N/ha (Tran Hoang Chat *et al.*, 2005).

3.7.2. Chemical composition of water spinach

Water spinach may be regarded as a potential source of feed protein concentrate. The edible portion can contain up to 29% crude protein on a DM basis, and may be as suitable a source of feed protein as alfalfa leaves (22% crude protein) (Thacker, 1990). Moreover, water spinach has a lower fiber content than alfalfa leaves (Bruemmer and Roe, 1979). Tran Hoang Chat *et al.* (2005) reported that water spinach foliage had a high potential as a supplement to concentrates for rabbits and supported higher live weight gain, milk yield and lower feed cost, compared with guinea grass.

According to Oomen and Grubben (1978) and Naren Tung *et al.* (1994), water spinach is also rich sources of minerals and vitamins, being especially rich in vitamins A (carotene), B1, B2 and C and in iron. The trace minerals content of fresh water spinach (mg/kg) were: Zn 5.03, Mn 22.2, Cu 1.37 and Fe 75.3 (NIAH, 1995). The chemical composition of fresh whole plant water spinach is shown in Table 5.

Table 5. Chemical composition of fresh water spinach foliage (NIAH, 1979 quoted by Naren Tung *et al.*, 1994).

Components	Water spinach
Water, %	91.6
Crude protein, %	1.90
Lipid, %	0.80
Cellulose, %	1.40
Non-protein N, %	3.20
Minerals, %	1.10
ME, MJ/kg	9.70
Amino acids, %	
Lysine	0.14
Methionine	0.07
Tryptophan	0.04
Threonine	0.14

According to Naren Toung *et al.* (1994), a vitamin/mineral premix did not need to be included in diets containing water spinach as no deficiency symptoms of ducks were observed on this diet. The ability of water spinach to supply minerals and vitamins is an important advantage in the rural areas where premixes are not usually available or are expensive. Based on the previous observation (Miech Phalla, personal communication), water was not provided as the fresh water spinach plant contained almost 90% moisture so that the rabbits were able to satisfy their needs from the feed source (386 g/head/day of water for growing rabbits with air temperature 30^{o} C) (Eberhart, 1980). The important characteristics of water spinach foliage are shown in Table 6.

Table 6. Characteristics of fresh water spinach foliage, % in DM except for dry matter which is on fresh basis.

	Proportions	DM[1]	CP[2]	CF[3]	References
Water spinach grown in water					
Leaves	-	12.9	31.9	-	Honthong Phimmasan *et al.* (2004)
Stems	-	8.43	18.2	-	
Leaves	46.1	11.6	35.1	8.58	Paper I
Stems	53.9	6.87	20.5	17.2	
Water spinach foliage		9.07	27.6	17.1	Prak Kea *et al.* (2003)
Water spinach grown on soil					

Leaves	28.3	11.6	27.8	7.30	Paper III
Stems	71.7	7.34	11.4	19.1	

[1]*DM: Dry matter;* [2]*CP: Crude protein;* [3]*CF: Crude fiber.*

3. 7. 3. Water spinach as a sole feed for rabbits

In Paper I and figure 1 it was shown that the digestibility of water spinach by rabbits was very high (80.5, 80.1, and 80.8% for DM, crude protein, and organic matter, respectively). Similar findings were reported by Honthong Phimmasan *et al.*, (2004). The digestibility coefficients in this experiment were higher than reported by Lei *et al.* (2004) for the dietary crude protein in the level of 18% (60.8%, 72.1% and 66.8% for DM, crude protein and organic matter); for a commercial pelleted feed Ramchurn *et al.* (2000a) reported 69.2% for DM and 74.0% for crude protein. Using a combination of Star grass with mash, the values were 68.8% for DM and 81.3% for crude protein (Ramchun *et al.* (2000b). Bamikole and Ezenwa (1999) fed Verano stylo and reported values of 50.2% for DM and 61.4% for crude protein; Cunha *et al.* (2004) offered alfalfa as source of fiber with digestibility coefficients of 61.4% for DM and 73.2% for crude protein, respectively.

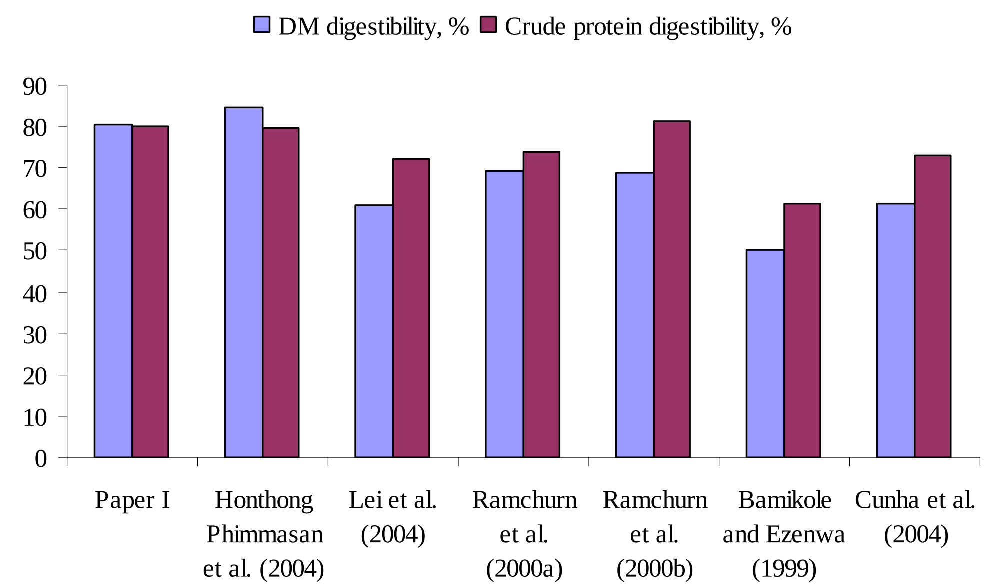

Figure 1. Digestibility coefficients for rabbits in a range of reports from the literature compared with the present study (Paper I).

The decrease in fiber digestibility, as the proportion of DM consumed as leaves increased (Paper III), indicates that the crude fiber in the leaves is less digestible than the crude fiber in the stems. This is the opposite of what occurs with most plant species where the cell wall component is less digestible in stems than in leaves (Van Soest, 1994). The reason for this difference could lie in the architecture of the water spinach plant. The stems (or stolons) of the water spinach rest on the soil (or in the water) and thus do not have to support the leaves. In contrast, in most plants the stems are upright and physically support the leaves (Rangnekar, 1991).

Fiber plays a vital role in the nutrition of the rabbit. According to Lebas *et al.* (1997), there is a minimum requirement for roughage in order to optimise the digestive processes, and the more digestible the fiber the higher is the requirement in order to satisfy the need for 10% of indigestible fiber in the diet. However, the problem with water spinach would not appear to be one of too high digestibility of the fiber, but rather too low concentration of fiber in the total plant. This hypothesis is supported by recent findings from an experiment in which two other sources of high-fiber feeds (grass and rice straw) were offered to rabbits in addition to the water spinach (Pok Samkol, Unpublished data). DM intake was increased by 50% when the rabbits had access to all three feed sources as compared with water spinach as the sole diet.

Growth performance and feed conversion of rabbits fed only water spinach were in the range 14 to 20 g/day and 3.83 to 5.3, respectively (Paper II and III), which is superior to findings reported from several tropical countries for a range of other feed resources (Table 7 and figure 2). The high nutritional potential of water spinach for rabbits is confirmed by the very high growth rate (31.4 g/day) that was recorded when it was given ad libitum as a combination with concentrates (Tran Hoang Chat *et al.* 2005).

Table 7. Performance of rabbits fed a range of diets in tropical countries.

Diets	Live weight gain, g/day	DM feed conversion	Countries	Authors
Water spinach	14.0	5.3	Cambodia	Paper II
Water spinach	20	3.8	Cambodia	Paper III
Banana and sweet potato mash	10	7.0	Vietnam	Nguyen Quang Suc *et al.* (2000)
Concentrate+grass	17.5	-	Vietnam	Dinh V. Binh *et al.* (1991)
Green grass	2.7	35	India	Roy *et al.* (2002)
Whole cassava plant	11.2	6.0	Nigeria	Akinfala *et al.* (2003)
Pelleted commercial diet	14.8	7.8	Mauritius	Ramchurn *et al.* (2000a)
African star grass	7.7	10.9	Mauritius	Ramchurn *et al.* (2000b)
Cereal grain, CSM and SBM	10.9	4.5	Cameroon	Mbaya *et al.* (2005)
Concentrate (Maize+SBM)+ Sugar cane leaves	19.5	-	Haiti	Bien-aime and Denaud (1989)
Sorghum offal	13.0	3.7	Nigeria	Uko *et al.* (1999)
Concentrate + water spinach	31.4	3.87	Vietnam	Tran Hoang Chat *et al.* (2005)

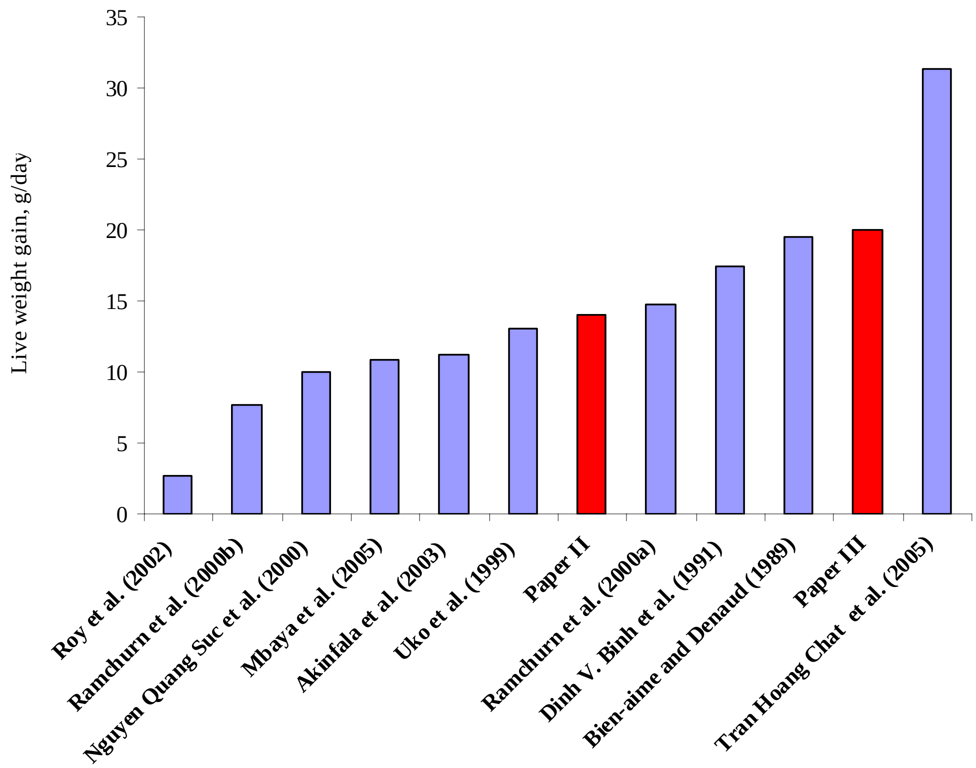

Figure 2. Growth rates of rabbits in a range of tropical countries fed local feeds compared with those in the present study (Papers II and III).

3.8. Broken rice as feed supplement for rabbits

According to Göhl (1975) broken rice is separated after the polishing stage. There is seldom any surplus of broken rice available for feeding to livestock as much as mixed back with the whole grain rice and sold as low grade rice. In some countries it is used for the production of arak or serves as the raw material for rice flour. The percentage of rice by-products is dependent on the milling rate, the type of rice, and the machine used for processing the grain. The whole rice contains 20% hulls, 10% bran, 3% polishing, 1-17% broken rice and 50-60% polished rice.

Broken rice is palatable and rich in energy. It has been used for all classes of live stock. But it is of special value in rations for growing chickens because of its high energy value and low fiber content (Göhl, 1975). However, it has limited availability for use as feedstuff for swine (Farrell and Hutton, no date).

The chemical composition of a good sample of broken rice is similar to that of polished rice but feed quality material may contain some contaminations. Chemical composition will vary with rice cultivar, growing conditions and season (Farrell and Hutton, no date) (Table 8).

Table 8. Chemical composition of broken rice, % in dry matter basis (except for DM which is on air-dry basis).

DM	Crude protein	Ash	Organic matter	Ether extract	References
87.6	7.10	0.50	99.5	0.90	Creswell (1987)
88.6	6.37	1.19	98.8	-	Paper I
89.5	6.88	1.20	98.8	-	Paper II

Broken rice has a high digestible energy (DE) content of 14.5 MJ/kg (Farrell and Warren, 1982) which compares with 15.5 MJ/kg DM for polished rice. Broken rice is relatively low in protein but the essential amino acid balance is good. The amino acid composition of broken rice from Malaysia and Thailand is shown in Table 9 (Creswell, 1988). These analyses suggest that broken rice is superior to maize.

Table 9. The amino acid composition of seven samples of broken rice from Malaysia and nine samples from Thailand, % as fed (Creswell, 1988).

Components	Malaysia	Thailand
Dry matter	87.2	87.5
Arginine	0.65	0.55
Histidine	0.19	0.16
Isoleucine	0.35	0.30
Leucine	0.66	0.57
Lysine	0.31	0.26
Methionine	0.23	0.18
Phenylalanine	0.44	0.38
Threonine	0.28	0.24
Tyrosine	0.32	0.25
Valine	0.74	0.40

Inclusion of broken rice in the diet based on water spinach of growing rabbits did not improve the growth rate or the feed conversion (Hongthong Phimmasan *et al.*, 2004; Paper II). The fact that the volatile fatty acid concentration in the faeces was increased when broken rice was fed suggests that it was not completely digested in the small intestine and the remainder was digested by fermentative activity in the caecum.

The lack of a growth response to supplementation with broken rice would appear to be the primary limiting factor is low fiber in water spinach. However it would also reduce protein supply particularly if it is mainly fermented in the caecum because the level of crude fiber in the water spinach was already borderline (or even too low), such that the addition of the low-fiber broken rice would thus reduce the crude fiber of the overall diet even more.

4. Conclusions

- Water spinach can be fed alone as the sole diet of rabbits as it appears to supply all the nutrient requirements including minerals, vitamins and water. In this case the feeding level should not be above 8% of the body weight (DM basis) to ensure that the rabbits consume the stems which have higher fiber content than the leaves. With this feeding system the growth rates ranged between 14 and 20 g/day with DM feed conversion of between 3.8 and 5.3.

- Fiber plays an important role in the nutrition of the rabbit. There is a minimum requirement of dietary fiber in term of optimising the digestive processes. Thus when the offer level was raised to 18% of body weight (DM basis) the rabbits preferentially selected the leaves and although digestibility and intake of crude protein were increased, the fiber intake was reduced and the live weight gain declined.
- There was no response to supplementation with broken rice apparently because this reduced the overall fiber content of the diet.
- Water spinach is easy to grow on soil or in water and is highly responsive in growth to fertilisers responds dramatically to fertilization with organic manure, especially the effluent from biodigesters. These advantages plus its high nutritive value for rabbits gives it a unique role in integrated farming systems for small-holder farmers.

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