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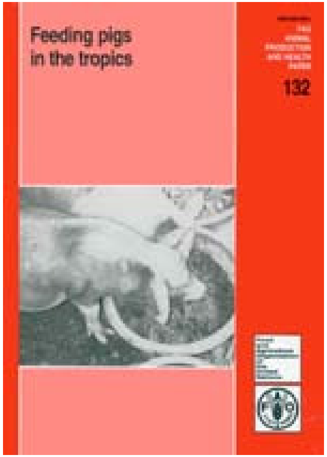

Feeding pigs in the tropics

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by
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Ministry of Sugar
Havana, Cuba

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Foreword

Pork is the largest source of meat at the world level, and considering that, due to religious beliefs, pork is not produced and consumed in many countries, its relative importance is even greater in the rest of the world.

The largest producer and consumer is the People's Republic of China, where the livestock sector, including swine, has been growing at an unprecedented rate during the last two decades. The preference for pork of the most populated country in the

world and the increasing demand resulting from its rapid economic growth, will require an enormous additional supply which would need huge amounts of grain and protein meals if the current feeding systems are maintained.

Monogastric production, both swine and poultry, has made a very important contribution to the production of animal protein in many countries around the world. The key of the success has been, so far, the importation of an almost complete package of technology, including parent and breeding stock, equipment, medicines and feed. Most of the diets are based on cereal grains and oil meals, which in principle compete directly or indirectly with human feeding, and utilize a large proportion of inputs derived from fossil fuels.

In order to assure the sustainability of swine production in many tropical countries, where the ingredients of the traditional diets can not be grown or destined to animal feeding due to the

priority of the large human population, alternative feeding systems need to be studied, developed and extended.

The extensive review of the research on non-traditional feedstuffs contained in this publication, will serve as the basis for the development of such appropriate feeding systems which reduce or eliminate the need for imported ingredients in the short, medium or long term.

Many efforts remain to be done in that direction, and we would like to encourage researchers and extensionists in tropical countries to work hard for the development of such feeding systems which do not compete with human requirements and are environmentally friendly.

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Director Animal Production and Health Division

Chapter 1 Principles of energy and protein nutrition

The potential of feed resources for pigs in the tropics is superior to that of the temperate zone. However, paradoxically, there has been much less effective research in the tropics on locally available, non-conventional feed resources and their nutritional value as animal feedstuffs (Ly, 1993). Undoubtedly, pig production has improved through a growing understanding of the mechanisms governing feed utilization and by the practical application of this new knowledge (Black *et al.*, 1986). Feed efficiency is now widely recognized as the principal factor in profitable animal production; thus, Phillips (1984) noted that the efficiency of utilization of ingested feed is affected by digestion, while Ball *et al.* (1986) called attention to the role of appetite on nutrient uptake, rate of digestion and rate of absorption. Often

valuable information resulting from studies in temperate countries requires proper interpretation before it can be applied in the tropics. And, although information concerning nutritional physiology has not always had a direct impact on animal performance, Rerat (1978) maintained that it was essential to any feeding strategy, while Braude (1979) pointed out that integrating information from studies of digestion and on-site feeding trials would result in improved performance and lowered costs.

Sugar cane is a good example of how the study of digestion in pigs has been used to develop strategies for tropical swine production. Sugar cane molasses (Figueroa and Ly, 1990), or sugar cane juice (Preston and Murgueitio, 1992), is now recommended as the sole source of energy for feeding pigs in tropical America. Trials have included the characterization of the digestive efficiency, as well as the metabolic aspects of these non-conventional alternative feedstuffs (Ly, 1990 c,d).

DIGESTIVE PHYSIOLOGY

The gastrointestinal tract of the pig is relatively simple (Ly, 1979a). It has three main compartments: the stomach, the small intestine and the large intestine (Figure 1.1). The stomach acts as a reservoir in which the mixed feed is subjected to the action of proteolytic enzymes in an acid medium, prior to being evacuated into the small intestine (Laplace, 1982). The first section of the small intestine, the duodenum, governs the gastric-emptying of digesta and serves to create an equilibrium between the rate of passage and the rate of nutrient absorption. Digestion, a complicated hydrolytic process, involves the movement of digesta along the small intestine. It must be sufficiently slow to allow for the action of the bile and the hydrolytic enzymes secreted by the pancreas, and for the absorption of the most important nutrients, such as amino acids, fatty acids and glucose (Cunningham *et al.*, 1963; Darcy, 1982).

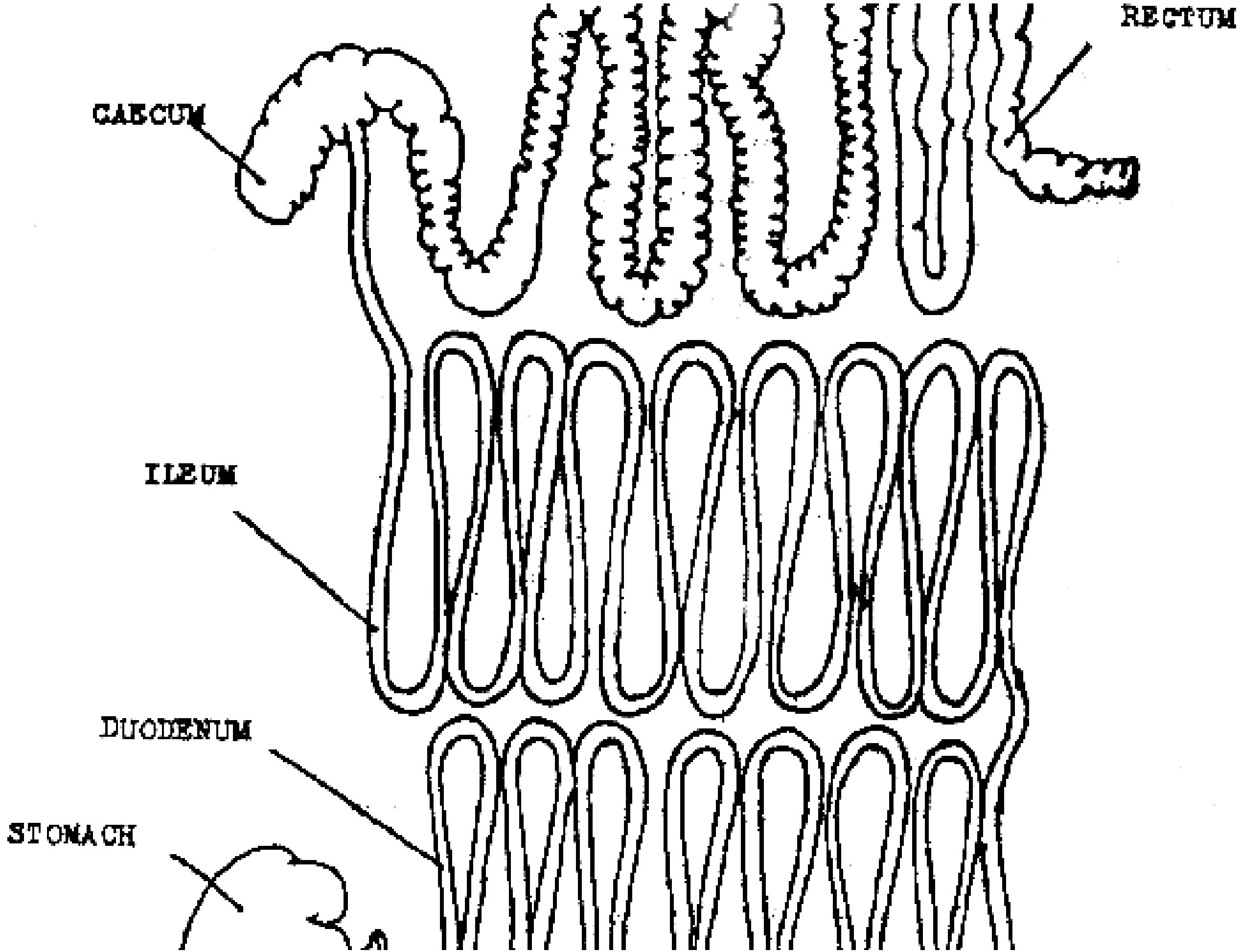
The small intestine of the adult pig is approximately 18 meters long. For this reason, the elapsed time between the ingestion of feed and nutrient absorption, approximately four hours, is relatively short compared to the time required for the passage of digesta along the entire gastrointestinal tract, some 24 hours (Ly, 1979b; Laplace, 1981). Digesta, as it leaves the small intestine, is a mixture of undigested feed residues, intestinal secretions and dequamated cellular particles that arise from the mucosa of the small intestine which is in a constant state of renewal. This material (digesta) enters into the relatively complex large intestine through the ileocaecal valve.

In the large intestine, the digesta is modified by flora indigenous to the gastrointestinal tract. This fermentative process "digests" 10 to 20% of the feed from mouth to rectum (Rerat, 1978; Kesting, 1985) and determines the entire transit time of the digesta through the gastrointestinal tract (Laplace, 1981; Kesting, 1985). In the caecum and in the proximal colon, the

digesta is still liquid. As it advances to the anus to be voided as faeces, it loses water and acquires a sticky, solid consistency (Hecker and Grovum, 1975).

The digestive capacity of the pig increases with age. Neonates and lactating piglets depend on a well-developed gastric ability to effectively clot milk (Moughan *et al.*, 1992). During the first few weeks of life, both the small intestine and the exocrine pancreas grow and develop. This prepares the piglet for weaning. The large intestine matures slower; this explains why the pig tends to digest fibrous feeds better in direct relation to its age (Mason, 1979; Laplace, 1981; Kesting, 1985).

Figure 1.1. Gastrointestinal tract of the pig.


RECTUM
CAECUM
ILEUM
DUODENUM
STOMACH

Each section of the gastrointestinal tract harbours a mixed microbial population that lives in equilibrium with the host animal (Cranwell, 1968; Rerat, 1978; Ratcliffe, 1985). Whenever this equilibrium is disrupted, a digestive upset can occur. Fermentation of undigested feed residue by gut microflora is a normal process and can partially determine the utilization of energy contained in the fibrous fractions of the diet. Pond (1989) observed that pigs fed a high fibre diet have heavier large intestines than those fed low fibre diets. In fact, in a review of this subject, it was pointed out that up to 30% of the energy requirements of growing/finishing pigs might be provided by short-chain, fatty acids arising from the degradation of fibre by microbes (Varel, 1987, cited by Pond, 1989).

The apparent digestibility of nutrients in a diet measures overall gastrointestinal function. As with other animals, in the pig this is influenced by factors such as age or body weight (Oude *et al.*, 1986). Since digestibility is closely correlated with performance, the concepts of digestible energy and digestible protein are commonly used to describe the nutritional value of feeds for swine (Dicrick, 1991).

Digestive and metabolic efficiency of sugar cane

The soluble fraction of sugar cane can provide different energy sources for pigs: juice, molasses or raw and refined sugar (see Chapter 3). However in all cases, the carbohydrate is sucrose and the products of its hydrolysis: glucose and fructose. Sugar cane molasses, in addition to sucrose, and depending on its type, contains different amounts of important minerals and non-identified organic matter (NIOM).

There are a number of constraints to using sugar cane products for pigs; one is that they have lower gross energy compared to cereals (Christon and Le Dividich, 1978). The data in Table 1.1 suggest that the gross energy in sugar cane products is about 80% that of maize. The digestibility of sugar cane molasses appears to be directly proportional, either to its sucrose content, or to the ratio of carbohydrates to NIOM (Ly 1990c). When starch is substituted by sucrose in the diet, the metabolizable energy/digestible energy (ME/DE) ratio is lowered by about four per cent (Ly, 1987b; Cuarón, 1992). Other constraints to the use of sugar cane products are a reduction in the digestion of energy due to the presence of NIOM and its influence at the intermediary level of metabolism. These ideas will be fully developed in the following sections.

Table 1.1. Caloric value of sources of energy: sugar cane derivatives vs. maize.

Source of		

energy	Gross energy, ki/g DM	Source
Syrup-off	15.9	Swine Research Institute, Minag, Cuba (1989)*
High-test molasses	15.0	
A molasses	14.9	
B molasses	14.7	
C molasses	13.5	
Refined sugar	16.4	Ly *et al.* (1984)*
Maize	18.4	NRC (1988)

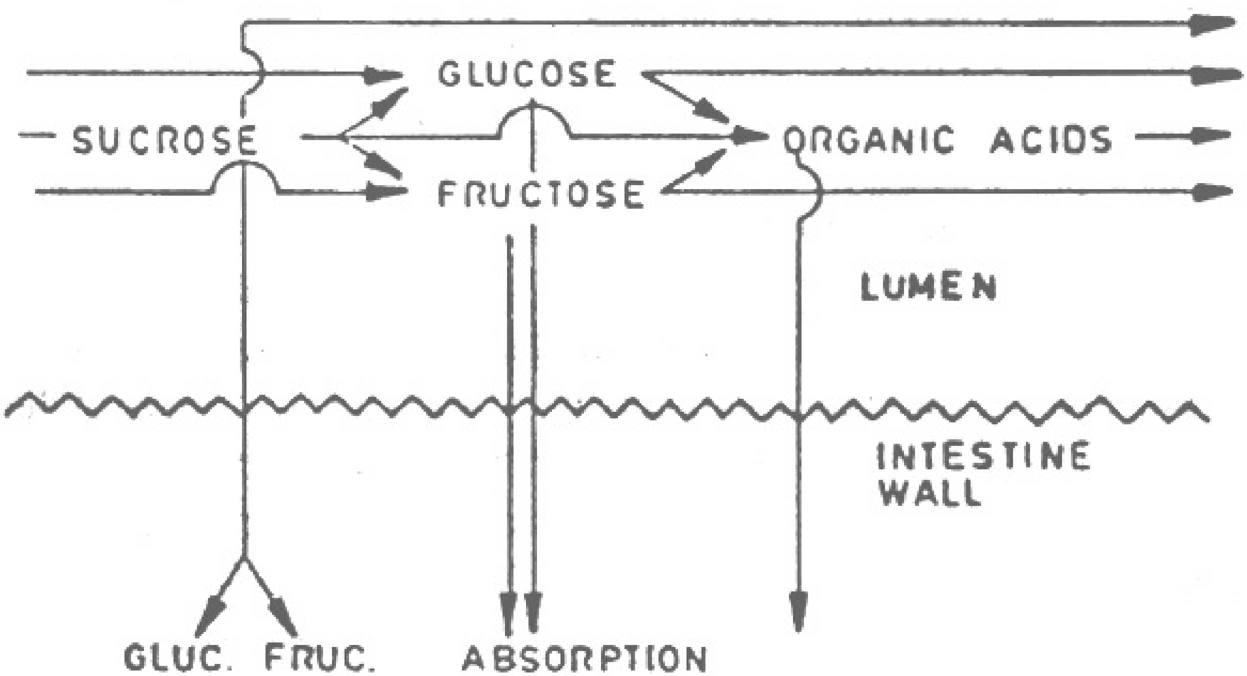
*** Unpublished data**

The energy efficiency of sugar cane-based feeds

Only one enzyme, sucrase, is needed to hydrolyze sucrose to

glucose and fructose, which in turn are absorbed through the wall of the small intestine (Figure 1.2). This suggests that the digestion of carbohydrate in sugar cane-derived feeds is simple, compared to that of starch in cereals or roots.

Figure 1.2. Digestion of sugars in the small intestine of pig.



The amount of energy produced from digestion in the small intestine of sucrose, or fructose and glucose, is the same, 15.66 kilojoules per gram (Ly, 1990c, d). Digestion is essentially a

hydrolytic process and, since the heat of combustion from the final stage of digestion of starch and sucrose is identical (Table 1.2), it would appear that neither has an advantage over the other. However, the digestion of certain organic compounds which accompany sucrose in some sugar cane derived feeds, such as molasses. merits a more detailed inspection.

Table 1.2 . Energy efficiency of the intestinal digestion of different sources of sucrose* compared to starch from cereals or roots.**

Dietary source of sucrose	Initial stage		Final stage	
	Substrates	Heat of combustion (kj/g DM)	Products	Heat of combustion (kj/g DM)
Raw cane sugar, sugar	sucrose	16.58	glucose	15.66

cane juice, C molasses			fructose	15.66
High-test molasses	glucose	15.66	glucose	15.66
	fructose	15.66	fructose	15.66
	fructose	15.66		
Fructose syrup	fructose	15.66	fructose	15.66
Cereals and roots	amylose	17.42	glucose	15.66
	amylopectin			

Source:*Ly (1990c); **Ly (1990d)

Digestion and adsorption of fructose from sugar cane

Feeds obtained from the soluble part of sugar cane contain varying amounts of fructose, either linked to glucose to form the

sucrose molecule, or in a free state. This free fructose is not completely absorbed when it is ingested (Ly, 1992). Small amounts can escape from the small intestine and are presumably fermented in the caecum and colon. However, when the sucrose molecule is split in the small intestine into glucose and fructose, both monosaccharides are completely absorbed. It is for this reason that it is better to feed pigs sucrose-containing feeds and not sucrose hydrolysis products.

A certain quantity of fructose is not metabolized and escapes in the urine (Ly and Macias, 1979; Ly *et al.*, 1985, 1989). Following the ingestion of fructose-containing feeds, an atypical urinary excretion of lactic acid occurs and the pH of the urine decreases, dramatically. The ensuing metabolic acidosis may depress feed intake and interfere with bone metabolism. It has been suggested (Ly, 1990a, b) that perhaps this could be avoided through the manipulation of the acid-base balance of the diet.

The nutritional influence of NIOM in cane molasses

The notion of the possible influence of NIOM on the performance of pigs was first discussed by researchers in Cuba. Velázquez and Preston (1970) suggested that "impurities" present in integral molasses might have caused the excessive water content of the faeces, 78% compared to only 59% in pigs fed high-test molasses. Later, Ly *et al.* (1985) reported that this NIOM fraction, if absorbed, was excreted in the urine (Table 1.3). This fraction accounts for the low ME/DE ratio usually found when sugar cane molasses is fed to pigs as the only source of energy (Pérez *et al.*, 1988).

Table 1.3. Urinary energy losses in pigs fed cane A molasses or cassava starch.

	A molasses plus:			Cassava starch
		torula	soya bean	plus torula

	alone	yeast	meal	yeast
(ME/DE) ×100	92.3	94.8	93.9	97.0
Urinary energy partition, %:				
N compounds	14.6	52.8	52.3	67.3
Fructose	19.9	10.8	7.5	0.0
Non-identified compounds	65.5	36.4	40.2	32.7
Non-metabolizable energy, % DE:				
N compounds	0.8	2.8	3.1	2.0
Fructose	1.2	0.6	0.4	0.0
Non-identified compounds	3.7	1.8	2.6	1.0
Total	5.7	5.2	6.1	3.0

Ly *et al.* (1985)

Figueroa and Macias (1988) isolated a fraction from different types of Cuban molasses based on a method developed for C molasses (McLaren, 1950). They fed rats up to 20% of this non-sugar fraction (NIOM) and found a marked decrease in fecal dry matter. Several additional studies in pigs have shown that either total or ileal digestibility of NIOM from different types of molasses is relatively low (Table 1.4).

Table 1.4. Ileal and total digestibility of the non-identified organic matter of sugar cane molasses in the pig (%).

Carbohydrates:	Ileal	Total	Source
Sucrose	98.3	-	Maclas *et al.* (1981)
Fructose	90.5	-	
Glucose	98.2	-	
Cassava starch	98.0	-	Figueroa *et al.* (1986)
A molasses	96.0	-	
High-test molasses	95.0	-	Figueroa *et al.* (1988)

C molasses	83.0	-	Diaz *et al.* (1990)
Non-identified organic matter:			
A molasses	14.0	79.0	Ly *et al*. (1987a)
High-test molasses	13.6	80.0	
Final molasses	51	70.0	

ENERGY AND PROTEIN IMBALANCE

There is a direct relationship between energy and protein in the diet of pigs. Protein imbalance is related to the amino acid composition of the ration, particulary the limiting amino acids.

Protein imbalance

Perhaps one of the more interesting experiments demonstrating the questionable effects of a high level of dietary protein on the performance of growing/finishing pigs is that of Sugahara *et al.*

(1970). These authors demonstrated that increasing the level of protein in a maize/soya bean meal diet from 16 to 32% crude protein, compared to feeding only soya bean meal of 48% protein, resulted in decreased appetite and a lowered daily weight gain but had no effect on feed conversion (Table 1.5). In addition, there was an increase in the percentage of lean cuts which was in direct relation to the amount of soya bean meal in the diet. Perhaps, the most important conclusion is that pig performance does not necessarily improve by increasing protein in the diet.

Table 1.5. The effect of high levels of protein in the diet on the performance of growing pigs.

	Protein in the diet, %		
	16* – 12	32	48
AD feed intake, kg/d	2.41	2.22	1.92
ADG, g	700	640	550

AD feed conversion	3.45	3.48	3.50

Source: Sugahara *et al.* (1970); *16% during first stage

Many studies have examined protein imbalance on low protein feeds to identify the minimum amount of essential amino acids. Low protein diets pose a greater risk of amino acid imbalance and incorrect amino acid supplementation produces poor pig performance (Table 1.6). Russell *et al.* (1986) demonstrated that the addition of methionine to a tryptophane deficient diet depressed feed intake and growth rates. Henry (1988), pointed out that the imbalance between the first and the second limiting amino acid is very common on low protein diets incorrectly supplemented with synthetic amino acids.

Table 1.6. The effect of low levels of protein in a diet supplemented with amino acids on the performance of growing pigs.

	Feed intake (kg/day)	ADG (g)	Feed conversion (kg/kg gain)
Protein, 12% (negative control)	1.56	557	2.78
Protein, 12% + threonine 0.10 + tryptophan 0.04	1.54	626	2.44
Protein, 12% + methionine 0.10 + tryptophan 0.10	1.46	560	2.56
Protein, 12% + threonine 0.10 + tryptophan 0.04 + methionine 0.10	1.60	659	2.38
Protein, 16% (positive control)	1.58	654	2.38

Source: Russell *et al.* (1986)

Amino acid imbalance

The amount of amino acids consumed by the pig is determined

by feed intake and the digestible energy in the diet. These factors, in turn, directly influence voluntary intake in growing pigs fed *ad libitum* (Chiba *et al.* 1991a,b). Therefore, the level of amino acids should be related to the digestible energy in the diet. Energy and amino acid imbalance results in improper growth, poorer feed efficiency and in an inadequate rate and efficiency of protein and fat deposition.

The concept of the "ideal" protein for pigs is relatively new (Cole, 1978); it should supply the exact proportion of required essential amino acids. The biological value of an ideal protein should be 1.0; this can be achieved if young animals are fed that protein together with an appropriate amount of non-protein energy, minerals and vitamins (Fuller and Chamberlain, 1983). The data in Table 1.7 illustrate how the crude protein content of the diet may be reduced from 17.6 to 14.5% by adding synthetic lysine, thus improving the balance of essential amino acids, in their order of importance.

Table 1.7. The reduction of dietary crude protein through the addition of synthetic lysine.

	Balance in the ideal protein (Cole, 1978, 1990)	Balance in the crude protein (Taylor *et al.*, (1979)	
		17.6%	14.5% plus lysine
Lysine	100	100	100
Methionine plus cystine	50	66	56
Threonine	60	78	63
Tryptophan	18	21	18
Isoleucine	50	75	59
Leucine	100	144	118
Histidine	33	43	35
Phenylalanine plus tyrosine	100	158	134

Valine	70	95	79

An "ideal" protein for pigs means that the proportion of essential amino acids should remain constant but the amount may vary depending on factors such as weight, sex and breed. There is reason to believe that climate should be included among these factors, as feed intake tends to be lower in tropical environments (Le Dividich and Rinaldo, 1988). Further studies about ideal proteins suggest slight changes in connection with threonine, methionine and tryptophan (Table 1.8).

Table 1.8. The proportion of essential amino acids in the ideal protein for the growing pig.

	Cole (1978)	**Fuller *et al.* (1979)**	**Yen *et al.* (1986a)**	**Wang and Fuller (1989)**
Lysine	100	100	100	100
Methionine plus				

cystine	50	53	50	63
Threonine	60	56	57	72
Tryptophan	18	12	20	19
Isoleucine	50	44	55	60
Leucine	100	84	100	110
Phenylalanine plus tyrosine	100	96	100	120
Histidine	40	32	35	-
Valine	70	63	70	75

Another approach to "ideal" protein is related to the availability of amino acids. ARC (1981) defined available amino acids as the proportions of dietary amino acids which are digested, absorbed and utilized to sustain life and/or the growth of new tissue. Amino acid availability increases the accuracy of the proportions of

essential amino acids in the ideal protein. Lysine was used by Batterham (1979) as the reference amino acid to establish an order of merit for eight protein sources (Table 1.9).

Table 1.9. Availability of lysine in eight protein sources according to growth or carcass evaluation trials in pigs (%).

	Growth assay with pigs	**Carpenter available lysine**
Blood meal	102	97
Fish meal	89	90
Skim milk powder	85	79
Soya bean meal	84	77
Rapeseed meal	68	71
Meat and bone meal	49	71
Cottonseed meal	43	65

Sunflower meal	40	88

Source: Batterham (1992)

It should be emphasized that amino acid availability and ileal digestibility are not the same. Batterham (1992) demonstrated that not all the lysine absorbed up to the distal ilcum is completely utilized, probably due to some structural change in the absorbed amino acid molecule. Presently, ileal digestibility, otherwise known as absorbability of amino acids, has been generally accepted to define or to categorize an ideal protein level for growth. An example is given in Table 1.10.

Table 1.10 The proportion of absorbable essential amino acids in the ideal protein for the growing/finishing pig

	Growing (25–55 kg)			Finishing (50–90 kg)		
	Boars	Gilts	Castrated males	Boars	Gilts	Castrated males

Lysine	100	100	100	100	100	100
Methionine	36	37	37	38	39	40
Methionine + cystine	51	52	52	55	58	60
Threonine	63	64	64	69	67	69
Tryptophan	18	19	19	20	21	22
Isoleucine	71	73	73	74	76	78
Leucine	128	130	130	136	140	145
Phenylalanine	83	86	86	91	95	99
Histidine	42	43	43	45	46	48
Valine	89	90	90	94	97	100

Source: Yen *et al.* (1986a,b)

Amino acid/energy ratio

Since the amino acid and energy ratio must be held constant, the

supply of amino acids should be adjusted to the amount of energy supplied in the diet (Henry, 1988). Given this notion, it becomes necessary to clarify aspects of pig nutrition in the tropics, such as including locally available fibrous feeds which often contain appreciable amounts of protein, as well as the interaction between the amino acid/energy ratio and the climate.

It appears that fibre depresses overall, but not ileal, amino acid digestibility; therefore, the fibrous plant cell wall apparently does not influence the availability of dietary amino acids (Sauer *et al.*, 1991). Although it has been claimed that the ratio of available lysine/MJ of digestible energy is not linear during the entire life cycle (Carr *et al.*, 1977; Whittemore and Fawcett, 1976), more recent studies have suggested, that for growing pigs up to 50 kg, the interdependence between energy intake and the rate of protein deposition is linear (Chiba *et al.*,1991a,b).

A more detailed prediction of the essential amino acid to

digestible energy ratio for the male pig can be seen in Table 1.11.

The studies carried out by Stahly and Cromwell (1987) and Le Dividich and Rinaldo (1988) have shown that if the protein: energy ratio is increased, similar performance traits might be obtained in a warm or temperate climate. This is attributable to the low energy requirement for pigs in warm climates compared to higher needs in temperate climates and the need to maintain a proper ratio of protein and essential amino acids.

Table 1.11. Available (predicted) essential amino acids to energy ratio (g/MJ DE) in a non-castrated, fast-growing genotype male pig.

		Liveweight (kg)	
	20	**50**	**90**
Phenylalanine plus tyrosine	0.67	0.54	0.45
Phenylalanine	0.36	0.29	0.24

Methionine plus cystine	0.24	0.28	0.23
Methionine	0.23	0.19	0.16
Valine	0.48	0.39	0.32
Isoleucine	0.44	0.36	0.30
Leucine	0.69	0.56	0.47
Threonine	0.39	0.32	0.27
Histidine	0.21	0.17	0.14
Lysine	0.77	0.62	0.52
Tryptophane	0.12	0.09	0.08

Source: Black *et al.* (1986)

ADJUSTED NUTRITIONAL REQUIREMENTS

Nutritional requirements for pigs reared in the tropics have yet to be adequately established. High energy diets are not necessary to maintain body temperatures and a depression in growth rate is

a well known consequence of a reduction in voluntary feed intake due to heat (Stahly *et al.*, 1979). These same authors have observed that, in heat-stressed pigs, these factors can be partially alleviated by altering the heat increment of the diet, i.e., by lowering the dietary protein level, thereby reducing the essential amino acids to the required minimum, as has been done with poultry (Waldroup *et al.*, 1976).

To sustain efficient pig feeding systems, some tropical countries have centred nutrient requirements on high energy, locally available crops. Research with genetically-improved pigs, fed non-conventional feeds such as sugar cane juice and raw oil or fibrous residues from the African oil palm, has shown that there are clear economic advantages when the protein supplement for growing/finishing pigs is lowered to 500 g/day to provide approximately 200 g of crude protein daily (see Table 3.5). At first, these results appear to contradict the current nutrient requirements for protein in pigs (NRC, 1988; ARC, 1981).

However, they are probably a consequence of the use of soya bean meal (see Chapter 2) as the major source of protein, or to the absence of poor amino acid-profile cereals such as maize (Speedy *et al.*, 1991).

In general, the basic non-conventional energy feeds like sugar cane juice, molasses, oil palm products, tubers and roots require supplementary vitamins and minerals. Perhaps one practical solution is to combine the macro elements with the restricted protein supplement (Ocampo *et al.*, 1990a,b; Ngoan, 1994; Ngoan and Sarria, 1994) which, if supplied as soya bean meal and fed at 500 g/day,would equal approximately 20% of total daily dry matter intake. The vitamin premix should not be included until feeding time due to the potential negative effect of extended storage in the tropics of concentrated amounts of vitamins and minerals together. Perhaps, this could be solved by more frequent preparation of the supplement.

A growing/finishing pig from 25 to 90 kg, fed according to a "tropical" as opposed to "temperature" (cereal) feeding system, requires 2.5 to 2.8 kg/day of dry matter which, in general, will consist of from 2 to 2.3 kg of an energy source plus 500 g of a protein supplement. Since the supplement is one-fifth of the total daily dry matter intake, the minerals and vitamins should be included in the supplement at five times the required concentration.

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Chapter 2 Protein sources from plants and microbes

The tropics are rich in plant and microbial protein resources which could be used for livestock production (Ly, 1993). Unfortunately, several of these resources contain compounds, known as anti-nutritional factors, that can depress animal performance. One such compound, a trypsin inhibitor, interferes with the proteolytic activity of the digestive enzyme, trypsin;

other inhibitors, such as, hemagglutinins, goitrogens, saponins and lipoxidase are not as well understood but are thought to also affect growth. The trypsin inhibitor and the hemagglutinins are destroyed by heat; however, overheating often changes the amino acid availability while underheating produces a bitter taste which affects palatability and therefore feed consumption. Even though most of this book deals with potential energy sources for pigs, such as sugar cane, oil palm, tubers and plantains, this chapter hopes to emphasize that one major constraint to developing alternative pig feeding systems in the tropics is directly related to optimizing the use of existing protein resources.

NON-OIL LEGUME SEEDS

Canavalia beans

***Canavalia ensiformis* is a good example of an alternative tropical**

legume for pigs. It can produce an annual yield of up to 6 t/ha of shelled beans and 10 t/ha of residues that could mean an annual yield of 3.6 t/ha of protein (Escobar *et al.*, 1983). However, because of anti-nutritional factors, the general use of this legume for pigs is best limited to no more than 5% of the diet. Ensiling or autoclaving the bean to reduce the inhibitors has been partially effective (Risso, 1984, cited by Escobar *et al.*, 1983); soaking and cooking do not help (Moncada *et al.*, 1990) and extrusion results in low intake and reduced average daily gains in young pigs (Risso, 1989). The chemical composition of canavalia beans is given in Table 2.1.

Table 2.1. The chemical composition of canavalia beans (% DM).

Form	CP	Ash	CF	EE	Source
Raw	28.4	-	-	-	León *et al.* (1990)a
Extruded	27.9	-	-	-	
Raw	31.0	-	-	4.0	Mora(1983)b

Raw	29.6	3.0	9.7	4.0	ICA (1988)c
Cooked	27.1	2.8	8.3	3.5	
Raw	35	-	10.5	-	Garcia and Pedroso (1989)
Autoclaved	28.7	4.5	14.6	-	Dominguez and. Ly (1992)d

a cited by Michelangeli *et al.* (1990); b cited by Escobar *et al.* (1983); c cited by Moncada *et al.* (1990); d unpublished data

The amino acid composition of canavalia beans and other non-oil legume seeds is shown in Table 2.2.

Table 2.2. The essential amino acid composition of non-oil legume seeds (%DM).

Amino acid	Canavalia bean	Pigeon pea	Cow pea
Arginine	1.56	1.28	1.52
Histidine	0.80	-*	-*

Isoleucine	1.12	0.78	0.92
Leucine	2.00	1.63	1.78
Lysine	1.43	1.42	1.57
Methionine + cystine	0.50	0.57	0.62
Phenylalanine + tyrosine	2.42	1.85	1.19
Threonine	1.09	0.83	0.88
Tryptophan	-*	0.25	0.34
Valine	1.26	0.94	1.09.

Source: D'Mello *et al.* (1985); CPNSA (1991); * not reported

Pigeon pea

Pigeon pea, a valuable legume consumed by both humans and animals, is cultivated extensively in India, Southeast Asia, parts of Africa and the West Indies. Although, the seeds and leaf meal contain adequate levels of nitrogen, the foliage has a high level

of crude fibre (FAO, 1993). There is little information concerning the use of pigeon pea leaf meal for pigs, however, several studies have determined the feeding value of the seeds. Growing pigs fed raw pigeon pea seeds performed poorly (Castro *et al.*, 1984; Visitpanich *et al.*, 1985a) mainly due to the trypsin inhibitor, which can be reduced by sterilizing (Visitpanich *et al.*, 1985b). Different ways of treating pigeon peas and the effect on the digestion of pigs have been thoroughly studied in Brazil (see Table 2.3).

Table 2.3. Chemical composition and digestibility of cow pea and pigeon pea.

	Composition (% DM)				Digestibility (%)	
	CP	Ash	CF	EE	N	Energy
Cow pea: raw	30.3	5.0	7.6	1.6	66.1	78.0
cooked	26.2	3.7	5.9	1.4	78.2	80.5
toasted	25.7	4.1	7.1	1.4	69.4	73.8

Pigeon pea:raw	23.8	4.3	10.6	1.4	71.5	77.4
cooked	23.0	3.4	10.3	1.1	81.6	83.4
toasted	22.4	3.9	10.6	0.9	76.3	83.4

Source: Fialho *et al.*, (1985)

Cow pea

The cow pea is a short-cycle legume that has not been sufficiently studied as a protein source for pigs. This may be because it has normally been used as grain or forage for ruminants (Das *et al.*, 1975). Table 2.3 shows data from Brazil related to the chemical composition and digestibility of the raw, cooked or toasted cow pea. Cooking involved either boiling for 40 minutes or sterilization at 100°C for 20 minutes. The digestibility study by Fialho *et al.* (1985) clearly indicates that, when cooked or toasted, there is an improvement in the digestion of nitrogen and energy.

Pigs fed toasted cow pea, in the form of meal and as the sole protein source, performed the same as pigs fed soya bean meal based diets. Other studies indicated that methionine supplementation of cow peas had no effect on pigs (Maner, 1971). The data in Table 2.4 support the idea that the trypsin inhibitor present in the seeds can be destroyed by cooking. With respect to on-farm trials. Gerpacio (1988) reported that cow pea meal could be included up to 30% in the diet.

Table 2.4. The effect of raw or cooked cow peas supplemented with methionine for growing/finishing pigs.

	AD feed intake (kg/d)	ADG (g)	AD feed conversion
Soya bean meal plus maize	2.02	799	2.53
Raw cow pea	1.89	551	3.43
Raw cow pea plus	1.49	483	3.09

methionine			
Cooked cow pea	2.04	816	2.50
Cooked cow pea plus methionine	1.98	815	2.43

Source: Maner (1971)

OIL LEGUME SEEDS

Groundnut

The groundnut is cultivated for its oil and for human consumption. The seeds contain a trypsin inhibitor which is neutralized by heat during oil extraction. After oil extraction the resulting cake contains 40 to 45% protein of medium biological value (Table 2.5).

Groundnut meal lacks sufficient lysine and, even though it

contains adequate amounts of methionine, threonine, tryptophan and nonessential amino acids (Green *et al.*, 1988), it cannot be used as the only protein source for pigs. The nutritive value of whole groundnuts and groundnut meal can be seriously affected by contamination with *Aspergillus* mould, particularly if the seeds or the meal are not carefully dried prior to storage. The resultant aflatoxin, produced by the mould, can seriously affect pig performance including loss of appetite. The composition of the essential amino acids of the groundnut is given in Table 2.6.

Table 2.5. The chemical composition of different forms of ground-nut.

	Composition (% DM)				Source
	Cp	Ash	CF	EE	
Ground-nut meal: solvent	51.8	6.1	11.0	1.5	CNPSA(1991)
Ground-nut meal: screw	45.3	4.5	4.7	8.3	Knabe *et*

press					*al.*(1989).
Ground-nut cake:hulled	49.5	5.7	5.9	6.9	Morrison(1956)
with hulls	46.5	5.2	18.5	2.1	

Table 2.6. Composition of the essential amino acids in ground-nut meal(% DM).

Amino acid	Ground-nut meal	Amino acid	Ground-nut meal
Arginine	6.07	Methionine + cystine	1.30
Histidine	1.25	Phenyalanine + tyrosine	4.95
Isoleucine	1.95	Threonine	1.46
Leucine	3.40	Tryptophan	0.54
Lysine	1.87	Valine	2.37

Source: INRA(1984)

Table 2.7 offers an excellent example of amino acid supplementation of groundnut meal for growing/finishing pigs. The addition of both lysine and methionine to the meal produced a feed conversion comparable to that of soya bean meal. In order that the trypsin inhibitor does not affect performance, no more than 20% of full fat groundnut should be used.

Table 2.7. The use of ground-nut meal supplemented with different amino acids for pigs (22–90 kg).

	AD feed intake (k/d)	ADG (g)	AD feed conversion
Soya bean meal	2.46	700	3.54
Ground-nut meal	2.86	540	5.28
Ground-nut meal plus lysine	2.39	600	4.01
Ground-nut meal plus lysine and methionine	2.40	670	3.57

Source: Brooks and Thomas (1969)

Soya beans

Soya beans, first used in China for human consumption, were brought to America in the early 1800s for the purpose of hay or silage for domestic animals, and as a green cover crop. Later, interest began to focus on their oil content (Table 2.8). The favourable amino acid composition (Table 2.9) of soya bean meal, or adequately treated whole soya beans, complements that of cereals, particularly maize, in pig and other livestock feeding systems often used in temperate countries; in fact, soya bean meal now accounts for approximately 80% of total protein supplements used in non-ruminant feeds (Herkelman and Cromwell, 1990).

Table 2.8. The composition of whole or solvent extracted soya beanseed (%DM).

Parameter	Whole seed		Solvent extracted seed		
	toasted	cooked	42% CP	45% CP	48% CP
Crude protein	41.5	43.0	48.0	50.8	54.7
Ether extract	17.6	19.6	2.3	2.0	1.6
Crude fibre	7.8	7.7	6.3	6.5	7.0

Source: CNPSA(1991)

The potential use of derivatives of sugar cane and oil palm, and of roots and tubers as alternative energy feed sources for pigs has provoked new interest in the use of the whole boiled seed (Sarria and Preston, 1992; Sarria, 1994) or even the ensiled soya bean plant (Chinh *et al.*, 1993) for pig production. In the former case, pigs from 30 to 96 kg, fed boiled soya beans, sugar cane juice and concentrated distillery solubles, grew at 810 g/day, similar to the average daily gain of 834 g/day reported by Pérez (1993) for pigs also fed a restricted amount of boiled soya beans

but only free-choice cane juice. When fed silage made from the entire soya bean plant, Chinh *et al.* (1993) were able to substitute from 25 to 37% of the dietary protein for growing pigs and from 20 to 30% for finishing pigs. The authors also emphasized that the yield of 8.1 t/ha of green soya bean foliage, about 70 days' growth, would represent 360 kg of crude protein, the same amount normally produced from one hectare of dry soya beans.

Table 2.9. The composition of the essential amino acids of soya bean products (% DM).

Amino acid	Soya bean meal	Cooked whole soya beans	Roasted whole soya beans
Arginine	3.45	2.58	3.21
Histidine	1.41	-	1.22
Isoleucine	1.98	1.77	1.67
Leucine	3.29	3.04	3.09
Lysine	2.90	2.27	2.37

Methionine + cystine	1.15	1.53	1.35
Phenylalanine + tyrosine	3.63	1.76	3.46
Threonine	1.71	1.52	1.72
Tryptophan	0.90	0.91	0.56
Valine	2.15	1.87	1.87

Source: CPNSA(1991)

The use of raw soya beans can affect the digestion and absorption of protein and fat (Combs *et al.*, 1967; Collins and Beaty, cited by Herkelman and Cromwell, 1990) and thus influence the performance of growing/finishing pigs. Pond *et al.* (1972) and Crenshaw and Danielson (1985a) showed that raw soya beans fed to growing pigs can reduce the average daily gain as well as increase feed conversion by more than 50

percent. Following that, Crenshaw and Danielson (1985b) studied the effect of raw soya beans on three consecutive parties and concluded that the raw, untreated bean can be effectively used during gestation. During lactation the sows were fed a 15% protein maize/soya bean meal ration.

The use of the raw bean during lactation has also been studied. There were no deleterious effects on first-litter sow reproductive traits when a mixture of soya bean meal and cottonseed meal was replaced by 10.4% of raw soya beans (Osorio and Buitrago, 1985, cited by Buitrago, 1987). Likewise, Newman *et al.* (1987) found that the reproductive performance of first-litter sows was not affected by feeding raw soya beans during both gestation and lactation.

Table 2.10. The effect of soya bean meal or whole soya beans on the performance traits of growing pigs (19–50 kg).

Composition:	Soya bean meal	Whole soya beans*

maize	82.8	-	-	-	
C molasses	-	30.0	40.0	30.0	40.0
sugar cane	-	36.8	26.8	26.8	16.8
soya bean meal	14.0	30.0	30.0	-	-
whole soya beans*	-	-	-	40.0	40.0
AD feed intake. kg/d	1.78	2.12	2.23	2.25	2.33
ADG, g	600	610	670	720	640
AD feed conversion	2.96	3.47	3.33	3.13	3.64

Source: Buitrago *et al.* (1977); Cooked 30 min. and sun-dried

Although several heat treatment methods such as toasting or extrusion been developed to neutralize the anti-nutritional factors contained in the raw bean, one simple method is to soak the bean overnight in water (1 part bean to 3 water) and boil the mixture for 15 minutes (Pérez, 1993). Another method is, without soaking, to boil the bean for 40 minutes (Sarria and Preston,

1992; Sarria, 1994). It has also been reported that pig performance was not affected when the whole soya bean was cooked for 30 minutes, and immediately sun-dried (Table 2.10). The author is presently performing observation trials using the entire soya bean plant, in late-milk stage, some 80 days' growth, for growing/finishing and gestating animals. The diet is diluted B molasses and from three to five soya bean plants, daily, depending on the category and size of the pigs.

NON-LEGUME OIL SEEDS

Sunflower seeds

Sunflowers do not contain the toxins found in legumes and although the principal producers of sunflower are found in the temperate climates, it can well adapt to the tropics (Sistach and Diaz, 1974). There are two main problems related to the use of sunflower seeds meal for pigs: its high fibre content and the low

level of lysine and threonine, the latter which varies according to the method of processing. The composition of different sunflower-derived feeds is presented in Table 2.11.

Table 2.11. The composition of different sunflower seed-derived feedstuffs.

	Composition, % DM				Source
	CP	Ash	CF	EE	
Sunflower seeds	18.8	3.9	15.4	42.4	Hartman 1983, cited by Wahlstrom (1985)
Sunflower seeds: non-dehulled, oil extracted	32.2	6.0	26.7	1.5	CNPSA(1991)
Sunflower heads	7.1	10.6	16.6	2.9	Gowd *et al.* (1987)
Sunflower seed kernels	26.4	3.3	3.4	50.4	Sistach and Diaz (1974)
Sunflower meal: hulled,	44.1	7.3	14	8.2	Pond and Maner

expeller					(1974)
Hulled, solvent extracted	50.3	8.3	11.8	3.1	

One example of the value of sunflower meal, in soya bean meal-based diets, including the effect of correcting the amino acid profile by adding lysine, may be seen in Table 2.12.

Table 2.12. The substitution of soya bean meal by sunflower meal supplemented with lysine for pigs (29-95 kg).

	AD feed intake, kg/d	ADG (g)	AD feed conversion
Soya bean meal (control)	2.36	720	3.26
Sunflower meal, 25 % in diet:	2.67	780	3.5
plus lysine	2.46	740	3.33
50% in diet	2.44	700	3.49

plus lysine	2.46	740	3.35
75% in diet	2.15	580	3.69
plus lysine	2.38	690	3.44
100% in diet	2.20	610	3.59
plus lysine	2.40	760	3.13

Source: Baird (1981), cited by Aherne and Kennelly (1983)

The necessity for lysine supplementation of sunflower-based diets is fully illustrated by the data in the previous table and by the amino acid status of this protein source (Table 2.13). Perhaps, the full-fat sunflower seed, correctly supplemented with lysine, could be more widely employed as an alternative protein source for feeding pigs in the tropics if sugar cane juice was the energy source. Hulling the seed to diminish the indigestible fibre fraction might be unnecessary, however, information is lacking. In conventional cereal diets that contained up to 50% sunflower

seeds (Laudert and Allee, 1975, cited by Wahlstrom, 1985), growth performance, but not feed efficiency, was affected.

In spite of its potential, one of the primary difficulties related to the production of sunflower in the tropics is the problem of harvesting, and more important, storage, particularly during the wet season. The author has preserved the entire sunflower head in molasses, a technique similar to the preservation of fish and fish wastes (see Chapter 6). Storing the entire sunflower head in this way inhibits the growth of mould, the main reason for having to dry the seeds for storage.

Table 2.13. Composition of the essential amino acids in sunflower seeds (%DM).

Amino acid	Sunflower seeds	Amino acid	Sunflower seeds
Arginine	2.16	Methionine + cystine	0.50
		Phenyalanine +	

Histidine	0.73	tyrosine	1.22
Isoleucine	1.27	Threonine	-
Leucine	1.81	Tryptophan	0.34
Lysine	1.02	Valine	1.74

Source: CPNSA (1991)

Cotton seed

Cotton seed contains 25% crude protein and 25% of oil and, after the extraction of the oil, the resultant meal contains slightly more than 40% crude protein (Table 2.14). However, both the cotton seed, and the meal, contain gossypol, a toxic pigment to which the pig is very sensitive. Although dietary levels of 0.01% are harmless for older animals (Aherne and Kennelly, 1983) levels as low as 0.02% can kill young pigs (Hale *et al.*, 1958).

Although various reviews about the use of cottonseed meal for

feeding pigs are available (Buitrago *et al.*, 1977; Aherne and Kennelly, 1983; Tanksley, 1990), one of the most practical suggestions is to include less than 10% of the seed in diets for young pigs, increasing this amount in older animals and breeding stock (Buitrago *et al.*, 1977). The amino acid composition of cotton seed is shown in Table 2.15.

Table 2.14. Composition of cottonseed meal (% DM).

Parameter	Screw press	Pre-press solvent	Solvent
Dry matter	91.4	89.9	90.4
Ether extract	3.7	0.6	1.5
Ash	6.2	6.4	6.4
Crude protein	4.0	41.4	41.4
N solubility	36.8	54.4	69.4
Lysine	1.59	1.71	1.76
Crude fibre	13.5	13.6	12.4
Free gossypol	0.04	0.05	0.03

Total gossypol	1.02	1.13	1.04

Source: Buitrago *et al.* (1977)

Table 2.15. Composition of the essential amino acids in cotton seeds (% DM).

Amino acid	Cotton seeds	Amino acid	Cotton seeds
Arginine	4.53	Methionine + cystine	1.52
Histidine	1.15	Phenyalanine + tyrosine	3.38
Isoleucine	1.45	Threonine	1.52
Leucine	2.63	Tryptophan	0.62
Lysine	1.70	Valine	1.95

Source: CPNSA (1991)

Coconuts

Two principal feeds can be produced from coconuts. One is the

byproduct of the extraction of the oil from the seed, known as coconut oil meal, coconut cake or copra meal and which represents approximately 34 to 42% of the weight of the nut (Hutagalung, 1981). The other is the broken kernel, usually known as raw copra. The main difference between the two products is the amount of protein and fat (Table 2.16).

Table 2.16. Composition of coconut products.

	Composition (% DM)				**Source**
	CP	**Ash**	**CF**	**EE**	
Coconut oil meal:					
solvent extracted	24.6	6.2	10.8	0.4	Thorne *et al.* (1989)
expeller	21.9	5.4	10.0	9.1	
Coconut oil meal: expeller	20.9	5.8	10.5	5.8	Creswell and Brooks (1971)
expeller	20.0	-	13.0	9.0	Hutagalung (1981)

expeller	25.4	5.8	12.6	17.1	CNPSA (1991)
Raw copra	7.6	1.2	3.5	66.2	Thorne *et al.* (1989)

Butterworth and Fox (1963) referred to the poor digestibility of coconut oil meal for pigs. Later, Hutagalung (1981) reported a higher value, 74%, for the digestibility of the protein in coconut oil meal. Recent Brazilian data reported levels as low as 67% and 63% for the digestibility of the nitrogen and the energy in expeller-pressed, coconut oil meal, respectively (CNPSA, 1991). It has been shown that coconut oil meal, at a dietary level of 30%, supports adequate performance in growing/finishing pigs (Grieve *et al.*, 1966; Malynicz, 1973) and if certain amino acids are added, it may be used up to a level of 40 percent (Table 2.17).

Table 2.17. The use of 40% coconut oil meal (COM) supplemented with different amino acids for pigs (18-93 kg).

	AD Intake		

	(kg/d)	ADG (g)	AD feed conversion
Maize/soya bean meal	2.21	740	2.98
Coconut oil meal	2.10	560	3.76
COM + lysine and methionine	2.09	640	3.27
COM + lysine, methionine and threonine	2.08	650	3.19
COM + lysine, methionine and tryptophan	2.09	650	3.24
COM + lysine, methionine, threonine and tryptophan	2.12	710	3.00

Source: Yuthana (1986), cited by Argañosa (1987)

The low level of lysine and other essential amino acids in coconut oil meal is summarized in Table 2. 18.

Table 2.18. Compositionof essential amino acids in coconut oil

meal (%DM).

Amino acid	Coconut oil meal	Amino acid	Coconut oil meal
Arginine	2.96	Methionine + cystine	0.65
Histidine	0.51	Phenyalanine + tyrosine	1.51
Isoleucine	0.89	Threonine	0.77
Leucine	1.71	Tryptophan	0.37
Lysine	0.72	Valine	1.24

Source: CPNSA(1991)

Rubber seed

Rubber seed meal is produced in substantial amounts in Southern Asia and parts of Africa where it is a valuable source of protein (Babatunde and Pond, 1988). Estimated annual yields of

the seeds, which contain up to 25% crude protein, are 0.1 t/ha (Table 2.19). Rubber seed meal is relatively poor in the amino acid methionine, while the levels of lysine and cystine are somewhat better. However, the main constraint to using rubber seed meal is the presence of hydrocyanic acid in the seeds, about 9 mg/100g, which, according to Devendra (1989), can be reduced by heat or storage.

Table 2.19. Composition of rubber seed products.

	Composition (% DM)				Source
	CP	Ash	CF	EE	
Rubber seed meal	38.0	5.3	3.9	12.6	Devendra (1979)
Rubber seed meal	28.0	-	13.9	11.5	Hutagalung (1981)
Hulled, solvent	31.2	-	-	31.8	Babatunde and Pond (1988)

Limited studies have been carried out using rubber seed meal as

pig feed. Ong and Yeong (1977) reported a reduction in growth when pigs were fed diets containing more than 20% of the meal (Table 2.20). Devendra (1989) also considered 20% as optimum.

Table 2.20. The effect of rubber seed meal on pigs.

% in diet	AD intake (kg/d)	ADG (g)	AD feed conversion
0	1.73	500	3.51
5	1.83	500	3.58
10	1.80	490	3.69
15	1.80	480	3.73
20	1.82	470	3.83
25	1.76	410	4.33

Source. Ong and Yeong(1977)

In Sri Lanka, Ravindran (1983) found impaired performance traits

with pigs fed more than 10 percent. However, this effect was attributed to a deficiency of lysine and methionine rather than to the cyanogenic glucoside present in the meal. This is fully illustrated in Table 2.21. More recently, Fuller (1988) suggested that with correctly treated meal, the diet could contain up to 40 percent. He also concluded that since rubber seeds slowly lose hydrocyanic acid, storage for a minimum of four months, or detoxification by roasting (350°C for 15 minutes), or soaking, in hot water or in a 2.5% ash solution for 12 hours, could solve this problem. These methods would eliminate the anti-nutritional factors and improve palatability.

Table 2.21. Composition of the essential amino acids in rubber seeds (%DM).

Amino acid	Rubber seeds	Amino acid	Rubber seeds
Arginine	2.86	Methionine + cystine	0.99
Histidine	0.74	Phenyalanine + tyrosine	2.37

Isoleucine	1.15	Threonine	1.12
Leucine	2.75	Tryptophan	0.36
Lysine	0.73	Valine	1.23

Source: Babatunde and Pond (1988)

FODDER TREES AND SHRUBS

Data concerning the feeding of fodder trees and shrubs for pigs is relatively scarce. Certain negative characteristics of these feeds, anti-nutritional factors and high levels of crude fibre, are known to affect performance, irrespective of the level of their inclusion (D'Mello, 1992). Also, in contrast to ruminants, most pigs are unable to "self-harvest" the foliage, meaning that the farmer has to cut and carry the feed for the animal.

Leucaena leucocephala* is a good example of the difficulty of using fodder trees and shrubs as pig feed. *Leucaena

***leucocephala* contains mimosine, a free toxic amino acid. Practical methods of detoxification aimed at reducing the mimosine content of the leaf meal have been studied by researchers in Thailand (Kassumma, 1987). Since mimosine is a water soluble amino acid, water soaking and washing the leucaena leaves for one day before sun drying and grinding was reported as an economical way to improve their nutritive value (Table 2.22). Interestingly, however, the best performance was obtained by simply sun-drying the leaves prior to use.**

An attempt to increase the level of soaked leucaena leaf, dried and prepared as a meal, from 15 to 25% in the diet, by adding 0.2% ferrous sulfate was unsuccessful. Pig performance tended to decline when more than 15% of treated, soaked meal was fed (Sanchisuriya, 1985, cited by Kassumma, 1987).

Table 2.22. The effect of including 15% *Leucaena* leaf meal for pigs (30–60 kg).

Form of administration	AD intake (kg/d)	ADG (g)	AD feed conversion
Dried *leucaena* leaves	2.09	770	2.71
Soaked 24 hr, before drying and grinding	1.91	680	2.81
Ground, before soaking for 24 hr	2.00	690	2.90
Fresh, unsoaked leaves	1.67	540	3.06

Source: Ruengpaibul (1984), cited by Kassumma (1987)

***Trichantera gigantea*, perhaps the most promising fodder tree from the point of view of yield, palatability, and source of protein (Gómez and Murgueitio, 1991) contains 18% crude protein in dry matter (leaves) and can produce, annually, from 40 to 60 t/ha of fresh foliage. Sarria *et al*. (1992) reported a decrease in the growth rate of pigs when *Trichantera gigantea* provided up to**

25% of the dietary protein in a sugar cane juice/soya bean meal feeding system, and it was suggested that performance was related to the lower nutrient digestibility or an imbalance of the essential amino acids in the foliage. This result was in contrast to an earlier observation that, as a source of protein for gestating sows, the use of up to 75% fresh *Trichantera gigantea* leaves was possible (Mejia, 1991, cited by Preston and Murgueitio, 1992).

Recently, Sarria (1994) concluded that there were no significant differences in the productive parameters of weaned piglets when the sows, during gestation, were fed a restricted amount of sugar cane juice, either soya bean meal or cooked soya beans, and up to 30% of daily protein requirements in the form of fresh *Trichantera* leaves, about one kilogramme per day.

AQUATIC PLANTS

Floating aquatic plants (macrophytes) can contribute to the protein content of the diet and, if grown in the liquid slurry of pig wastes (runoff) which have been treated anaerobically, may also contribute to the recycling of nitrogen. The protein content of some aquatic plants such as *Lemna minor* and *Azolla* spp is as high as 29 and 24%, in dry matter, respectively. Annual yields of water hyacinth can fluctuate between 3 and 15 kg of DM /m ^{2} (Steward, 1970) whereas yields of *Azolla filiculoides* have been reported as 3.9 kg DM/m^{2} (Becerra *et al.*, 1990). Although aquatic plants have the capacity to double their biomass every 3 to 4 days, the use of water plants for pigs is limited due to their relatively high content of fibre and minerals (Table 2.23).

In the Philippines, *Azolla*, the traditional green manure of rice fields, is fed both fresh and ensiled to pigs (Table 2.24). In Colombia, where researchers have successfully used palm oil to replace sorghum as the only energy source in growing-finishing

diets, *Azolla* has been used to replace 10% of the protein, provided by 500g of soya bean meal, in the growing and 20% in the finishing phase, respectively (Ocampo, 1994).

Table 2.23. Composition of some floating aquatic macrophytes (%DM).

	DM	CP	Ash	CF	Source
Water hyacinth: chopped	3.8	11.3	23.0	-	Baldwin *et al*. (1975)
Pressed	10.0	10.6	17.3	-	
Water hyacinth: fresh	-	26.7	13.0	17.4	Bonomi *et al*. (1981)
Water hyacinth: fresh	8.0	11.0	14.7	22.3	Mishra *et al*. (1987)
Azolla: dried, milled microphilla	-	23.7	28.7	15.0	Alcantara and Querubin (1989)
Azolla filiculoides	-	23.7	-	-	Becerra *et al*. (1990)
Lemna minor: fresh"	-	29.6	17.0	9.7	Bonomi *et al*. (1981)
"	6.5	33.0	15.0	-	Lincoin *et al*. (1986)

Table 2.24. Performance traits of pigs fed *Azolla* spp.

Form of feeding and % in diet		Liveweight (kg)	ADG (g)	AD feed conversion	Source
Meal:	0	16–25	223	3.40	Alcantara and Querubin
	15	"	267	3.33	(1989)
Meal:	0	35–60	557	4.11	Alcantara and Querubin
	30	"	520	4.42	(1989)
Silage:	0	33–59	701	3.22	Querubin *et al*. (1988)
	20	"	778	3.16	
	30	"	748	3.18	
Fresh,	0	24–89	482	4.73	Becerra *et al*. (1990)
Wilted	30	"	454	5.26	

Wilted	[illegible]		[illegible]	[illegible]	
Fresh	0	20–90	526	2.10*	Ocampo (1994)
		12.6	"	452	2.20*

*** DM feed conversions; raw palm oil as basal diet (See Chapter 4)**

The amino acid profile of *Azolla* is given in Table 2.25.

Table 2.25. Composition of essential amino acids of *Azolla microphylla*(%DM).

Amino acid	Freeze-dried	Oven-dried	Amino acid	Freeze-dried	Oven-dried
Arginine	1.54	1.29	Methionine + cystine	0.61*	0.58*
Histidine	0.50	0.48	Phenyalanine + tyrosine	2.80	2.29

Isoleucine	1.46	0.80	Threonine	1.17	1.42
Leucine	3.25	2.27	Tryptophan	**	**
Lysine	2.03	1.16	Valine	1.59	1.45

Source: Querubin *et al*. (1988); * cystine was not reported, ** not determined

MICROBIAL PROTEINS Microalgae

Recently, Ly (1993) emphasized that an integrated plant-animal production system could provide a viable contribution to protein-deficient animal feeding systems in the tropics. According to this author, aquatic floating plants and microalgae (microphytes) should be given first priority. Their production would rely on substrates such as pig wastes. This would prevent environmental contamination, at the same time would permit the recycling of valuable nutrients, particularly nitrogen compounds. An attractive strategy is the bio-transformation of manure into

methane gas for fuel through inexpensive, simple techniques like those developed in Taiwan (Chung *et al*., 1978), followed by the use of the effluent from the generation of methane to produce microalgae. The composition of some microalgae are described in Table 2.26.

One of the main constraints in producing microalgae is the difficulty of separating the biomass from the water. However, Lincoln *et al*. (1986) have claimed that due to their high yields and dense stand, 2 to 12 t DM/ha, an economically sound strategy would be to harvest the algae by flotation or sedimentation techniques, followed by chemical floculation. Moreover, Fuller (1988) has suggested that some of the algae can be separated by simple filtering methods.

Table 2.26. Composition of some microphytes.

Microphyte	Composition, %DM			Source
	CP	Ash	CF	

Spirulina	67.7	7.5	-	Ishizaki[1]
"	60.5	6.9	-	Ross (1990)
"	62.9	-	-	Chung *et al.* (1978)
"	58.3	9.8	4.5	Février and Seve (1976)[2]
Chlorella	55.5	8.3	3.1	Lubitz[3]
"	63.1	-	-	Chung *et al.* (1978)
Scenedesmus	22.2	-	-	
Mixed culture				
Various[4]	24.9	21	1.6	Harrison *et al.* (1981)
Various[5]	50.9	6.2	6.2	Hintz *et al.* (1966)

[1]Cited by Hugh *et al.* (1985); [2]Values corresponding to the sample named M6, [3] Cited by Oeio *et al.* (1973), [4]*Chlorella* spp,

***Scenedesmus obliquus* and *S.quadricauda*, [5] Predominantly *Synochocystis* spp**

The filamentous algae, *Spirulina*, seems to be the most promising microphyte. Although researchers have evaluated this microalga as a protein replacement in pig diets, the maximum level of algal protein is yet to be established (Hugh *et al*., 1985). Protein digestibility can be depressed in young pigs if the level of *Spirulina* in the diet is elevated (Février and Seve, 1976). Hintz *et al.* (1966) suggested that the complex algal cell wall was resistant to digestive enzymes. However, trials did not support his assumption. Contradictory results were also reported by Février and Seve (1976), who assumed that the digestive disadvantages related to the introduction of algae in the pigs diet were largely compensated for by improved metabolic utilization of the absorbed nutrients. The amino acid composition of some microphytes is presented in Table 2.27.

Table 2.27. Composition of essential amino acids of some microalgae (%DM).

Amino acid	*Spirulina*	*Chlorella*	*Scenedesmus*
Arginine	2.73	2.15	0.54
Histidine	0.55	1.40	1.08
Isoleucine	1.05	1.29	1.83
Leucine	3.01	3.44	4.09
Lysine	1.68	3.33	2.90
Methionine + cystine	1.02	1.08	1.40
Phenylalanine + tyrosine	2.96	4.73	3.76
Threonine	1.79	3.23	3.76
Tryptophan	-*	0.97	0.86
Valine	1.19	2.26	3.12

Source: Ako (1985), cited by Hugh *et al.* (1985); INRA (1984); * not reported

Yeast Strictly speaking, yeasts do not depend on climatic conditions for their production. Therefore, they are not natural tropical protein feed resources, unless, of course, the substrate defines their origin. In such case, yeasts can be obtained from derivatives of tropical crops such as sugar cane.

***Saccharomyces* yeast is a byproduct of the alcohol industry. There are a considerable number of Brazilian studies concerning the utilization of *Saccharomyces* (brewers) yeast in pig production (Miyada, 1990). Likewise, torula yeast from sugar cane molasses has been widely used in Cuba (Figueroa and Ly, 1990). The composition of these yeasts is shown in Table 2.28.**

Table 2.29 presents the results of including graded levels of *Saccharomyces* yeast in the diets of growing/finishing pigs. According to the data from Miyada *et al.* (1988) cited by Miyada (1990) only the highest level, 25% dry matter of *Saccharomyces* yeast, affected the average daily gain, and this was perhaps due

to a decrease in feed intake. This same result was not observed when *Saccharomyces* yeast completely substituted fish meal in cane C molasses-based diets (Lezcano and Elias, w1975). Possibly, the low palatability of the yeast was masked by the sweetness of the molasses.

Table 2.28. Composition of yeast produced from sugar cane C molasses (% DM).

Type of yeast		CP	Ash	CF	EE	Source
Saccharomyces yeast: type A		34.9	4.1	0.5	0.2	Fialho *et al.* (1985)
	type B	37.0	5.5	0.7	0.3	
Saccharomyces yeast average		31.6	10.3	0.8	1.0	Miyada (1990)
Saccharomyces yeast: average		34.8	10.2	1.0	0.9	CNPSA (1991)
Torula yeast: average		45.7	9.0	-	-	IIP (1988)*

Torula yeast:	low CP	34.7	-	2.5	-	Garcla and Pedroso (1989)
	medium CP	40.4	-	2.5	-	
	high CP	49.1	-	2.5	-	

*** Cited by Figueroa and Ly (1990)**

Table 2.29. The use of *Saccharomyces* yeast for pigs (23–93 kg).

%DM in diet	DM feed intake (kg/d)	ADG (g)	DM feed conversion
0	2.66	810	3.28
5	2.57	820	3.16
10	2.71	850	3.23
15	2.62	830	3.16
20	2.56	800	3.21
25	2.41	740	3.23

Source: Miyada *et al.* (1988), cited by Miyada (1990)

Both *Saccharomyces* and torula yeast contain a high level of lysine and other essential amino acids, except methionine plus cystine. If low amounts of yeast are included in the diet, a complementary sulfurcontaining, amino acid-rich protein supplement or synthetic DL-methionine might be included in the ration. However, the beneficial effect of the inclusion of methionine for growing/finishing pigs fed high amounts of *Saccharomyces* (Ceballos *et al.*, 1970), or torula yeast (Lezcano *et al.* 1992), has not been demonstrated. The amino acid composition of yeast is offered in Table 2.30.

Table 2.30. Composition of the essential amino acids of yeast (% DM).

Amino acid	*Saccharomyces*	Torula
Arginine	1.51	2.04
Histidine	0.77	0.71

Isoleucine	1.64	1.95
Leucine	2.41	3.00
Lysine	2.30	2.57
Methionine + cystine	0.91	0.76*
Phenyalanine + tyrosine	2.29	3.24
Threonine	1.75	2.19
Tryptophan	0.58	-
Valine	1.97	2.29

Source: Anon (1985); CPNSA (1991); methionine

Throughout the life-cycle of the pig the use of torula yeast as a protein source is as effective as *Saccharomyces* yeast (Figueroa and Ly, 1990). Table 2.31 shows a good example of substituting a conventional protein source (fish meal) with dry torula yeast for growing/finishing pigs in Cuba.

Table 2.31. Comparison of fishmeal to dry torula yeast as the only source of protein for growing/finishing pigs* (34–90 kg).

% DM in diet	DM intake (kg/d)	ADG (g)	DM feed conversion
Fishmeal,24	2.38	680	3.50
Dry torula yeast, 33	2.28	650	3.60

Source: Lezcano (1980), cited by Diaz *et al.* (1985), * fed C molasses as the energy source

Approximately, one-half of the fuel needed to produce torula yeast is used in drying the yeast cream. One innovative technique involves mixing, on a dry matter basis, 30% of plasmolyzed cells of liquid torula yeast with 70% of cane B molasses. The resulting liquid diet is called "protein molasses" (ICIDCA, 1988). It contains 36% dry matter and between 13 and 14% protein, also in dry matter, and has been used in Cuba as a commercial diet for growing/finishing pigs (See 3.3.2.5).

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Chapter 3 Sugar cane

Sugar cane *(Saccharum officinarum* L.) is a tropical, perennial grass that tillers at the base to produce multiple stems, three to four metres high and approximately five centimetres in diameter. Its composition varies depending upon the climate, soil type, irrigation, fertilizers, insects, disease control, varieties, and the harvest period (Meade and Chen, 1977). The air-dry (AD) "millable" cane stalk, approximately 75% of the entire plant, contains 11–16% fibre, 12–16% soluble sugars, 2–3% non-sugars, and 63–73% water (Dillewijn, 1952). Although the average yield of

"millable" cane is 60 t/ha/yr (FAO, 1992a), this figure can vary between 30 and 180 tons per hectare.

Sugar cane can be used as a major feed resource for most livestock, either by the small-scale farmer who grows between one and five hectares and has several pigs, some ducks and small ruminants (Preston and Murgueitio, 1992), or by the sugar factory that manages up to 10,000 ha and needs to diversify and/or produce food for its workers (FAO, 1988). In fact, one group of researchers in Puerto Rico has promoted the idea of "energy" cane, using the entire crop to exploit its biomass potential by bringing the whole plant into the factory to be used for raw sugar, animal feed and energy. They maintain that the growth potential of sugar cane, long thought of only in terms of the "millable" stem for sucrose, has been "underrecognized and underutilized", and that the production of up to 286 t/ha of sugar cane biomass is possible (Alexander, 1988).

Sugar cane, reportedly one of the most efficient plants to use solar energy to convert carbon dioxide and water to carbohydrates, is presently undergoing a "user-friendly" metamorphosis with regard to its potential both as an industrial raw material and for feeding all kinds of livestock (Table 3.1), not only pigs, the objective of the remainder of this chapter.

PRODUCTION AND TECHNOLOGICAL PROCESSES

Sugar cane is presently grown in more than 100 countries. The following figures refer to "millable" cane (Table 3.2).

Table 3.1. Energy feed resources from industrially-processedsugar cane: sugar cane juice (SCJ) in raw sugar factory and raw sugar in a cane refinery.

Product	Yield, % AD of cane	% DM in product	Composition, % dry matter (DM)		
			Total	NIOM[a]	Ash

			sugars		
SCJ (simple crusher)[b]	40–60	16–24	84–90	7.5–9.2	2.5–2.8
SCJ (raw sugar factory))[c]	92–96.5	15–19	77–85	4.5–6.5	33–4.8
High-test molasses	16.8–22.2	79–84	77–85	4.2–6.1	3.8–5.0.
A molasses	7.5–8.8	79–84	76–83	8.2–14.2	4.0–5.3
B molasses	52–7.0	79–84	68–72	12.0–17.5	5.0–7.5
C molasses	3.2–3.9	79–84	62–70	919.0–24.0	9.1–13.0
Crystal seed-sugar[d]	25–3.0	99–99.6	85–90	9.8–14.7	0.57–0.9
Raw sugar	9–13	99–99.6	985–99	0.60–	0.40–

				0.7	0.6
Syrup-off	-	72–76	91–93	3.0–3.8	1.3–1.8

a NIOM = non-identified organic matter.b SCJ = sugarcane juice (non-industrial).c water is added during the extraction process, the real extraction rate is 82–86% of total available juice in millable cane which is 72–75% of totaljuice; d dried for storage, contains 2–3% moisture

Tabel 3.2. Sugar cane production: world, regional & highest regional producer.

Region and production*		Top producer x region		
		country	production*	%of region
Africa	71 369	South Africa	18 500	26

North & Central America	166 281	Cuba	58 000	35
South America	347 649	Brazil	270 672	78
Asia	485 854	China	249 300	51
Europe	174	Spain	170	98
Oceania	33 253	Australia	29 300	88
World	1 104 580			

Source: FAO (1992)a; * 1 000 mt of "millable" cane

THE PRODUCTION PROCESS FOR INDUSTRIAL RAW CANE SUGAR.

The harvested cane stalks are sent to the factory where they are crushed by means of a series of three to six "3-roller-mills". Water is added to improve juice extraction; this increases the weight of the diluted juice to between 90 and 96% of the weight

of the milled cane. The extracted sugar cane juice is immediately subjected to three processes: liming, heating and settling, which is carried out in sedimentation tanks, called clarifiers. After two to three hours, the resulting "clarified" juice is sent to the evaporators where it is concentrated to a syrup.

Bangasse, a fibrous residue of 50% dry matter, is screened through rotary or vibrating sieves to sift out finer particles called bagasse pith. The pith is used to filter a mud-like sediment produced in the clarifiers which, after processing, is called "filter-press mud" or"filter-press cake". Most of the remaining bagasse is burned in the mill to produce steam and electricity to operate the factory.

The syrup, meanwhile, undergoes a progressive series of steps in the vacuum pans to produce industrial raw sugar. A and B, combined to form commercial raw sugar non-commercial raw sugar C (low-grade or crystal seed-sugar) and final or C

molasses. The final or C molasses is pumped out of the mill. Approximately two-third's of the C sugar (crystal seed-sugar) is dissolved and incorporated in the original syrup. The A and B commercial raw sugar can be bagged or sent to the refinery.

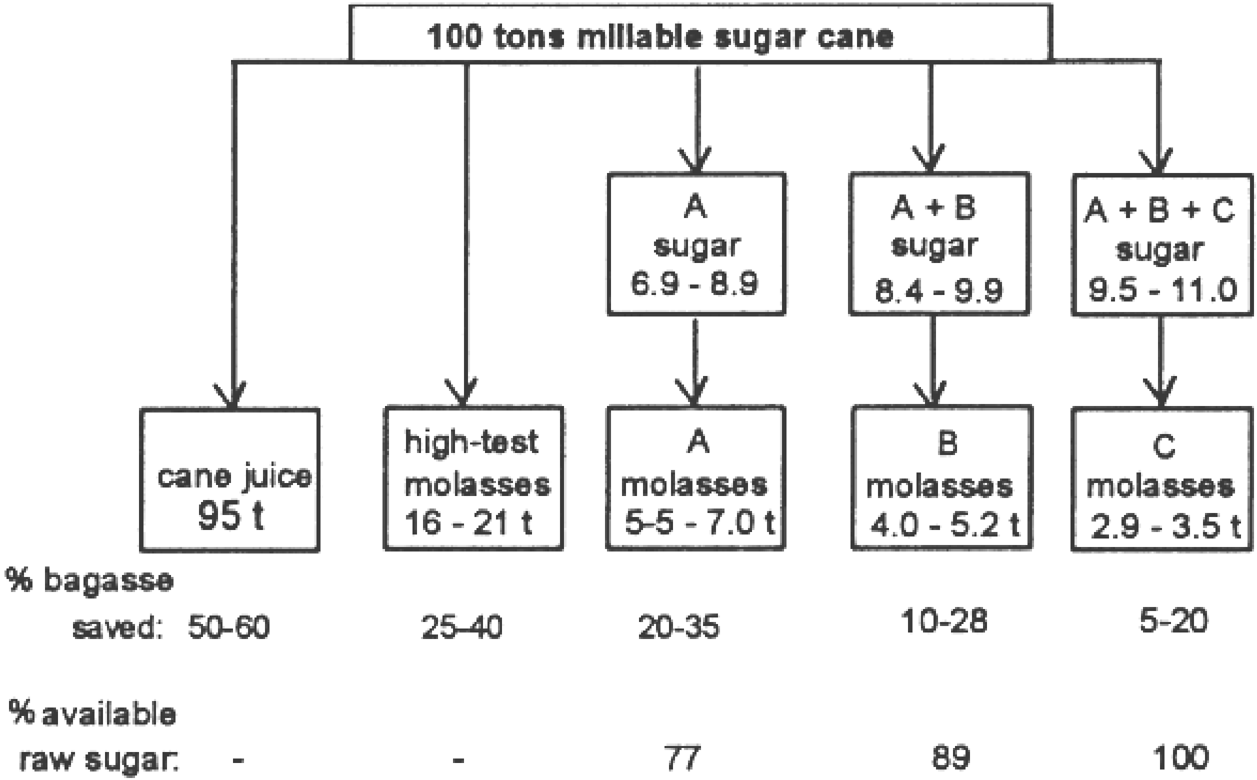
Raw sugar, processed to white or refined sugar, produces a residue called “refinery final molasses”, similar to C molasses. The amount is insignificant and generally if the refinery is part of the sugar factory it is simply deposited in the C molasses tanks. The entire process for the production of raw sugar, from start to finish, requires 20–28 hours.

PRODUCTION ALTERNATIVES FOR A SUGAR FACTORY

The following diagram shows the five alternatives, together with average yields, when 100 tons of millable cane enters a traditional raw sugar factory (Figure 3.1.). Four tons of bagasse has been considered the thermal equivalent of one ton of fuel oil.

This fact has been emphasized due to the potential use of bagasse to generate electricity.

Fig. 3.1. Schematic representation of 100 tone of millable cane in a sugarmill (Pérez 1990).



The first alternative is the production of diluted cane juice of 15 to 19% dry matter, depending on the stage of the harvest and the

amount of water added during the grinding process. If the sugar mill is used exclusively to produce diluted juice then the amount of surplus bagasse would be between 50 and 60% of the total amount needed to produce the vapor for a traditional factory. In a non-industrial operation (simple crusher), 100% of the pressed cane stalk (bagasse), together with a significant amount of residual cane juice, would be available for small ruminant feeding (Preston, 1990a; Vargas, 1993), as fertilizer or a fuel (Preston and Murgueitio, 1992).

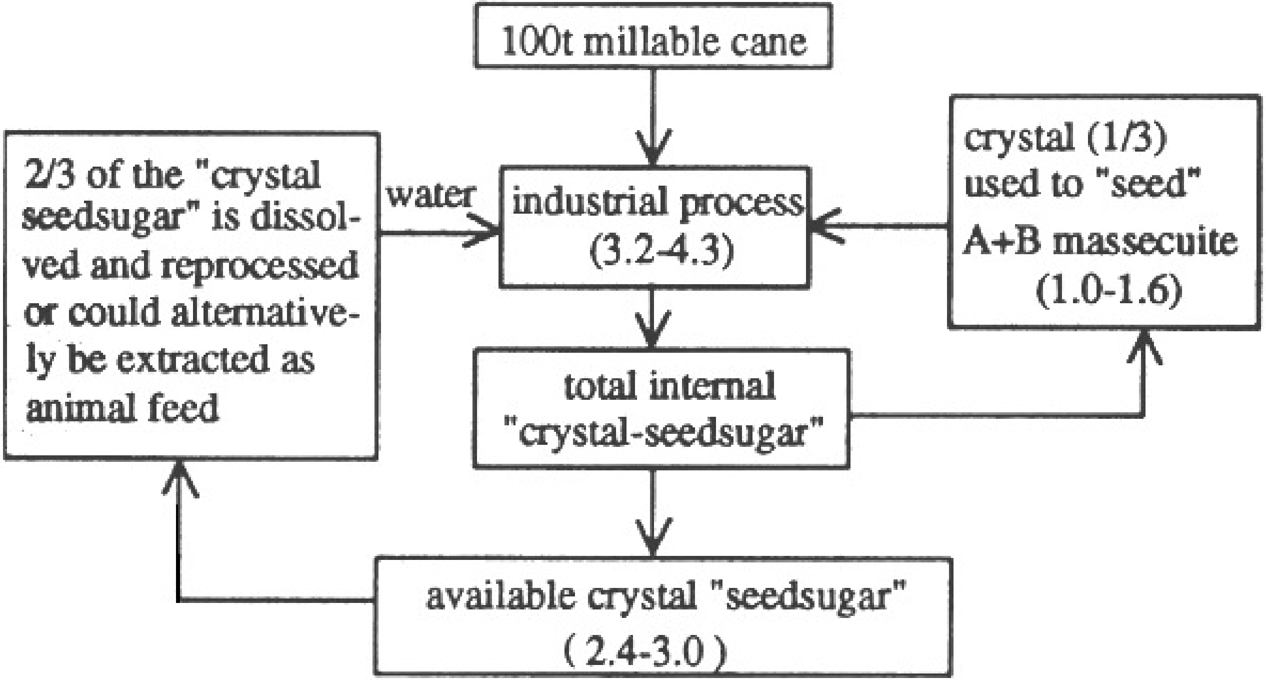
The second alternative is the production of high-test molasses which is clarified and partially inverted concentrated cane juice. This option would save between 25 and 40% of available bagasse, which as earlier emphasized might be used to generate electricity. High-test molasses can completely replace cereals in liquid diets for pigs and has been used for this purpose when market conditions and/or tariffs have blocked the commercialization of raw sugar.

The third alternative is the production of raw sugar A, about 77% of available raw sugar, together with type A molasses. This alternative could save between 20 and 35% of the total amount of bagasse produced. If stored, the A molasses would have to be partially inverted to avoid crystallization. Inversion requires the addition of 0.5 kg/t of hydrochloric or sulphuric acid followed by mixing for 30 minutes, and finally neutralization with lime. Type A molasses still contains a considerable amount of commercial raw sugar, therefore, although it has been increasingly promoted for the experimental feeding of pigs (see below) it has not, as yet, been utilized as an important energy resource for commercial livestock production.

The fourth alternative is the production of commercial A and B raw sugar, some 89% of the total available raw sugar, and B molasses which does not frequently crystallize. This option saves 10 to 30% of the total bagasse needed to run the factory and was the alternative first developed in Cuba for commercial

pig feeding systems (see below).

Figure 3.2. Schematic representation of the internal production of "crystal seed-sugar".



The fifth alternative, that which is normally done in a traditional raw sugar factory, is the production of A and B commercial sugar and non-commercial C sugar, also known as low-grade or crystal seed-sugar, and C or final molasses. Low grade sugar has been studied as a complete substitute for cereals in fattening rations for swine (see below). The removal of excess crystal seed-sugar would improve the overall thermal balance in a traditional raw sugar factory, where normally only 5 to 20% of the bagasse is not needed to produce vapour. The only drawback to using C sugar as a feedstuff would be the need to remove some water; at this stage it contains between 2 and 4% moisture. However, this could be easily remedied by mixing the crystal seed-sugar immediately upon leaving the centrifuge with the other dry components of the ration (Fig. 3.2).

PRODUCTION ALTERNATIVES FOR SUGAR CANE CRUSHERS

Approximately 12% of all raw sugar for human consumption is

produced in simple sugar cane crushers (FAO, 1992). These crushers could be used to obtain juice to feed pigs and other livestock. Cane juice, extracted in this way, contains approximately 10 to 13% more total sugars compared to factory juice, principally because no water is added. However, because less pressure is applied and no water added, the extraction rate is only half that of a sugar factory (Table 3.1).

OPTIONS FOR USING SUGAR CANE AS FEED FOR PIGS

Development of a sugar cane juice feeding system

One of the first countries to publish promising results related to cane juice as a partial or complete replacement for cereals in swine diets was Brazil (De Felicio and Speers, 1973). Subsequently, research in Mexico (Preston, 1980; Mena, 1981), and further studies in the Dominican Republic (Fermín, 1983; Fernández, 1985), alerted other tropical countries to this new

development (FAO, 1988). In fact, Mena (1987) reported that by the end of 1986, ten thousand pigs in the Dominican Republic had been fattened on cane juice as a substitute for imported maize.

In Mexico, the initial investigative work on the use of sugar cane juice for pigs used fortified soya bean meal to meet protein requirements as established by the National Research Council (NRC, 1979) at that time. For that, three groups of pigs with an average initial weight of 40, 50 and 60 kg were fed until 90 kg liveweight free-choice cane juice and 0.77, 0.81 or 0.96 kg/day of a 40% crude protein supplement. The pigs in each group, until slaughter, consumed 308, 324 and 384 g of protein daily, an average saving of 20% of the then prevailing NRC requirement (NRC, 1979). The control diet was a mixture of sorghum and soya bean meal. The average daily gains and feed conversions of the pigs on the cane juice treatments were 20 and 25% superior to that of the cereal control, respectively (Mena, 1981).

In the Dominican Republic, Estrella *et al.* (1986) promoted a cane juice feeding system in an attempt to produce lard, normally imported. For that study, three groups of finishing pigs were fed fresh cane juice and different amounts of a protein supplement: 180, 270 or 360 g/day. Surprisingly, the pigs in each group grew at approximately the same rate (Table 3.3: Exp.1). Following that, similar trials were carried out in Colombia using concentrated scums, a waste product from the production of pan sugar. The results (Table 3.3: Exp. 2) supported those of studies previously cited from Mexico and the Dominican Republic, that pigs fed *ad libitum* sugar cane juice grew well, if not optimally, with approximately one-half the amount of protein provided in cereal feeding systems (Moreno *et al.*, 1989, cited by Sarria, 1990).

To emphasize this essential point: the daily amount of protein currently recommended by NRC for pigs between 50 and 100 kg, fed *ad libitum* a 13% crude protein, air-dry, cereal diet, is 404 g. The expected average daily gain is 820 g; the air-dry feed intake

is calculated as 3.11 kg and the air-dry feed conversion as 3.79 (NRC, 1988). The figures for daily feed intake and feed conversion, adjusted to 90% dry matter, would be 2.8 kg and 3.41 respectively (Table 3.3).

In conventional cereal diets, 50% of the protein needs are supplied by low amino acid-profile cereals, equivalent to approximately 70% of the formula. The protein requirement is achieved through animal or vegetable protein supplementation, at a level of about 30%, the remaining portion of the diet. However, in the case of cane juice diets, all of the protein must come from an outside source, which could mean a superior amino acid balance (Speedy *et al.* 1991).

Table 3.3. Comparison of NRC guidelines with the performance of pigs fed different amounts of a 40 % protein supplement and either free-choice sugar cane juice (SCJ: Exp 1) or free-choice concentrated scums (CS: Exp 2).

		Experiment 1	Experiment 2

Parameters	NRC[a]	Experiment 1 (SCJ)[b]			Experiment 2 (CS)[c]		
Initial liveweight, kg	50	76	77	78	24	25	30
Final liveweight, kg	110	105	106	107	85	81	98
ADG, g	820	838	840	830	622	736	670
Protein suppl., kg AD/d	-	0.45	0.68	0.90	0.47	0.52	0.66
DM intake, kg/d	2.80	3.98	3.61	3.57	2.80	2.50	3.10
DM feed conversion	3.41	4.75	4.51	4.27	4.15	3.96	4.15

Sources: [a] NRC (1998); [b] Estrella *et al*. (1986); [c]Moreno *et al*. (1989), cited by Sarria (1990)

A "sugar cane juice feeding system" has developed: it refers to growing/finishing pigs fed free-choice sugar cane juice and a restricted amount of high-quality protein (approximately 200

g/day) generally obtained from 500 g of a soya bean meal-based supplement, preferably fortified with minerals and vitamins (Moreno *et al.*, 1989; Preston, 1990b; Sarria *et al.*, 1990). This same feeding system has now been successfully promoted in Southeast Asia (Van and Men, 1992) and in Africa (Speedy *et al.*, 1991). In Cuba, apart from soya bean meal, 500 g of dry torula yeast has been used (Table 3.4).

Table 3.4. Performance of pigs fed a restricted protein supplement and free-choice sugar cane juice

Region	Liveweight range (kg)	ADG (g)	Country and source
Asia	14.6–70.0	460	Philippines: FAO (1991)
	9.4–91.2	495	Vietnam: Van and Men (1992)
Africa	24.2–89.5	7.32	Swaziland: Speedy *et al.* (1991)

Latin America	49.3–91.2	729	México: Mena (1981)
	16.2–91.0	775	Dom. Republic: Fernández (1988)
	25.0–91.0	640	Colombla: Sarria *et al.* (1990)
	25.0–85.0	710	Trinidad/Tobago: FAO (1992)
	25.0–90.0	637–660	Cuba: IIP (1991)*

*** best gains for 32,000 pigs at 5 different locations fed 0.8 kg/day soya bean meal and free-choice cane juice**

Fresh sugar cane juice: farrow-to-finish herd

One of the first references to a swine reproductive herd, fed either fresh sugar cane juice and a restricted protein supplement or a cereal-based commercial ration, referred to the performance of both gestating and lactating sows (Estrella *et al.*, 1984). The confirmed pregnancy rate (85.7 vs. 92.0%) and the piglet average birth weight (1.38 vs. 1.47 kg) was higher on the cane juice feeding system, whereas the average number of live piglets born per litter was lower (8.28 vs. 10.09). Similarly, Piña (1988), reported stronger, more vigorous piglets at birth, and sows that produced more milk and lost less weight during lactation when one month prior to farrowing fresh cane juice (7 kg/day) was added to their other rations.

In Cuba, a 300-sow, farrow-to-finish herd, with a daily average of 3,000 pigs was fed factory-produced fresh juice during the cane harvest season and diluted syrup-off or B molasses during the non-cane season. The protein supplement was soya bean meal (Table 3.5). After a period of six to eight months the following

differences in the reproductive herd production parameters were noted: an 8 percent improvement in the farrowing rate (natural service); an increase in the average number of live births per litter (8.6 to 9.3); an increase both in the average live piglet birth weight (0.9 to 1.3 kg) and the 33-day weaning weight (5.0 to 6.8 kg), and most importantly, an average reduction of five days in the weaning to service interval, one of the most difficult indices to improve in a swine reproductive herd, particularly in the tropics. With respect to the productive herd, the average liveweight for age at slaughter increased monthly, during a period of four months, from 79, 83, 94, to finally 102 kg at six months (MINAZ, 1990). This same final liveweight for age on a sugar cane juice feeding system, 100 kg at six months of age, was also reported in the Dominican Republic (Piña ,1988).

The 300-sow, farrow-to-finish herd referred to in Table 3.5 required approximately 20 tons of juice per day. As earlier mentioned, when sugar factory juice was unavailable due to

shutdowns for maintenance, prolonged rainy periods, or during the non-harvest season, either diluted B molasses or syrup-off, mixed with three parts water and called "reconstituted cane juice" was used. It was observed that in order to optimize the seasonal opportunities for factory-produced juice, the reproductive herd might be bred to farrow mostly at the beginning of the dry, cane harvest season. This would allow for the majority of pigs to be fattened on the fresh juice, with slaughter at the end of the harvest. In this way, only a skeleton reproductive or maintenance herd would have to be fed during the wet, non-cane season and this could be more easily accomplishied using "reconstituted cane juice". The unusual growth potential of pigs fed sugar cane juice, between 650 and 700 g/day, as opposed to approximately 500 g/day for most types of molasses systems could mean a weekly net saving of 0.75 kg of protein supplement per head (see Tables 3.13, 3.15).

The feed calculation for a 300-sow, farrow-to-finish unit is

presented in Table 3.5.

Table 3.5 Feed calculation (AD) for a 300-sow, farrow-to-finish swine unit based on: sugar cane juice [a] (SCJ), a protein supplement[b] (PS) and "soya-sugar"[c] (90 kg at 26 weeks).

Category	head x day	Kg/head/day		Kg/day		Tons/year	
		PS	SCJ	PS	SCJ	PS	SCJ
Boars	22	0.5	8	11	176	4	64
Sows:open	24	0.5	10	12	240	4	88
Sows:bred (confirmed)	75	0.5	10	38	750	14	274
Sows:gestating	143	0.5	11[d]	73	1573	27	574
Sows:lactating	60	1.5	18	90	1080	33	394
Piglets 33-day weaning (5w)	530	0.05[c]	-	27[c]	-	10[c]	-
1st stage weaners: 33-60d (4w)	389	0.45[c]	-	175[c]	-	64[c]	-

2nd stage weaners: 60-90d (4w)	389	0.5	5	195	1945	71	710
Grower/finishers: 90-180d (13w)	1165	0.5	12	583	13980	213	5103
Total	2797			1002	19744	366[d]	7207

Source: Pérez (1993); [a] fresh or reconstitued juice; [b] fortified soya bean meal or torula yeast; [c]"soya-sugar," a 16% CP in DM seedsugar-based dry ration for piglets and weaners to 60 days (see 3.3.3.3); [d]because the gestating sows receive 14 kg during last month, use 11 kg for calculation; protein supplement only

An analysis of the data shows that:

- **The annual, herd-average dry matter feed requirements are: 1693 t (the soya-sugar and protein supplement contain 90% dry matter; the juice contains an average of 18% dry matter).**

- **The daily, herd-average air-dry feed needs are: 0.2 t soya-sugar, one ton of protein supplement and 20 tons of juice.**

- **Each sow and all progeny, generally referred to as the "sow-reproductive-unit", consumes annually, in air-dry: 1.2 t protein supplement and 24 t of cane juice. Theoretically, if this 300-sow, farrow-to-finish herd produced 400 t liveweight yearly, each ton of liveweight would require in air-dry: 0.91 t protein supplement and 18 t of juice.**

- **The herd-average dry matter feed conversion is 4.23, that of the productive herd is calculated as 3.42.**

- **The daily herd-average air-dry feed intake is: 0.38 kg protein supplement and seven kg of cane juice. The calculated average daily gain from farrow-to-finish is 490 g (See Table 1.5).**

For pigs unaccustomed to a sugar cane juice feeding system, the growing/finishing period might require three to four additional weeks. This is partly due to the need to adjust to the new diet. The following data (Table 3.6) suggest that each pig would require 60 kg of protein supplement and 1.3 t of juice. In either case, the daily protein supplement should preferably be given in two equal portions (Ly and Muñiz, 1979; Cervantes *et al.*. 1981).

Table 3.6. Guidelines for feeding growing/finishing pigs (25–100 kg) a restricted protein supplement (500 g/day) and sugar cane juice (SCJ).

Week	SCJ	Week	SCJ	Week	SCJ	Week	SCJ
1	6.0	6	9.0	11	12.0	16	15.0
2	6.5	7	9.5	12	12.5	17	16.0
3	7.5	8	10.0	13	13.0	total kg	1291.5
4	8.0	9	11.0	14	14.0	kg/day	10.8
5	8.5	10	11.5	15	14.5		

Source:adapted from Preston and Sansoucy (unpublished data)

Sugar cane juice generally ferments within 12 hours, however, it can be preserved for up to three days using either 0.01 to 0.06% formalin (formaldehyde at 30% concentration) or sodium metasilicate at 5 to 7 g/l (Larrahondo and Preston, 1989), and or up to seven days with 0.15% sodium benzoate (Bobadilla and Preston, 1981). Mena (1988) recommended a 40% formaldehyde solution used at the rate of 0.04 v/v, while Duarte (1981) reported using 28% of aqueous ammonia wt/vol at 1.5 percent. Due to the high cost of chemical preservatives and the need to preserve fresh juice, particularly over the weekend, the use of certain macerated leaves have been studied (Larrahondod and Preston, 1989).

Concentrated sugar cane juice (sugar cane syrup)

For small-scale cane producers, who perhaps raise one or two pigs and have access to a cane crusher, the idea of feeding sugar cane juice is attractive but often too time consuming. Two pigs require 20 kg of juice daily and, although this amount could be obtained from 50 kg of clean stalk, the daily effort to cut, carry, perhaps hook up the water buffalo or oxen, or start an engine, to grind such a small amount of cane often negates the practicality of the entire feeding system. Sometimes a farmer has access to a local crusher and only needs a way to preserve some juice. An FAO Technical Cooperation Project in the Philippines found that some farmers preferred to evaporate (boil) the fresh juice, place the resultant syrup in a covered drum alongside the pig pen and reconstitute this syrup with three parts of water whenever the pigs needed to be fed (FAO, 1991).

In a feeding trial to compare the performance of pigs given 0.5 kg of soya bean meal daily and either C molasses, fresh muscovado scums (see below) or concentrated cane juice (reconstituted),

most farmers defended the concentrated cane juice system. The C molasses had to be purchased and muscovado scums were available only six months of the year, besides, most farmers preferred to feed them to their water buffalos. For these farmers, an average daily gain of 450 g with concentrated juice/soya bean meal was an excellent system considering the initial liveweight (Table 3.7) and the fact that growth performance was double that obtained on the previous diet of kitchen scraps and forages.

Table 3.7. Performance of growing pigs fed sugar cane syrup, muscovado scums and C molasses in the Philippines.

	Liveweight range (kg)	ADG (g)	DM feed conversion
Sugar cane syrup	12.0–68.0	450	5.33
Sugar cane syrup	14.6–70.0	460	5.23
Muscovado scums	12.0–69.0	430	6.57

C molasses	22.0–70.0	400	6.80	

Source:FAO (1991)

Protein-enriched (fermented) sugar cane juice "Protein-enriched" sugar cane juice was first described by Diaz *et al.* (1992). Fresh cane juice was fermented with one percent urea during 12 hours. Oxygen was incorporated at hourly intervals and formaldehyde was added (2 cc/kg) to preserve the fermented product. It was reported that the fermented juice of 10% dry matter contained 22% crude protein and 13.0 MJ of digestible energy/kg, both in dry matter. Weaned piglets were used to compare restricted feeding systems in which 20 or 30% of protein-enriched cane juice replaced ground wheat (Table 3.8). The authors concluded that the poorer results from the experimental diets might have been due to a lack of fish meal. They also stated that certain symptoms of drunkenness were probably related to the formation of alcohol due to inadequate fermentation.

Table 3.8. The use of protein-enriched sugar cane juice (PESCJ) for weaned pigs (% DM)*

	0% PESCJ**	20%PESCJ	30% PESCJ
Protein-enriched cane juice	-	20.0	30.0
Soya bean meal	14.0	24.9	22.5
Ground wheat	51.0	29.9	22.5
ADG, g	209	171	169
DM feed conversion	2.77	3.39	3.26

Source: Diaz *et al.* (1992); * all diets contained 20% rice polishing and different proportions of micro/macro elements; ** contained 8.7% fishmeal and 2.7% yeast

CANE MOLASSES C molasses has been recommended as an additive to improve the palatability of dry rations, and particularly in cane-producing countries, as an addition to concentrate or

swill-based rations at levels up to approximately 30 percent (Buitrago *et al.*, 1977; Preston, 1982). Higher levels have generally not been recommended. The reasons have been; difficulties in handling and mixing; loose feces associated with diarrhoca; dirtier animals and floor pens, and most importantly, an increasingly inferior feed conversion as higher levels of molasses were used (Preston *et al.*, 1968; Velázquez, 1970; Castro, 1976). In summary, certain physiological constraints inherent in C molasses support poor pig performance (Chapter 1).

The fact that large ruminants in Cuba had been successfully fed diets in which C molasses made up 70% of total dry matter (Preston *et al.*, 1967) led to the experimental (Velázquez *et al.*, 1978), and finally commercial practice (MINAG, 1982) of the use of high levels of C molasses for all categories of swine (Table 3.9). This was followed by the first use of another type of molasses, type B, for wide-scale, commercial pig production

(Perez *et al.*, 1982; Pérez, 1988).

Table 3.9. The use of molasses [a] in swine feeding systems in Cuba.[b]

Category	Feeding system (kg air-dry/day)	Molasses, % total DM
Sows:bred, confirmed and gestating	1 kg 22% protein supplement plus 2 kg molasses	64
Grower/finishers (25–90 kg): swill[c]	9 kg processed swill plus 0.86 kg dry commercial feed	33
Protein molasses[d]	6.7 kg of a mixture of B molasses and torula yeast cream	70
Protein supplement + molasses	1.8 kg protein supplement plus 1.8 kg molasses	47

[a]converted from C to B molasses in the 1980s; [b]100 thousand sows and 500 thousand grower/finishers; [c]processedorganic wastes, molasses and water (20%DM);[d]contains 36%DM

There have been many attempts to ameliorate certain of the aforementioned negative effects associated with feeding pigs high levels of C molasses. For example, Brooks and Iwanaga (1967) proposed the use of bagasse pith and fat, while Preston *et al.* (1968) suggested the addition of raw sugar. Combinations of high-test and C molasses were studied by Marrero and Ly (1976); in the end, they questioned its "doubtful practicality". Castro and Elias (1978) even recommended using low levels of the mineral zeolite.

Molasses, commonly used as a source of energy, contains approximately 80% of the energy of cereals (Table 1.1). It is practically free of fat and fibre, has low nitrogen content and the

amount of ash fluctuates between nine and thirteen percent of dry matter. The nitrogen-free-extract, the main fraction representing between 87 and 95% of total dry matter, is composed of a mixture of simple sugars (62 to 70%) and non-identified organic matter (19 to 24%). The latter has an apparent digestibility of only 51 percent (Ly 1989).

According to the results of several recent studies, it is the increasing amount of this non-identified organic matter in each successive type of molasses, from A to C, that determines the nutritional value of molasses. The amount (% dry matter) of this substance in each type of Cuban molasses is: high-test, 4 to 6%; A molasses, 8 to 14%; B molasses, 12 to 17%; and C molasses, 19 to 24% (Table 3.1). This could be partially related to the fact that mechanically-harvested sugar cane, which in the case of Cuba represents 70% of total cane, contains a higher level of extraneous material which is reflected in the molasses.

In addition, during the process of producing industrial raw sugar, various chemical substances are added, such as; electrolytes, formaldehyde, sulphur dioxide, hypo-chlorides, sodium bi-sulphite, as well as several tenso-active compounds. The concentration of these substances, which increases from A to C molasses, might possibly affect metabolism, and therefore, swine performance.

During 20 years, researchers, mostly from Cuba, have systematically studied the performance of pigs fed high levels of molasses (Figueroa and Ly, 1990; Diaz and Ly, 1991). As an example of their hypothesis, finishing pigs fed a daily average of 2.75 kg of dry matter, particularly where C molasses constituted 60% of the ration, received 14% of their daily ration in the form of non-identified organic matter. A further 10% of ash in the C molasses would mean that 20% of the daily ration was non-identified organic matter and ash. Undoubtedly, the performance data presented in Tables 3.13 and 3.15 reflect this situation.

It was finally decided that from the point of view of both animal and sugar mill performance, it would be better to change to B molasses. This meant that in 1989. over 400,000 t of B molasses were extracted for pig production from 37, of the then functioning 156 sugar mills, and C molasses was left for ruminants. The following description of the study of different types of molasses for pig feeding attempts to focus on this most interesting experience.

Integral molasses

Integral molasses is produced from unclarified sugar cane juice which has been partially inverted to prevent crystallization, then concentrated by evaporation to approximately 85% dry matter. Because unclarified juice is used, the evaporative process produces heavy encrustations and scum deposits that can lead to frequent mill breakdowns. Velázquez and Preston (1970) compared integral and high-test molasses as basal energy

sources for pigs; they used two levels of fishmeal. There was no significant difference in feed conversion between energy sources, and it was concluded that the lowered growth performance with integral molasses might have been due to a reduction in voluntary intake. This hypothesis confirmed an earlier observation by MacLeod *et al*. (1968) that the lack of difference in average daily gain between two protein levels in high-test molasses diets (12.6 and 16.2%) might have meant that when fishmeal was used as a protein supplement, the protein requirement was lower compared to that of a cereal feeding system (Table 3.10).

High-test molasses

High-test molasses is clarified, partially inverted, concentrated cane juice from which sucrose has not been extracted (Table 3.1). Perhaps for this reason, and also because in most cane sugar-producing countries pig production has remained

independent of the sugar industry, the commercial use of high-test molasses for feeding pigs has not been practised.

Table 3.10. Performance of growing/finishing pigs fed basal diets * of integral or high-test molasses and two levels of fishmeal (FM), % DM.

	Integral molasses		High-test molasses	
	24% FM	18% FM	24% FM	18% FM
Initial liveweight, kg	29.6	29.6	29.6	29.4
Final liveweight, kg	78.9	75.3	80.8	80.5
ADG, g	476	541	609	605
DM intake, kg/d	1.73	2.03	2.19	2.37
DM feed conversion	4.15	3.82	3.80	4.12

Source: Velázquez and Preston (1970); * all diets contained 3% *Saccharomyces* yeast and 2% macro/micro elements

Recently, Pérez (1993) suggested that one way to maximize protein efficiency for the production of pigs would be to use fresh juice during the cane harvest season and diluted high-test molasses during the non-cane harvest season. The data in Table 3.11, particularly the superior results of high-test molasses as the only energy source, support this idea: the substitution of only 15% high-test molasses by C molasses reduced the average daily gain by 15% (almost 100 g/day), as well as increased the dry matter feed conversion by more than five percent. High-test molasses, compared to C molasses, contains a minimum of non-identified organic matter; this must favor the digestibility of the diet (Chapter 1), and thus the dry matter feed conversion.

Table 3.11. Performance of pigs (32-90 kg) fed ad libitum diets * of different proportions of high-test/final (C) molasses and a protein supplement.

High-test molasses, % DM	75	60	45	30	15

C (final) molasses, % DM	0	15	30	45	60
ADG, g	655	559	532	507	519
DM intake, kg/d	2.66	2.41	2.67	2.54	2.56
DM feed conversion	4.09	4.32	5.12	5.06	4.99

Source: Marrero and Ly (1976); * all diets contained: 21% fishmeal, 2.5% saccharomyces yeast and 1.5% mineralsand vitamins.

A molasses

One of the first references to the use of A molasses in animal feeding referred to its use in processed swill for fattening pigs where it was compared to C molasses under commercial conditions. A mixture in dry matter of 40% processed swill and 60% type A molasses produced an improvement of 15% with respect to final liveweight (Pérez, 1975). Following that trial, A

and B molasses were compared to C molasses under experimental conditions, where the different types of molasses represented 69% of dictary dry matter. The protein supplement was a mixture of fish meal, soya bean meal and torula yeast. The average daily gain for three groups of pigs of average initial liveweight of 25 kg fed the A, B and C molasses was: 638, 715 and 586 g/day, respectively. The higher concentration of sugars and the lower concentration of ash and non-identified organic matter were indicated as the factors responsible for the improved performance of the A and B molasses diets (Figueroa *et al.*, 1983).

A total of 160 pigs with an average initial liveweight of 25 kg was used to compare the performance of growing/finishing pigs fed four types of cane molasses: high-test, A, B and C molasses produced in the same factory (Cervantes *et al*., 1984). The sugar factory also produced torula yeast cream. The diets were a mixture of approximately 70% molasses and 30% torula yeast

cream in dry matter (Table 3.12). The authors concluded, that "the results pointed out the disadvantage of continuing to use C molasses for pigs ".

Table 3.12. The use of high-test, A, B and C molasses as energy sources in liquid diets * for growing/finishing pigs (% DM).

	High-test	**A molasses**	**B molasses**	**C molasses**
Energy source	69.0	68.9	69.5	70.2
Torula yeast cream	30.2	30.3	29.7	29.0
ADG,g	572	558	530	414
DM feed conversion	4.10	4.30	4.50	5.70

Source: Cervantes *et al*.,(1984); * all diets contained 0.4% of salt and 0.4% of micro/macro elements

In Victnam, A molasses was used at an air-dry level of 55% to replace a mixture of broken rice and rice bran for pigs of

between 50 and 80 kg. The average daily gain was slightly lower (551 vs. 538 g), as was the daily dry matter feed intake (2.06 vs. 1.84 kg), however, the dry matter feed conversion was better (3.74 vs. 3.42) for the group fed A molasses (Van and Men, 1990). In a second experiment, either A molasses or sugar cane juice completely replaced cereals for pigs weighing between 9 and 80 kg. The average daily gain (g) and dry matter feed conversion on the A molasses, cane juice and the cereal control treatments were, respectively; 430, 4.02; 495, 3.88 and 473 and 3.33 (Van and Men, 1992).

B molasses

In Cuba, over a period of 15 years, a pig feeding system gradually developed based on processed organic wastes, C molasses and concentrates. By 1980, the daily ration for almost five hundred thousand pigs from 25 to 90 kg was 2.4 kg/day (dry matter) of a mixture of processed swill and molasses, and

supplementary concentrates, (MINAG 1982). In this way, processed swill, C molasses and concentrates, of 20, 80 and 90% dry matter respectively, represented approximately 37,33 and 30% of total daily dry matter consumption (see Chapter 6).

Performance was generally poor and since the results of several observation trials had shown the superiority of B molasses, it was decided to immediately extend those results to a commercial feedlot of 17,000 head. There, an experimental group of 220 pigs during a 92-day trial, showed a net liveweight difference of 12 kg in support of the use of B as opposed to C molasses. It was also observed that in addition to the difference in liveweight, the pigs ate their ration faster and did not leave any residues in the through as when C molasses was fed. Interestingly, the diarrhea-like symptoms subsided, the feces were harder. This meant that less water was needed to maintain pen hygiene and animal cleanliness. It was also observed that culling due to lameness and other hoof problems gradually subsided; this was attributed

to the need for less water for cleaning and the dryer floor pens (Pérez *et al*., 1982).

Performance data summarized in Table 3.13 indicate a certain advantage to the use of B molasses (89% of available sucrose extracted), even when compared to high-test molasses. This could be partially due to the fact that the former contains less free, poorly-digested fructose (Chapter 1).

Table 3.13. The use * of high levels of cane molasses for growing/finishing pigs (% DM).

Type of molasses	% DM in diet	Liveweight (kg)	ADG (g)	DM feed conversion	Source
Integral	77	30–75	541	3.82	Velázquez and Preston (1970)
High–test	74–80	30–150	602	3.96	Velázquez *et al.* (1972)
					Marrero and Ly

	75	32–90	655	4.09	(1976)
	80	60–90	693	4.04	Ly and Castro (1984)
A molasses	60	30–85	524	-	Pérez (1975)
	69	25–90	558	4.30	Cervantes *et al.* (1984)
	69	25–90	638	-	Figueroa *et al.* (1983)
	55	50–78	538	3.42	Van and Men (1990)
B molasses	69	25–90	715	-	Figueroa *et al.* (1983)
	70	25–85	530	4.50	Cervantes *et al.* (1984)
	72	30–90	742	4.23	Figueroa (1991)
C molasses	60	32–90	519	4.99	Marrero and Ly (1976)

	63	31–88	459	6.38	Castro *et al.* (1981)
	70	25–71	414	5.70	Cervantes *et al.* (1984)
	83	60–90	540	5.00	Ly and Castro (1984)

[*] note: experimental results; if applied commercially reduce overall performance by about 15%

One of the most difficult problems encountered in commercial pig production in the tropics relates to the presentation of estrus, particularly during the hot and humid summer months (Tomes and Nielsen, 1979). In Cuba, Arias and Perez (1985) studied during two summer months the reproductive performance of four groups of weekly weaned sows, a total of 90

sows per group, fed to service or up to a maximum of ten days post-weaning, one kg of a 22% protein supplement and two kg of either C or B molasses, or only concentrates. Immediately after service, and until farrowing, all the sows were fed protein supplement and C molasses, the feeding system used at that time for all open and gestating sows in that country. During lactation concentrates were fed. Both the farrowing rate and the weaning to service interval improved with the use of B molasses (Table 3.14).

Table 3.14. Reproductive indices of sows * fed during 10 days post-weaning: a restricted protein ** supplement (PS) and either C molasses (CM), B molasses (BM) or concentrate ration (CR), kg AD/day.

	1 kg PS + 2 kg CM	1 kg PS + 2 kg BM	CR 2.5 kg	CR ad lib
Presentation estrus to 9 d post-weaning, %	57.8	64.4	64.4	80.2

Farrowing rate, %	75.0	84.2	74.1	73.9
Weaning to service interval, days	6.3	5.7	6.7	6.3
Piglets born: total vs. live	9.0–8.4	8.6–8.2	9.3–8.8	9.2–8.6

Source Arias *et al.* (1985); * a total of 356 sows in 4 treatments fed once daily during July/Aug in Cuba; ** 22% CP in DM

The effect of feeding a restricted protein supplement and C or B molasses during two consecutive reproductive cycles was subsequently studied in two groups of sows of similar weight by Lan *et al.* (1986). During an average 33-day lactation, both groups were fed concentrates. At the end of the second reproductive cycle, the group fed B molasses weighed an average of 152 kg compared to 133 kg of the C molasses-fed

group. A similar difference was reflected in the piglets. At 21 days of age, the average weight difference in favor of the piglets whose mothers had been fed during gestation a protein supplement, and B rather than C molasses, was 0.5 kg. At weaning this difference was 0.7 kg, some 11% superior to the piglet weaning weight of 6.2 kg obtained from sows fed the C molasses system. In addition to growth performance, Pérez (1988) reported that when B molasses replaced C molasses in the reproductive herd (see Table 3.9) the farrowing rate, measured the same month the following year and with data from eight thousand sows, improved from 75 to 82 percent.

Finally, in a review of nine publications related to the reproductive performance of sows fed high levels of C molasses, Velazquez and Diaz (1989) pointed out, that the average net liveweight gain of sows fed high levels of C molasses during gestation was only 15.4 kg, compared to a net loss during lactation of 17.5 kg. All of these results were incorporated into

Cuba's swine feeding program which at that time meant 100,000 sows and progeny, approximately one million animals. The revised guidelines of the new feeding program were:

- **upon weaning, and until presentation of estrus and service, sows would remain on concentrates;**
- **after service, sows were to be fed a restricted protein supplement, but B rather than C molasses; and**
- **C molasses was replaced by B molasses in all growing/finishing diets using: processed swill or a protein supplement and molasses (Table 3.9).**

C molasses

This section on molasses would not be complete without a discussion of the information contained in Table 3.15 which compares the performance and the behavior of pigs fed ad

libitum maize, high-test or C molasses diets (Ly and Castro, 1984). The authors confirm an earlier observation of Preston *et al.* (1968) that for pigs maize is superior to high-test molasses, which in turn is superior to C molasses. They also suggested that in the case of liquid molasses diets, perhaps the classic approach to animal nutrition does not apply; that is, since molasses diets contain less energy per unit of dry matter, the pigs should have compensated by eating more, however, the reverse seems to be the case. The pigs on the C and high-test molasses diets consumed 86 and 89%, respectively, of the total dry matter intake of the maize diet.

Other observations related to this phenomenon, but during the first stage of growth from 50 to 60 kg, and using torula yeast instead of fishmeal as the only source of protein, have shown that in some cases voluntary feed intake increases during the first stage, but that eventually feed consumption decreases, leading to an overall "normal" pig performance (Figueroa *et al.*,

1988; Maylin *et al.*, 1989). It has also been noted that with sucrose or molasses-based diets the pattern of feed intake is modified due, perhaps, to the concomitant metabolic acidosis from fructose in the diet (see Chapter 1).

The pigs on the C molasses diet, upon receiving their ration and during the first hour, ate 13.8 times and drank water 13 times. The authors suggest that this unusual water drinking pattern, also reported by Marrero and Ly (1977), might have influenced voluntary intake. Called "osmotic shock" by Figueroa *et al.* (1983), this phenomena perhaps explains the low dry matter content of the feces, 16% as compared to more than 30% on either the maize or high-test diets, as well as the diarrhoea-like symptoms of pigs fed high levels of C molasses.

Table 3.15. Comparison of maize, high-test and C molasses free-choice diets * for finishing pigs from 60–90 kg (% DM).

	Maize		

		High-test	C molasses
Energy source, % DM in diet	89.0	80.0	83.30
Fishmeal	6.0	16.0	13.70
ADG, g	791	693	540
DM feed intake, kg/d	3.13	2.80	2.70
DM feed conversion	3.96	4.04	5.00
Energy: kcal/g DM	4.35	4.00	3.85

Measurements during first hour of an once-daily, 8 am, ad libitum feeding:

D M feed intake, % of offer	59.6	42.7	31.7
Feed intake, g/pig: AD/DM	1956/1765	1573/1255	1110/926
Times seen: eating/drinking	2.8/2.5	10.8/10.8	13.8/13.0
Time spent eating, min.	13.3	25.0	25.8
Velocity of ingestion, g AD/min.	148	64	44

Digestive parameters:

% DM in feces	36.3	39.3	16.3
% digestibility: DM/N/energy	86.3/82.6/85.2	92.7/81.1/81.5	80.0/76.5/76.3
Transit, mouth-rectum, hr.	28	32	4

Source: Ly and Castro (1984); * all diets contained 2.5% saccharomyces yeast, the molasses and maize dietscontained 1.5% and 2.5% micro/macro elements, respectively

Protein molasses

Protein molasses, a liquid feed for swine of 36% dry matter (Argudin and Chong, 1972; ICIDCA, 1988) is made by combining

on a dry matter basis 70% of B molasses with 30% torula yeast cream (*Candida utilis*). The yeast cream, a fermentation product of C molasses, contains between 44 and 46% protein in dry matter. Because it contains an average of 17% dry matter and the B molasses 82%, a common procedure is to mix two parts by weight of yeast cream to one of B molasses.

Figueroa (1989) reported that under commercial conditions a group of approximately three thousand pigs of average initial weight of 28.6 kg gained 507 g/day during a 120 day fattening period. The herd-average daily dry matter feed consumption was 2.45 kg; the dry matter feed conversion was 4.90.

CANE SUGAR

Raw cane sugar

There are few published reports on the use of raw cane sugar for

fattening pigs. Perhaps this is because the major cane producing countries also produce molasses, no doubt a cheaper alternative. Nevertheless, one early study from the southern United States, referred to "sugar cane left standing in the fields due to a lack of information on how it could be used" (Singletary *et al.*, 1957). The authors substituted maize for 10, 20 and 30% of raw sugar in 16% crude protein, free-choice rations for growing/finishing pigs of an initial liveweight of 29 kilograms. The average daily gain (g), air-dry daily feed consumption (kg) and feed conversion for the maize control diet and the treatments containing 10, 20 or 30% raw sugar groups were: 764, 3.0, 3.93; 818, 3.2, 3.88; 841, 3.1, 3.71 and 791, 3.0 and 3.77, respectively.

A second study, also 35 years ago (Thrasher *et al.*, 1958), interestingly supports the current recommendation to restrict the amount of high-quality protein supplement to approximately 200 g/day in sugar cane product-diets for growing/finishing pigs. The authors designed a trial consisting of a maize control and five

experimental groups. The first four experimental groups were fed 20, 30, 40 and 50% raw cane sugar in free-choice mixed rations that also contained maize and a protein supplement (Table 3.16). The fifth experimental group was fed raw sugar, maize and the protein supplement, free-choice, but separately. This last group, which gained weight at about the same rate, 795 g/day, as the maize control, consumed 2.63 kg daily, air-dry (43% sugar, 40% maize and 17% protein supplement). This meant that the pigs in group five consumed an average of 10% crude protein compared to 15% in the mixed rations. The intake of only 236 g/day of protein, in dry matter, compared to an average of 329 g in the other four groups that received mixed rations, represented a net saving of 28% protein, daily.

Table 3.16. Pigs fed free-choice/separate (FC/S) or free-choice/mixed (FC/M) diets containing: raw cane sugar, maize and a protein supplement, kg AD/day (25-90 kg).

Treatment:	0	20	30	40	50	FC/S

Raw cane sugar	-	0.55	0.84	1.08	1.34	1.12
Maize	2.06	1.50	1.24	0.75	0.43	1.05
Protein supplement*	0.59	0.73	0.82	0.86	0.91	0.45
ADG, g	786	814	818	809	873	795

Source: Thrasher *et al.* (1958); * 20% alfalfa meal, 20% meat/bone meal, 52% soya bean meal and 8% other.

In an attempt to improve the daily liveweight gain and feed conversion in growing/finishing pigs when more than 30% C molasses in dry matter was used, Macleod *et al.* (1968) substituted raw sugar for molasses. The average daily gain improved as sugar replaced C molasses. Feed conversion was best on the high-test molasses control diet and deteriorated as the proportion of raw sugar decreased (Table 3.17). It was reported that the pigs fed 20% sugar, i.e. those fed the highest level of C molasses, produced a more liquid feces compared to

that of the other diets.

Buitrago *et al.* (1969) substituted maize for raw cane sugar and found that as the amount of sugar was increased in the diet of growing/finishing pigs both the average daily gain and feed conversion improved (Table 3.18). For piglets, to improve palatability, a common commercial practice is to include from 5 to 15% of raw sugar (Ly, 1983).

Table 3.17. Performance of pigs (20-90 kg) fed * high-test molasses or final molasses and raw cane sugar (% DM).

	Final molasses plus:			High-test molasses
	20% sugar	40% sugar	60% sugar	
ADG, g	511	555	586	575
DM feed intake, kg/d	1.86	1.93	1.92	1.76

DM feed conversion	3.70	3.57	3.37	3.10

Source: Macleod *et al.* (1968); * all diets contained in DM up to 25% fishmeal, 2.5% yeast and 1.5% minerals andvitamins

Table 3.18. The use of raw cane sugar in rations for growing/finishing pigs.

Cane sugar:	**0%**	**15%**	**30%**	**45%**	**60%**
ADG, g	730	850	760	820	750
AD feed intake, kg/d	2.71	3.01	2.70	2.71	2.66
AD feed conversion	3.72	3.54	3.56	3.30	3.55

Source: Buitrago *et al*. (1969); maize was the alternative energy source, soya bean meal was the source of protein

Refined cane sugar

As refined cane sugar was used as a substitute for ground maize in exactly the same proportions as shown in the preceding table, both the average daily gains and the feed conversion improved (Table 3.19). In fact, Maner *et al*. (1969) demonstrated that by feeding a ration that contained 60% refined sugar, it would take only 70 days to fatten a pig! Brooks (1972) also demonstrated the superiority of refined sugar over maize for fattening pigs. A diet, in which the energy source consisted of 50% refined sugar and 10% fat, produced liveweight gains of 740 g/day and a feed conversion of 2.30. Growth performance on the maize diet was 700 g/day and feed conversion was 3.00 which meant that the refined sugar ration represented a 23% improvement in feed conversion. The data of Maner *et al.* (1969) indicate that there are no nutritional advantages favoring starch as opposed to sucrose-based diets. In fact, sucrose is completely absorbed in the small intestine and there are no significant amounts of carbohydrates fermented in the caecum and colon (Chapter 1).

Table 3.19. Use of refined cane sugar * for swine (25-90 kg).

Refined cane sugar:	0%	15%	30%	45%	60%
ADG, g	820	870	890	950	930
AD feed intake, kg/d	2.68	2.78	2.81	2.83	2.75
AD feed conversion	3.27	3.19	3.16	2.98	2.96

Source: Maner *et al.* (1969); * % air-dry

C sugar (low-grade or crystal seed-sugar)

C sugar, also known as low-grade or crystal seed-sugar, is produced in a raw sugar factory during the production of raw commercial B sugar and B molasses. It is a non-commercial type of sugar of which one-third is used for “seeding” (hence its name); the other two-third's is normally dissolved and sent back to the boiling house for reprocessing (see Fig. 3.2). It has been suggested that the removal of excess crystal seed-sugar for

animal feeding would improve the overall thermal balance of a traditional sugar factory (Pérez, 1990). In this regard, Sarria (1990) reported an average daily gain of 643 g when C sugar was used as the only energy source for growing/finishing pigs. Table 3.5 refers to a dry ration for piglets, called “soya-sugar”, that contains in air-dry: 50% C sugar, 30% soya bean meal, 10% rice polishing and 10% of a macro/micro premix. It was emphasized that because soya bean meal was used, the protein level was reduced by 25 percent.

CANE REFINERY PRODUCTS

Syrup-off and refinery final molasses

Syrup-off, known also as “liquor-off” or “jett”, is the end-product obtained after centrifuging the final massecuite in a raw sugar refinery. It contains 90 to 92% sucrose and for that reason is normally sent back to the raw sugar, or front section of the

refinery, where it is reprocessed in order to recover additional sucrose. However, similar to the process for upgrading crystal seed-sugar (C sugar), it is a costly, energy-consuming operation. In Cuba, diluted "syrup-off" has been used as an excellent substitute for fresh cane juice during mill maintenance or the 6-month, non-cane season. Interestingly, the refineries generally only shut down for one month each year. There is still another type of molasses produced in a raw sugar refinery. It is called "refinery final molasses". However, because it represents less than 1% of the processed raw sugar, it is usually deposited in the C molasses tanks.

"Syrup-off" was compared to both C molasses and refinery final molasses in a 112 day feeding trial in which the three energy sources made up 65% of the dietary dry matter (Pérez *et al.*, 1984). The protein supplement was dry torula yeast, 34%, with an added 1% mineral-vitamin premix. The pigs fed "syrup-off" grew 25% faster, as well as converted their ration, including the

protein supplement, into liveweight 22% more efficiently compared to the group fed C molasses (Table 3.20). Figueroa (1990) also reported that pregnant sows, fed "syrup-off" or C molasses as a major source of energy during gestation, were heavier at 105 days of gestation (61.1 vs. 48.1 kg) and farrowed more live piglets (10 vs. 8.9).

Table 3.20. Performance of growing/finishing pigs fed as an energy source: syrup-off, refinery final molasses or C molasses (% DM).

Performance parameters	Syrup-off	Refinery final molasses	C molasses
Initial liveweight, kg	28.6	31.0	27.7
Final liveweight, kg	94.9	95.1	80.7
ADG, g	592	573	473
DM feed consumption, kg/d	2.40	2.60	2.50

DM feed conversion	4.17	4.56	5.34

Source: Pérez *et al.* (1984)

RESIDUES

Filter-press mud (filter-cake)

Filter-press mud of approximately 25 to 28% dry matter represents 3% of millable sugar cane. Because it ferments within 24 hours, it is normally returned to the cane fields as fertilizer. Filter-press mud has been used experimentally to replace 5 or 10% of dietary dry matter in C molasses basal diets for pigs (Olengui, 1978, cited by Castro and Lon-Wo, 1990) and up to 13% in processed swill feeding systems (Table 3.21); however, both studies showed that the addition of only 5% filter-mud adversely affected performance.

Table 3.21. The use of filter-press mud in processed swill diets

for growing/finishing pigs between 25-90 kg (% DM).

Filter-press mud:	0%	5%	9%	13%
Organic wastes	41.2	39.2	37.5	35.3
C molasses	42.8	40.7	38.9	37.2
Soya bean meal	15.6	14.8	14.1	13.5
Filter-press mud	-	4.8	9.0	13.0
ADG, g	483	476	491	451
DM feed conversion	3.90	4.30	4.10	4.60

Source: Patterson *et al*. (1983)

Cane wax oil

Cane wax oil results from the purification of raw cane wax extracted from filter-press mud. One ton of millable cane produces 33 kg of filter-press mud which contains 0.8 kg of unrefined wax. The composition of the unrefined wax is: 40%

refined wax, 40% oil and 20% resin. This means that one ton of millable cane contains 0.32 kg of cane wax oil (MINAZ, 1980). The use of this product to increase the energy content of C molasses diets for growing/finishing pigs (Brito *et al*., 1985), and for gestating sows (Díaz and Rodriguez, 1987) was unsuccessful. The authors attributed the extremely poor results to impurities in both the oil and the C molasses.

Bagasse pith

Bagasse pith, also known as “fines”, have been fed at air-dry levels of either 30 or 40% together with 30% C molasses, 27% of a protein supplement and 3% of macro/micro elements in a complete self-fed ration for pregnant sows housed in dry lot (Thrasher and Brown 1961). The 30% bagasse pith ration contained 12% of ground maize. The control group was fed a cereal-based gestation ration at a rate of 2.25 kg AD/day. The sows fed the ration containing 30% bagasse pith consumed 53%

more compared to those on the 40% pith ration and therefore had the highest daily feed cost. The authors reported that the 40% high-fibre bagasse ration was very satisfactory for self-feeding under dry lot conditions and suggested it also be tried under pasture conditions.

Fresh sugar cane juice scums

The term sugar cane juice “scums” refers to the flocculated, colloidal-like material removed from the surface of boiling cane juice during the production of pan sugar. It is produced by adding calcium to the gently boiling juice while agitating the mixture with certain tree branches that contain tannins which coagulate the extraneous materials at the surface. Besides these residual tannins, the scums contain sugars, minerals, proteins and particles of soil that have adhered to the cane stalk (Preston and Murgueitio, 1992). They ferment rapidly, generally within 24 hours.

Scums, which contain only 20% dry matter, can replace cereal grains in the diet of finishing pigs but tend to cause diarrhoea in younger pigs and in lactating sows (Preston and Sansoucy, 1987). Sarria *et al.* (1990) reported an average growth performance of 670 g on nine small Colombian pan-sugar (panela) farms for growing/finishing pigs fed 500 g/day of a 40% protein supplement and free-choice fresh scums. There results were superior to those of the Philippines, where pigs fed 0.5 kg soya bean meal and fresh scums grew at only 430 g/day, however, double their previous performance (Table 3.7).

The production of pan sugar, a batch-type process, often requiring up to three days to complete, means that by the time the second batch is finished, the scums, which ferment within 24 hours, are no longer usable. A practical method of conservation is to boil the fresh scums in open vats to about 50–60% solids. In Latin America, this material is known as concentrated scums or as "melote".

Concentrated scums (melote)

The performance of three groups of growing/finishing pigs, fed free-choice concentrated scums mixed with two parts of water and different amounts of protein supplement, supports the thesis that 200 g/day of high-quality protein during both the growing and finishing phases is optimal (Table 3.22). An additional trial in Colombia compared diluted, concentrated sugar cane scums to fresh cane juice. The supplement was 500 g/day of a 40% protein supplement based mainly on soya bean meal. Growth performance was superior (780 vs. 640 g); total dry matter intake was higher (2.8 vs. 2.4 kg) and feed conversions were better (3.70 vs. 3.80) on the concentrated scums feeding system (Sarria *et al.* 1990).

Table 3.22. Performance of pigs fed concentrated sugarcane scums (melote) and three levels of protein: low, medium and high.

Performance parameters	low*	medium**	high***
Initial liveweight, kg	23.8	24.7	30.5
Final liveweight, kg	84.6	81.3	97.5
ADG, g	622	736	670
AD feed intake, kg/d: concentrated scums	4.60	3.90	4.80
protein supplement	0.47	0.52	0.66
DM feed intake, kg/d	2.8	2.5	3.1
DM feed conversion	4.15	3.96	4.15

Source:Moreno *et al.* (1989), cited by Sarria *et al.* (1990); * 200 and 150 g/d of protein during growing and finishingphases, respectively; ** 200 g/d during both phases; * 300 g/d during both phases**

SUGAR CANE STALKS

Fresh, clean (millable) cane stalks

Surprisingly, there is very little information on the use of fresh, clean cane stalks, chopped or ground, for pigs. In view of the performance of growing/finishing pigs fed 500 g/day high-quality protein supplement and free-choice cane juice, perhaps similar studies will determine this same requirement for ground sugar cane.

In Haiti, the work of Bien-Aime and Francois (1990) showed that pigs are only slightly less efficient than simple cane crushers in their ability to extract juice from chopped sugar cane: 43% compared to 49% in a crusher. These authors offered pigs either fresh juice or chopped cane; the protein sources were soya bean meal and fresh *Leucaena* leaves. The control treatment was a maize/soya bean meal ration (Table 3.23). They concluded that even if the chopped cane system took longer, five months and 25 days, it was better than the results obtained by many commercial

farmers in Haiti, and definitely superior to the 12 and 24 months required by the poor peasant farmer to fatten a pig.

Table 3.23. Performance of pigs fed sugar cane juice (SCJ) vs. chopped sugar cane(CSC) with either soya bean meal (SBM), or soya bean meal and *Leucaena* leaves (LL), kg AD/day.

Treatment:	Maize-soyaa	SCJ-SBM	SCJ-SBM-LL *	CSC-SBM	CSC-SBM-LL
	1.4-0.4	9.4-0.93	8.6-0.91-1.7	8.6-0.91	7.8-1.0-1.4
Initial liveweight, kg	23.4	23.5	23.7	22.2	22.4
Final liveweight, kg	86.3	87.8	93.2	78.3	82.3
ADG, g	560	572	450	325	344
DM feed intake, kg/d	1.65	2.06	2.03	1.45	1.58

DM feed conversion	2.95	3.60	4.51	4.46	4.59
Months/days to finish	3m/22d	3m/22d	5m/9d	5m/25d	5m/25d

Source: Bien-Aime and Francois (1990);* fresh *Leucaena* leaves

In Trinidad and Tobago, a FAO Technical Cooperation Project on Sugar Cane for Livestock has pursued this idea. The possibility to use the same machine to grind sugar cane for both pigs and small ruminants could be decisive for the resource-limited, small-scale farmer. It was reported that one farmer ground the stalk to a sawdust-like consistency, added 30% water (by weight), added cooked chicken entrails and fed his pigs this slurry. The squeezed-out fibre was subsequently collected and fed to his small ruminants (FAO, 1992b).

Sugar cane pith

In Barbados, fresh sugar cane pith has been used experimentally as the major source of energy in rations for growing/finishing pigs. In a project designed to use the rind of the cane stalk to manufacture compressed wallboard, the inner portion, 80% of the air-dry weight of the stalk, was used as a major source of energy for all kinds of livestock (James, 1973). For pigs, the fresh pith was incorporated in a 16% iso-proteic diet at air-dry levels of 35, 50 and 75 percent. Raw sugar and water were added (Table 3.24). Pigs of initial weight of 20 kg were assigned to three experimental groups and fed twice daily with ration allocations based on NRC recommendations at that time. A fourth group constituted a cereal control. Performance was best where either 35 or 50% of pith was used.

Table 3.24. Performance of pigs fed different amounts of fresh sugar cane pith [*] vs. cereal control, % AD.

Treatment:	Control	35% pith	50% pith	75% pith
Energy source: cereal or pith	100	35	50	75

Energy source: cereal or pith	100	35	50	75
Raw sugar	-	17	12.5	5
Filter (water)	-	28	17.5	-
Feed intake, kg/d: AD/DM	2.4/2.2	5.0/2.2	4.9/2.2	4.2/1.9
ADG, g	523	600	555	445
DM feed conversion	4.16	3.71	3.91	4.24

Source: James (1973); * all pith diets contained 20% of a 38% crude protein supplement

A second trial produced entirely different results. It examined the effect of using a level (air-dry) of 60% fresh cane pith in free-choice rations calculated for 15.5% crude protein in dry matter, and in which, either raw sugar or C molasses, or both, were added. Twenty-five percent of a 38% protein supplement was the only source of protein used in the pith diets. The cereal control ration was of commercial origin. The pigs on the cane pith

rations gained significantly less (451 vs. 686 g/day) and converted their rations into liveweight 20% less efficiently; however, the authors, maintained that there was a decided advantage to using up to 75% local ingredients (Donefer *et al.*(1975).

Sugar cane meal

Sugar cane meal, clean cane stalks dried six to eight hours prior to grinding, has been incorporated at levels of 10, 20 and 30% in rations for weaned piglets (Table 3.25). The composition of the meal (dry matter) was: crude protein, 2.4%; ash, 4.6%, crude fibre, 26.0% and total sugars, 66.0 percent. It contained 90% dry matter and hemicellulose represented 45% of the plant cell wall.

At a level of 20% in the diet, there was no significant liveweight or feed conversion difference with respect to the cereal control. It was suggested that performance could be partially explained by

the relatively high digestibility that pigs show for hemicellulose.

Table 3.25. Performance of weakned piglets (7 kg) fed concentrate diets * containing different levels of sugar cane meal (% DM).

Sugar cane meal:	0%	10%	20%	30%
Cereal	55.0	54.0	41.0	28.5
Torula yeast	10.0	11.5	13.0	14.0
Soya bean meal	10.0	13.7	15.2	16.7
Final liveweight, kg	14.3	13.3	13.7	13.6
ADG, g	205	180	204	192
DM feed conversion	2.35	2.68	2.38	2.52

Source: Lamazares *et al.* (1988); * all diets contained 8% of fishmeal, 0.8% of calcium carbonate and 2% of avitamin/mineral premix; the control diet, in addition, contained 13.2% of rice

polishing and 1% of dried grass meal

Protein-enriched sugar cane meal

Protein-enriched sugar cane meal (Saccharina) was first described by a group of Cuban researchers interested in promoting the use of sugar cane in concentrate rations for dairy cows (Elias *et al.*, 1990). They proposed a process for the solid-state fermentation of carbohydrates in sugar cane: non-protein nitrogen, in the form of urea, mixed with ground cane, would supposedly promote the growth of microbes and yeasts that adhered naturally to the cane stalk. The multiplication of single cell organisms would increase the level of protein to approximate that of a cereal.

Table 3.27. The performance of piglets fed different levels of protein-enriched sugar cane meal (PESCM) in concentrate rations* (% DM).

PESCM:	0%	10%	20%	30%	40%	50%
Cereal	69.2	59.2	48.2	37.2	27.2	16.2
PESCM	-	10.0	20.0	30.0	40.0	50.0
Protein supplement	28.0	28.0	29.0	30.0	30.0	31.0
ADG, g	228	261	246	196	161	123
DM feed conversion	2.30	1.90	2.10	2.60	3.00	3.90

Source: Lezcano *et al*, (1990);* 22% CP in DM; the ration also contained macro/micro elements

The first published trial (Table 3.27) using protein-enriched sugar cane meal for pigs referred to weaned piglets of an average liveweight of 7.2 kg allocated to five experimental rations in which protein-enriched sugar cane meal replaced from 10 to 50% of cereals (Lezcano *et al.*, 1990). During a four-week feeding trial, the piglets were offered, weekly, 270, 470, 700 and 870 g/day of the experimental rations. Performance was superior when 10 or

20% of the enriched meal was incorporated in the diet. It was reported that when more than 20% of protein-enriched meal was used the piglets did not consume all of their ration.

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Chapter 4 African oil palm

The African oil palm, *Elaeis guineensis* (Jacq.), is characterized by its vertical trunk and the feathery nature of its leaves. Every year, 20 to 25 new leaves, called "fronds", develop in continuous whorls at the apex of the trunk. The fruit bunches develop between the trunk and the base of the new fronds. Although new plantations start to bear at three years, generally the first commercial crop requires between five and six years and continues to produce for 25–30 years, or until the palms grow too high to be harvested. Once a plantation reaches full production, a new inflorescence is produced every 15 days. It weighs between 15 and 20 kg and can contain up to 1500 individual palm fruits of between 8 to 10 grammes each. The individual fruits consist of the following four parts:

- **a pericarp, a thin outer skin, which upon ripening changes from brown to orange;**
- **a mesocarp, a layer of fibrous material, which surrounds the nut;**
- **an endocarp or hard inner shell (nut) to protect the seed or kernel, and**
- **the seed (kernel).**

PRODUCTION AND TECHNOLOGICAL PROCESS Production

The African oil palm, which yields about 20t/ha/yr of fresh fruit bunches (Bolaños, 1986; Espinal, 1986: Garza, 1986), is capable of producing between three to five t/ha of crude oil from the fruit (mesocarp) and an additional 0.6 to 1.0 t/ha from the palm kernels (Ocampo *et al.*, 1990a). Its productivity is influenced by climate, soil type, genetic factors, maturity, rainfall, fertilization

and the harvest period. Mijares (1985) has stated that for optimum annual production the African oil palm requires a minimum of 1600 mm of well distributed precipitation, a relative humidity no less than 75%, a minimum and maximum temperature of between 17 and 28°C., a total of 2000 hours of light and soil depth of 100 centimetres.

There are two distinct types of oil palm: the “dura” and the “pisifera.”. The basic difference has to do with the inner nut. The nut of the dura type of oil palm has a thick and hard shell while the pisifera type has a small kernel, with no shell, but rather surrounded by a ma'rix of fibre. When a pisifera male is crossed with a dura female, a “tenera” type of fruit is produced; its shell is of intermediate thickness. Currently, it is this type of oil palm that is most widely grown in plantations:

The African oil palm produces two main commercial products: raw or crude oil, approximately 22% of the weight of the fresh

fruit bunch, and the palm nuts which represent 4–6%. When the nut is processed, it yields palm kernel oil and palm kernel meal (Figure 4.1). The two main industrial residues, the oil-rich fibrous residue and the palm nut shells, are used as sources of energy to run the factory. The empty fruit bunch is normally incinerated and the ash is returned to the plantation as fertilizer.

The initial interest in the African oil palm as a feed resource for pigs was in the extracted and non-extracted palm kernel meal. This was because when nuts of the oil palm were first brought to Europe from Africa as ship's ballast, they were jettisoned into the sea before the ships were reloaded. However, soon the oil millers recognized their value and began processing them for oil in order to supplement copra oil in the manufacture of soap, paints and for other industrial applications (Collingwood, 1958). The meal was used as a major protein supplement for pigs and cattle until soya bean meal became commercially available.

Oil palm cultivation started at the beginning of this century (Devendra, 1977). By 1980, production of oil had risen to slightly more than five million tons and, by 1992, annual world production reached thirteen million tons. As seen in Table 4.1, the primary areas of production are Southeast Asia, followed by the west coast of Africa and Latin America. Currently, Malaysia produces half the world's production of palm oil, followed by Indonesia and Nigeria. Presently, the fourth and fastest growing producer of palm oil is Colombia, where production has more than quadrupled in 12 years. In that country, (Ocampo *et al.*, 1990b) has reported that the average annual production of fruit is 15 t/ha of which raw oil represents slightly more than three tons.

Table 4.1. Production of African palm oil: world, regional and top four countries, tonnes (FAO, 1992).

Geographical area	1979–81	1992
World	5 046 308	12 725 346

Africa	1 337 913	1 835 888
Nigeria	666 667	900 000
Latin America	190 780	753 251
Colombia	70 500	304 496
Asia + Oceania	3 502 851	10 136 207
Indonesia	720 826	3 162 228
Malaysia	2 528 947	6 373 461

TECHNOLOGICAL PROCESS

The technological process by which the oil is extracted from the palm fruit consists of the following steps; note that the fresh fruit bunch includes the stem and the adhering individual palm fruits.

***Reception*: where sand, dirt and gravel are separated from the fresh fruit bunch.**

***Sterilization*: necessary to rapidly inactivate certain enzymes which tend to reduce the quality of the oil by increasing the amount of free fatty acids. In addition, this process contributes to the mechanical separation of the fruit from the stem and to the rupture of the oil cells within the mesocarp.**

***Oil extraction*: An oil press, into which hot water is injected, is used to separate the crude oil from the solid or fibrous-like material containing the nuts. The crude oil is then pumped to the purification section.**

Figure 4.1 shows the quantities of the principal components of the oil palm based on 100 tons of the fresh fruit bunch. The nuts are treated and cracked to extract the kernel which contains approximately 50% oil. The oil-rich fibrous residue, traditionally used as a source of energy to run the plant, has a caloric value superior to 18.8 MJ/kg. This is largely due to the residual oil, calculated as between 8 and 18 percent (Brezing, 1986; Solano,

1986; Wambeck, 1990).

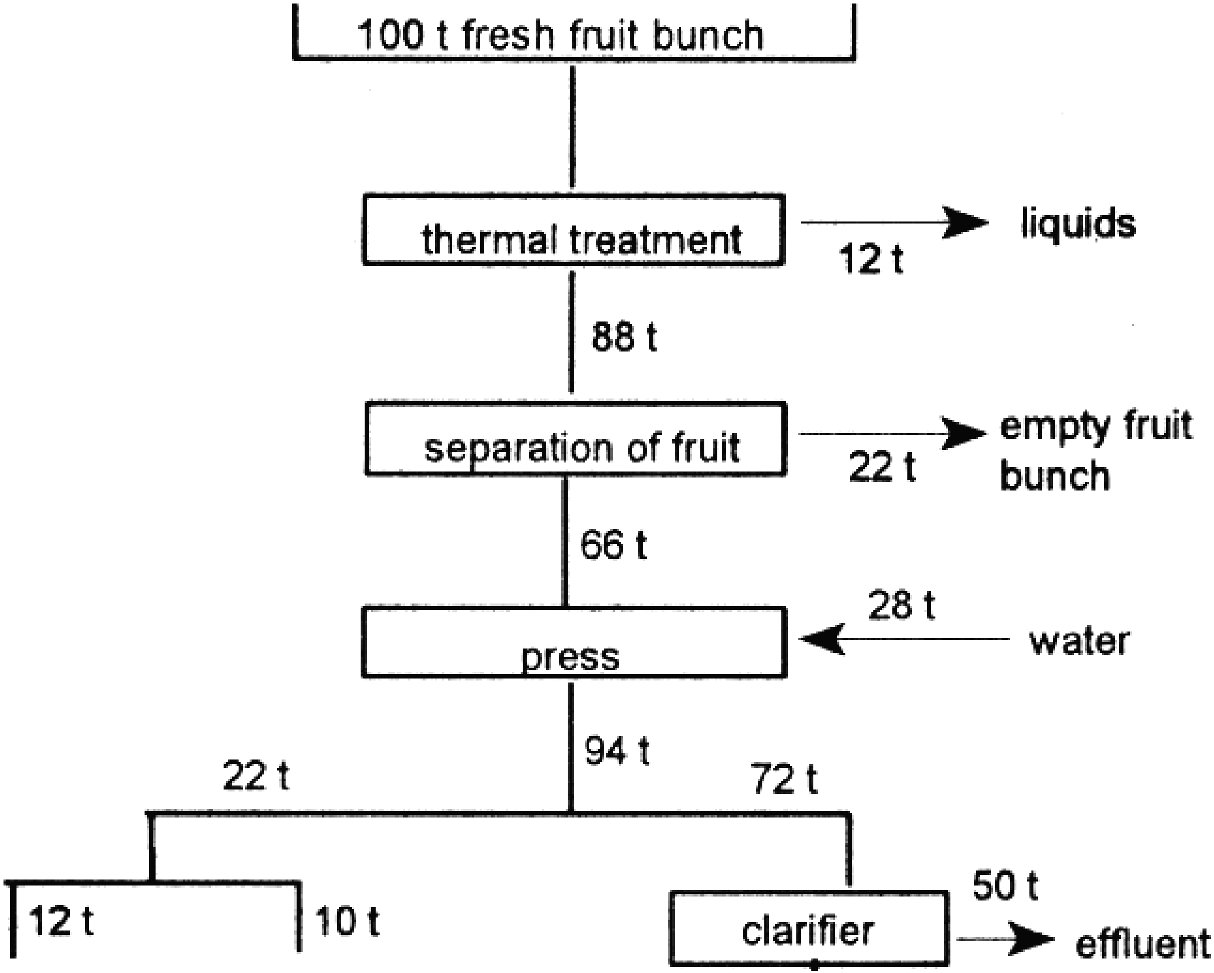
Similar to the proposal for livestock diversification within the sugar industry (FAO, 1988), the integration of pig production within the oil palm industry might introduce a certain degree of flexibility in the entire enterprise, resulting in: an increase in the productive capacity of the plant, particularly during the period of maximum industrial yield; a significant reduction in plant maintenance; increased employment opportunities related to the utilization of the different byproducts for livestock feeding; the production of animal wastes and thereby organic fertilizer for the plantations and, perhaps most importantly, an overall reduction in the amount and/or concentration of the industrial effluents which threaten the contamination of the surrounding ecosystem (Ocampo, personal communication).

As a follow-up to these observations, the following information summarizes the average daily amount of products and sub-

products produced in a oil palm processing plant of 125 t/day and 10t/hour (Table 4.2).

One factor that might require attention if derivatives from the African oil palm present new opportunities to be used as energy feed resources for pigs is the cyclic nature of its production. Bolaños (1986) has reported that in Costa Rica the average monthly yield of fresh fruit bunch can vary from 6% during the dry winter months to 10 or 12% during the rainy, summer season. In that country, the annual yield of the fresh fruit bunch is 20 t/ha and with the oil-rich fibrous residue representing 12% of this amount, this could mean the production of 0.3 t/ha of oil-rich fibrous residue during the wet season as opposed to only 0.15 t/ha during the dry or winter season.

Figure 4.1. Production technology for 100 t of fresh fruit bunch of African oil palm (Solano 1986).


100 t fresh fruit bunch
thermal treatment
12 t
liquids
88 t
separation of fruit
22 t
empty fruit bunch
66 t
28 t
water
press
94 t
22 t
72 t
12 t
10 t
clarifier
50 t
effluent

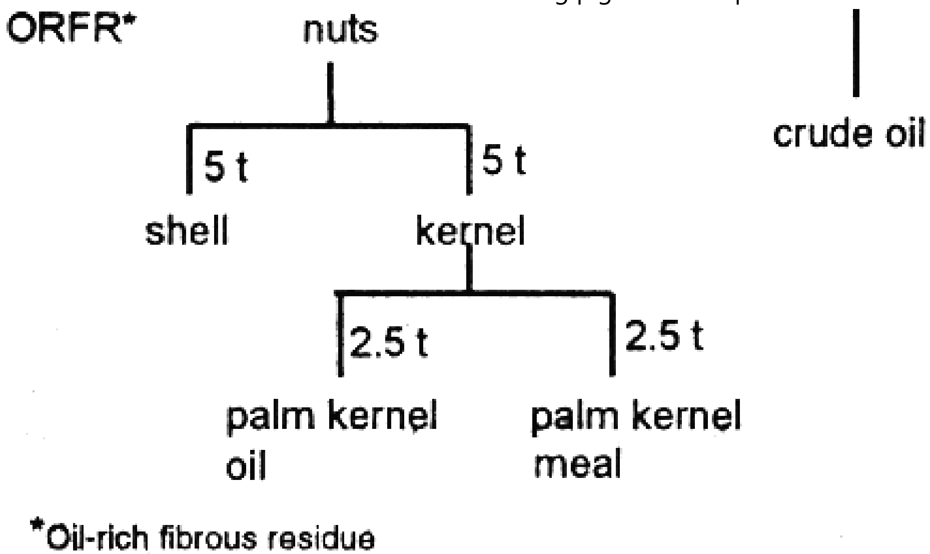


Table 4.2. Potential feed resources in an African oil palm processing plant, air-dry basis.

	t/day	t/year	t/ha/yr
Fresh Fruit Bunch	125	25000	20
Palm oil	25	5000	4
Palm Kernel meal	2.5	1000	0.8
Empty Fruit Stem	40	8000	6.4

Ash (from stem)	0.6	125	0.1
Effluent	80	16000	13
Oil-rich fibrous residue	13.7	2750	2.2
Shell (from kernel)	12	2500	2
Ash (from shell)	0.6	16000	13

Source: Brezing (1986)

However, if sugar cane, generally harvested only in the dry season, was integrated into this feeding system, the two energy feed resources might complement each other. The data in Tables 4.6 and 4.7 tend to support this interesting concept.

USE FOR PIGS

As earlier mentioned, one of the first references to the use of derivatives of the oil palm for pigs referred to the use of the

extracted and non-extracted palm kernel meal in complete, dry rations for growing/finishing pigs. Most pig farmers contended that the gritty texture of the meal affected consumption, and therefore performance. However, palm kernel meal continued to be used for many years as a replacement for scarce cereals, mainly because it was available, relatively inexpensive and highly nutritious (Crowther, 1916, cited by Collingwood, 1958). In the 1930s, when a commercial process for extracting oil from the soya bean was perfected and it was seen that a higher quality animal protein supplement (soya bean meal), would be commercially available, the byproduct from the extraction of the oil from the kernel, palm kernel meal, was destined for ruminants (PNI, 1990). Currently, palm kernel meal represents about one per cent of world trade in oil seed meals. Table 4.3 gives the chemical composition of several oil palm byproducts.

Table 4.3. Chemical composition of African oil palm byproducts.

	Oil-rich fibrous	Dry	Fresh centrifuged

Componenet	**residue[a] (% DM)**	**sludge[a] (% DM)**	**sludge solids[b] (% AD)**
Dry matter	86.2	90.3d	15.0–20.8
Crude protein	4.0	9.6	3.1–3.4
Crude fibre	36.4	11.5	3.0–5.2
Ether extract	21.0	21.3	2.4–3.5
Ash	9.0	11.1	2.8–3.4
Nitrogen free extract	29.6	46.5	-
Calcium	0.31	0.28	-
Phosphorous	0.13	0.26	-
Gross energy (MJ/kg)	18.1	18.7	-

Sources:[a] Devendra (1977); [b] Ong (1982)

To date, derivatives of the African oil palm have shown potential feeding value for pigs in conventional, cereal-based rations: the de-hydrated palm oil mill effluent and the fresh centrifuged sludge solids have been studied both by Devendra *et al.* (1981) and by Ong (1982), and the whole palm nut by Flores (1989) and Chavez (1990). However, recent interest has focused on the use of primary products and by-products of the African oil palm as a partial or complete energy source replacement in swine rations, particularly where the protein is offered separately, in the form of a restricted amount of a high-quality supplement. It has been shown that the oil-rich fibrous residue (ORFR), normally used as a source of energy to run the factory, can also furnish the necessary energy for the pig (Ocampo *et al.*, 1990a, 1990b). As exemplified in following sections, the successful experimental use of the crude oil (Ocampo, 1994b), combinations of the crude oil and sugar cane juice (Ngoan and Sarría, 1994) and even the whole fresh palm fruit (Ocampo, 1994a, b) further emphasize the fact that other oil palm byproducts can serve to completely

replace cereals in rations for swine.

Crude (raw) palm oil

Crude palm oil has traditionally been used up to about 5% in dry diets for pigs in a manner similar to molasses: to improve palatability, to reduce dustiness, to supply vitamins and to improve the texture of rations prior to pelleting (Devendra, 1977; Hutagalung and Mahyudin, 1981). The oil contains approximately 80% of unsaturated fatty acids (Table 4.4) and 10% of linoleic acid, an essential fatty acid required at a dietary level of 0.1% for pigs (NRC, 1988).

Table 4.4. Composition of the fatty acids in the oil from fruit and kernel of the African oil palm (% AD).

Fatty acids	Palm oil	Palm kernel oil
Myristic	1.6	-
Palmitic	45.3	7.8

Stearic	5.1	2.5
Oleic	38.7	12.6
Linoleic	9.2	1.7
Lauric	-	15.7
Capric	-	47.3
Caprilic	-	4.1
Caprolic	-	4.3

Source:Pardo and Moreno (1971), cited by Ocampo *et al.* (1990b)

The addition of from 2 to 10% of crude palm oil in the diets of growing pigs was studied by Fetuga *et al.* (1975) who found no significant effect on performance. When palm oil was compared to groundnut oil, lard or beef tallow, there were no significant growth differences, however, increasing the level of palm oil in the diet slightly increased the percentage of lean cuts

(Babatunde *et al*., 1971, 1974, cited by Devendra, 1977). This same observation was reported by Balogun *et al*. (1983) cited by Ngoan and Sarria (1994) who noted that the addition of 30, 64 or 97 g/kg of palm oil to the ration increasingly improved muscle development.

In Malaysia, it was reported that six groups of pigs from 16 to 81 kg were fed iso-nitrogenous diets containing different levels of palm oil, from 5 to 30 percent. Although the results were reported as not significant, the average daily gains obtained on the experimental diets were 10% superior compared to that of the cereal control; in addition, where palm oil was included, the conversions were improved by an average of 17 percent (Devendra and Hew, cited by Devendra, 1977).

Recently, Ocampo (1994b) showed that palm oil and a source of protein, either fortified soya bean meal and rice polishings, or combinations of fortified soya bean meal/fresh *Azolla* and rice

polishings, might provide an interesting feeding system for the production of pigs in the tropics, particularly if the pigs were integrated with the palm plantations. Pigs of an initial average liveweight of 30 kg were fed diets in which 10, 20 and 30% of the protein from fortified soya meal was replaced by fresh *Azolla filiculoides*, a water fern (Table 4.5).

Table 4.5. Composition of diets using crude palm oil, rice polishings and fresh *Azolla filiculoides* as a replacement for the protein in soya bean meal (kg AD/day).

	% replacement of protein in soya bean meal by *Azolla*							
	growing phase: 30–60 kg				finishing phase: 60–90 kg			
	0	10	20	30	0	10	20	30
Protein supplement	0.50	0.45	0.40	0.35	0.50	0.45	0.40	0.35

Rice polishings	0.10	0.10	0.10	0.10	0.15	0.15	0.15	0.15
Crude palm oil	0.50	0.50	0.50	0.50	0.80	0.80	0.80	0.80
Fresh *Azolla*	0.0	1.74	3.48	5.21	0.0	1.74	3.48	5.21

Source: Ocampo (1994b); * contains: soya bean meal, 86%; dicalcium phosphate, 10%; salt, 2% and avitamin/mineral premix, 2%

In the morning, the pigs were fed the daily ration of protein supplement and rice polishings, and half the daily allowance of oil and *Azolla*. In the afternoon, they received the remaining portion of *Azolla* and oil. The average daily gain (g) and dry matter feed conversion for the control treatment, without *Azolla*, and the groups where 10, 20 and 30% of the protein in soya bean meal was replaced by that of *Azolla* were: 526, 2.10; 561, 1.98; 535, 2.00 and 452, 2.20, respectively.

In the same publication reference was made to a commercial piggery that used the following "palm oil feeding system". For that, a total of 170 growing/finishing pigs, in 4 groups, were fed daily one kilogramme of protein supplement and 0.5 kg of crude palm oil. The protein supplement contained: 450 g soya bean meal, 374 g palm kernel meal, 150 g rice polishings, 20 g dicalcium phosphate and 3 g each of salt and a vitamin/mineral premix. The initial average liveweight (kg), average daily gain (g) and dry matter feed conversion for each of the 4 groups were 32.0, 722, 1.80; 24.2, 628, 2.00; 25.8, 524, 2.40 and 26.0, 464, 2.80, respectively. In spite of the fact that the diet was the same for all groups, no explanation was offered for the observed variation in performance, inferring, perhaps, that the "palm oil feeding system" requires further refinement.

Palm oil has also been studied as either a partial or complete energy source replacement for pigs, also fed fresh sugar cane juice and a restricted protein supplement. The oil replaced 25, 50,

75 and 100% of the energy in cane juice in both the growing and finishing phases of this most interesting and unique feeding system to study the potential integration of sugar cane and the African oil palm as dry/wet-season energy feed resource alternatives for pig production in the tropics (Table 4.6).

The average daily gain was not significantly affected by treatment in the growing phase, however, during the finishing phase, gains were significantly lowered when palm oil replaced 75 and 100% of the juice (Table 4.7). In both phases, the average daily feed intake was lower for those pigs fed palm oil which according to the authors, might have been related to its low palatability or high energy content. They reported a digestible energy value for palm oil and sugar cane juice in pigs as 37.5 and 14.5 MJ/kg of DM, respectively. Feed conversions were significantly improved by the addition of palm oil. Carcass measurements were not affected.

Table 4.6. Replacement of the energy in sugar cane juice (SCJ)

Table 4.6. Replacement of the energy in sugar cane juice (SCJ) by that in palm oil (PO) for growing/finishing pigs (kg AD/day). *

Liveweight, kg	<30	40	50	60	70	80	90	>90
100 SCJ	6.0	7.5	8.5	9.5	10.5	11.5	13.0	>14
75 PO/25 SCJ	4.5/.1	6.0/.15	7.0/.2	8.0/.2	9.0/.25	10/.25	11.0/.3	12.0/.3
50 PO/50 SCJ	3.0/.2	4.0/.3	4.5/.35	5.0/.4	5.5/.45	6.0/.5	6.5/.55	7.0/.6
25 PO/75 SCJ	1.5/.3	2.0/.45	2.5/.5	2.5/.6	3.0/.65	3.0/.75	3.5/.8	3.5/.9
100 PO	0.4	0.6	0.7	0.8	0.9	1.0	1.1	1.2

Source: Ngoan and Sarría (1994).* plus 500 g/d of a 40% crude protein supplement

Table 4.7. Performance of finishing pigs (50–90 kg) fed a restricted protein supplement (RPS)* with energy from sugar

cane juice (SCJ) increasingly replaced by palm oil (PO).

	100 SCJ	75 SCJ 25 PO	50 SCJ 50 PO	25 SCJ 75 PO	100 PO
Initial liveweight, kg	51.1	50.1	48.9	50.2	45.2
Final liveweight, kg	99.5	93.7	91.2	89.8	84.2
ADG, g	768	693	672	628	615
DM feed intake, kg/d	3.05	2.32	2.14	1.77	0.92
DM feed conversion	3.97	3.35	3.18	2.82	1.47

Source: Ngoan and Sarría (1994); * The RPS was 500 g/day of 91% soya bean meal, 6% minerals,1% salt and 2% of a vitamin premix.

Oil-rich fibrous residue (ORFR)

The residue which remains after the crude oil is separated from the sterilized fruit by means of a screw-press, represents

approximately 12 to 15% of the fresh fruit bunch. The chemical composition of this residue is presented in Table 4.3. This material, reported to contain from 63% (Wambeck, 1990) to 70 or 85% dry matter (Solano, 1986) still contains from 6 to 8% of residual oil. It is of a deep yellow-tangerine color, with a fibrous consistency, sweetish smell and greasy-like texture (Ocampo *et al*., 1990a). It is used as the main source of energy to run the plant.

ORFR has been studied as a complete replacement for the energy derived from cereals. Diets in which sorghum was the sole energy source, or where 25, 50, 75 or 100% of the energy from sorghum was replaced by this residue, were offered ad libitum to pigs from 20 to 90 kg, also fed a restricted amount of fortified soya bean meal to meet the current, daily, NRC (1988) requirement for crude protein (Ocampo *et al*., 1990a). Preliminary results showed that pigs can grow extremely well on this type of feeding system. Where ORFR replaced 100% of the energy

supplied by sorghum, the average liveweight growth was 639 g/day. The pigs consumed a daily average of 0.75 kg of protein supplement together with 2.32 kg of oil-rich fibrous residue (Table 4.8).

Table 4.8. Oil-rich fibrous residue as a partial or complete replacement for the energy in sorghum for pigs (20–90 kg).

	0% ORFR	25% ORFR	50% ORFR	75% ORFR	100% ORFR *
Initial liveweight, kg	19.8	20.6	21.7	22.2	22.6
Final liveweight, kg	89.7	91.1	92.5	92.6	94.2
Days to finish	133	119	112	112	112
ADG, g	525	592	632	629	639
DM feed intake, kg/d	2.1	2.1	2.2	2.3	2.8
DM feed conversion	4.00	3.59	3.49	3.75	4.47

Source:Ocampo *et al.* (1990a); * fed 0.55, 0.64 and 09 kg/day of fortified soya bean meal (see Table 4.5) during the3 phases of: weaners, growers and finishers, respectively

Following this initial trial, Ocampo *et al*. (1990b), attempted to prove an observation of Sarría *et al*. (1990), that when pigs are fed a restricted amount of a high quality protein supplement, particularly when the required levels of essential amino acids are supplied by soya bean meal, lower amounts of total crude protein are feasible. This amounts to approximately 200 g/day and can be provided in 500 g/day of a 40% protein, soya bean meal-based supplement. The concept had been first developed through feeding systems based on sugar cane juice (see Chapter 3).

For this study, the basic diet was ORFR, fed *ad libitum*. Three groups of growing/finishing pigs were fed constant amounts (high, medium or low) of fortified soya bean meal throughout the

entire experimental period. A fourth group, the control, received different amounts of fortified soya bean meal (high, medium and low) to correspond with the needs of each of the three developmental phases: weaners, growers and finishers (Table 4.9). The authors concluded that the two groups that received the least amount of protein exhibited an inferior performance but gave the highest economic returns. A more recent trial studied the effect of supplementing this unusual feeding system (*ad libitum* ORFR and a restricted amount of protein supplement) with methionine and/or B-complex vitamins (Ocampo, 1992). None of the experimental treatments produced significant results.

Table 4.9. Different amounts of restricted protein supplement (RPS) * and free- choice oil-rich fibrous residue for pigs from 22 to 90 kg.

	Control	High	Medium	Low

	**	(0.64 kg/d)	(0.57 kg/d)	(0.50 kg/d)
Initial liveweight, kg	22.7	22.8	22.8	22.1
Final liveweight, kg	90.2	90.0	90.4	90.3
Days to finish	121	126	124	135
ADG, g	558	532	545	505
AD feed intake, kg/d: RPS	0.70	0.64	0.57	0.50
ORFR	2.33	2.44	2.22	2.56
DM feed conversion	4.80	5.20	4.60	5.40

Source: Ocampo *et al.* (1990b), * see Table 4.5; ** 0.50, 0.64 and 0.90 kg/day of RPS fed during three consecutive40-day periods: weaners, growers and finishers.

Palm oil mill effluent and palm oil sludge

The palm oil mill effluent, the final liquid discharge after extracting the oil from the fresh fruit bunch, contains soil particles, residual oils and suspended solids but only 5% of dry matter. While Wambeck (1990) stated that it represents 0.5 t/t of fresh fruit and can cause serious problems to the entire surrounding ecosystem, Brezing (1986) went one step further and estimated that a processing plant with a capacity of 10 tons fresh fruit per hour would require a water treatment plant comparable to that required by a population of half a million inhabitants!

Palm oil sludge is the material that remains after decanting the palm oil mill effluent (Devendra *et al*., 1981). It can be either filter-pressed, before dried and ground to produce dehydrated palm oil mill effluent, or centrifuged in the wet state, after having undergone anaerobic, thermophilic and acidophilic fermentation. In the latter case, the product is known as fresh centrifuged sludge solids of 15 to 20% dry matter and may be dehydrated to

form dry centrifuged sludge solids of between 94 and 97% dry matter (Table 4.3). The composition of the essential amino acids in palm oil sludge and palm kernel meal is given in Table 4.10. Although, there is insufficient information concerning the amino acid composition of different African oil palm products, data from Table 4.10 suggest that lysine is not present in an appropriate proportion in the protein.

Table 4.10. Composition of essential amino acids in palm oil sludge and palm kernel meal (% CP).

Amino acid	Palm oil sludge	Palm kernel meal	Amino acid	Palm oilsludge	Palm kernel meal
Arginine	0.19	2.20	Methionine+cystine	0.28	1.98
Histidine	0.14	0.27	Phenylalanine+tyrosine	0.77	1.28
Isoleucine	0.35	0.63	Threonine	0.34	0.54
Leucine	0.60	1.05	Tryptophan	0.12	0.17

Lysine	0.21	0.56	Valine	0.36	0.9

Source: Devendra (1977)

Fresh centrifuged sludge solids have been incorporated in a concentrate ration daily at a level of 14% total dry matter for pigs from 30 to 90 kilogrammes. The average daily gain and dry matter feed conversion for the maize control group and one of the experimental treatments containing fresh centrifuged sludge solids was: 700g, 3.36 and 650g and 3.83, respectively (Ong, 1982).

Dehydrated palm oil mill effluent has been incorporated up to 20% in dry rations for growing/finishing pigs; however, with increasing inclusion of dehydrated palm oil mill effluent, performance was poorer and carcass fat deposition increased (Table 4.11).

Table 4.11. The use of dehydrated palm oil mill effluent for

Table [illegible]. The use of dehydrated palm oil mill effluent for growing/finishing pigs (19–92 kg).

	0%	5%	10%	15%	20%
Maize, ground	78.9	74.9	70.4	65.9	61.4
Soya bean meal	13.5	12.5	12.0	11.5	11.0
Dehydrated palm oil mill effluent	-	5.0	10.0	15.0	20.0
ADG, g	730	700	690	720	650
AD feed intake, kg/d	2.24	2.30	2.34	2.38	2.34
AD feed conversion	3.04	3.31	3.38	3.34	3.60
Fat, % of carcass	16.7	17.9	20.4	19.9	19.5

Source: Ong (1982); all diets contained 5.5% fishmeal, 1.95% minerals and vitamins and 0.15% methionine

There have been numerous attempts to convert palm oil mill effluent into a viable animal feed resource; however, most methods have been discontinued due to the large initial capital

investment required, and particularly to the cost of fuel for dehydration. In Malaysia, one method used to convert fresh palm oil mil effluent into a potential feedstuff involved concentration by centrifugation or decantation, followed by absorption on other dry feeds like tapioca chips, grass meal or palm kernel meal. The absorption process can be repeated several times before final dehydration (Webb, Hutagalung and Cheam, 1976, cited by Devendra *et al*., 1981).

Perhaps, one idea would be to promote the use of the fresh centrifuged sludge solids (15–20% dry matter) for finishing pigs which, compared to younger animals, have a greater capacity to effectively use larger amounts of more liquid feeds. To date, apparently, this material has only been used in dry, concentrate rations (Ong, 1982). This approach might require supplementation to increase the crude protein content to that of a cereal, as well as some molasses to improve palatability. It would have to be fed immediately, preferably near the factory in

order to avoid transportation of a product that contains 80% of water. Interestingly, this approach was indicated by Devendra *et al.* (1981) for feeding sheep and cattle (Devendra, 1992); he referred to the use of this residual product alone, or combined with oil-rich fibrous residue. Perhaps, this same recommendation might be applied to feeding pigs.

In Ghana, oil palm slurry (sludge) has been used to replace 15, 20, 25 and 30% of maize in ad libitum diets for growing pigs to 70 kg. The control group was fed a maize-based diet; performance was not affected by the use of sludge. It was emphasized that with the exception of the loin-eye area, carcass measurements were improved when pigs were offered the slurry-containing feed (Abu *et al.*, 1984). The use of unconventional feeds for pigs in Ghana was also studied by Hertrampf (1988), who reported using oil palm sludge in place of maize at a level of from 15 to 30 percent. An increase in the daily feed intake and the average daily gain, in addition to a significant reduction in feed costs, was

reported.

Palm kernel meal

The palm kernel represents 5% of the weight of the fresh fruit bunch; it contains approximately 50% oil (Beltrán, 1986). The meal is produced by extracting the oil from the kernel within the palm nut. The resultant meal, sometimes also referred to as "palm kernel cake", can contain from 12 to 23% of crude protein depending upon the efficiency of the process used to extract the oil (Table 4.12).

As expressed earlier, the first oil palm by-product reportedly used for feeding pigs was the extracted and non-extracted palm kernel meal. It was first used in Europe as a substitute for wheat bran in rations for growing/finishing pigs. Currently, because of its poor palatability and high fibre content, it is more commonly fed to ruminants where it produces a hard, white carcass fat in

meat animals and a saturated fatty acid profile in the milk of lactating animals (PNI, 1990).

In Nigeria, palm kernel meal was used for pigs but it ranked lowest in protein quality compared to other local protein sources and produced a loss in weight (Fetuga *et al*., 1974, cited by Devendra, 1977). However, in Colombia, good results have been reported (Ocampo, 1994b) when almost 40% of palm kernel meal was used in the form of a restricted protein supplement that also contained soya bean meal. Correct storage, to reduce the risk of mould and the production of aflatoxins, was emphasized. The chemical composition and digestibility of palm kernel meal is shown in Table 4.12.

Table 4.12. Chemical composition/digestibility of palm kernel meal for pigs (%).

	average composition	digestibility
Dry matter	90	-

Crude protein	16	60
Crude fibre	16	36
Nitrogen free extract	48	77
Ether extract	10	25

Source: PNI (1990)

Whole fresh palm fruit

The chemical composition of the flesh (mesocarp) which surrounds the palm nut, and interior kernel, is presented in Table 4.13. The whole fresh palm fruit constitutes a potential energy feed resource for the small-scale pig producer without access to factory produced palm oil derivatives, such as, crude oil or oil-rich fibrous residue. In an experiment to determine the performance of pigs from 27 to 90 kg, fed twice daily with a restricted amount of protein, and whole fresh palm fruit as a partial or complete replacement for sorghum, Ocampo (1994a)

surprisingly found that, apart from consuming easily the fibrous material adjuring to the nut, the pigs often ate the entire fruit including the palm nut and the interior kernel. It was observed that first they ate the fibrous material surrounding various nuts, accumulated the nuts, then procceded to crack and extract the kernel within the nuts. One interesting observation was that when the fresh fruit was stored for more than seven days, palatability, and therefore voluntary consumption, was noticeably affected.

Table 4.13. The chemical composition of the pulp (mesocarp) and kernel of the fruit of the African oil palm (% DM).

	pulp	kernel
Crude protein	9.26	11.9
Crude fibre	25.5	31.6
Nitrogen free extract	31.3	25.9
Ether extract	28.6	26.9

Ash	5.4	2.5

Source: Ocampo (1994b)

Although the data in Table 4.14 show that best growth was obtained when only 25% of the fresh fruit was used in place of sorghum, it was emphasized that best economic gains were when 75 or 100% of the fruit was used. In a second trial, Ocampo (1994c) used 4 groups to study the optimum amount of rice polishings as a source of carbohydrate for growing/finishing pigs, also fed a restricted protein supplement (500 g/day) and whole, unprocessed African oil palm fruit, fed *ad libitum*. The amount of rice polishings offered during the growing phase (20–60 kg) was 100,200,300 and 400 g/day, and during the finishing phase (60–90 kg), 150,250,350 and 450 g/day. During the entire experimental period, the average consumption of the fresh fruit was 1.1, 1.1, 1.0 and 0.9 kg AD/day; the average liveweights were: 485, 515,492 and 497 g/day and dry matter conversions

were: 3.20, 3.20, 3.30 and 3.30, respectively. Reportedly, the most economic levels of rice polishings were 200 g/day during the growing phase and 250 g/day during the finishing phase.

Table 4.14. Whole fresh palm fruit (WFPF) as a partial or complete replacement for sorghum in diets for pigs from 27–90 kg.

% WFPF	25	50	75	100
Initial liveweight, kg	28.1	27.0	26.7	27.0
Final liveweight, kg	89.3	85.7	90.2	85.7
Days to finish	98	98	126	126
AD feed * intake, kg/d: sorghum	1.30	0.86	0.20	0.00
oil palm fruit	0.54	0.97	1.43	1.53
ADG, g	625	598	503	466
DM feed intake, kg/d	2.02	1.94	1.68	1.59
DM feed conversion	3.20	3.20	3.30	3.40

Source: Ocampo (1994a); [*]also fed 500 g/d of protein supplement: soya bean meal, 97.6%; dicalcium phosphate,2%; salt, 0.3% and vitamin/mineral premix, 0.3 percent

For the low income farmer in the tropics, the possibility to fatten a pig with one's own fresh palm fruit, and perhaps purchase only 60 kg of a high-quality protein supplement, or even use some rice polishings, is definitely an example of an alternative feeding system for pigs. This same author also emphasized that if a feeding system based on the whole fruit was used, there would be approximately 100 g/day of protein available to the pig via the kernel, and that this fact merited even further study. Obviously, the African oil palm has definite potential as a feed resource for pigs in the tropics. Perhaps, its utilization might be improved if more basic information related to its nutritional value was available.

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Chapter 5 Roots, tubers, bananas and plantains

Maize, high in energy due to its low fibre content and the high digestibility of its starch, is frequently used as the standard with which to compare other sources of energy for animals. However, roots, tubers, bananas and plantains are also rich sources of carbohydrate energy and, as such, constitute one of the basic components of the human diet in the tropics and subtropics. Because they can tolerate a wide range of climatic conditions

and infertile or marginal lands, their production is relatively stable which means that they are particularly well suited to sustainable farming systems.

The energy in roots, tubers, bananas and plantains is in the form of starch, and the structure of the starch in tubers does not differ significantly from that in cereals. The main objective of this chapter is to show that the digestible energy content of these alternative feedstuffs approximates that of cereals, therefore, they might offer considerable potential to furnish a considerable large share of the nutrients currently provided by more conventional energy sources for pigs (FAO, 1992).

BANANAS AND PLANTAINS

Although bananas (*Musa cavendishii*) and plantains (*Musa paradisiaca*) are mainly used as human food, a considerable amount of reject fruit could be fed to livestock, particularly to

pigs. The vegetative part of the plant, the pseudo-stems and leaves, contains more than 60% of the dry matter of the whole plant (Table 5.1) and has been used experimentally as meal for pigs in concentrate rations (Garcia *et al.*, 1991a,b).

Green bananas contain 20 to 22% of dry matter, mainly in the form of starch. When bananas ripen, the starch changes into simple sugars, sucrose, glucose and fructose. Compared to the ripe pulp which contains only 0.5% lignin some 60% of the crude fibre in the whole green banana is lignin, and this affects its digestibility (Van Loesecke, 1950). The inorganic fraction is poor in calcium and phosphorus but rich in potassium. Both green and ripe bananas have a low crude protein content and are particularly deficient in lysine and in the sulphur-containing amino acids. Additionally, green bananas contain tannins which cause the unripe banana to taste bitter and which can affect palatability, and therefore, voluntary consumption.

Table 5.1 Average yield of different parts of banana plants

Table 5.1. Average yield of different parts of banana plants.

Parts of the plant	Fresh		Dry matter	
	kg	%	kg	%
Pseudo-stem	27.0	60.5	4.2	54.5
Leaves	6.4	14.3	0.5	6.0
Fruit	11.2	25.2	3.0	39.0
Total	44.6	100.0	7.7	100.0

Source: Foulkes *et al*. (1978)

Chemical composition and digestible nutrients

The chemical composition of bananas and plantains is shown in Table 5.2.

Table 5.2. Chemical composition of bananas and plantains (% DM).

Components	DM	CP	CF	EE	Ash	NFE

Banana pseudo-stems*	5.1	2.4	20.5	2.3	14.3	60.5
Banana pseudo-stems**	6.3	4.9	25.1	-	17.7	-
Banana leaf meal*	94.1	9.9	24.0	11.8	8.8	45.5
Fresh banana leaves**	19.5	11.4	28.3	-	10.9	-
Plantain pseudo-stems*	-	2.8	13.8	1.2	15.6	66.6
Plantain leaves*	-	9.5	23.1	5.6	13.3	48.5
Green bananas*	20.9	4.8	3.3	1.9	4.8	85.2
Ripe bananas*	31.0	5.4	2.2	0.9	3.3	88.2

Source: * FAO (1993); ** Garcia *et al*. (1991a)

The digestibility of raw or cooked, peeled or non-peeled, green or ripe and fresh or dried bananas for pigs is presented in Table 5.3. The high level of free active tannins in fresh green bananas

and their residual presence in fresh ripe bananas is reflected in their negative protein digestibility. The ripe meal form produced the poorest results with regard to nutrient digestibility. This was no doubt due to the elevated temperature employed during processing which destroyed many of the nutrients.

Table 5.3. The digestibility of different forms of ripe and green bananas for pigs.

Type of banana	% digestibility of:				DE (MJ/kgDM)	Source
	DM	OM	N	GE		
Green bananas	76.9	-	-102.0*	-	13.39	Clavijo and
Ripe bananas	84.3	-	-42.7	-	13.05	Maner
Ripe banana meal	50.5	-	-126.6	-	7.13	(1973)
Green banana meal	83.6	-	3.4	-	13.42	
Green bananas	83.5	84.2	-19.0	79.5	13.31	Le Dividich

Cooked green bananas	87.9	88.6	26.4	84.3	14.39	and Canope (1975)
Peeled green bananas	88.6	89.1	-1.6	85.5	14.39	
Ripe bananas	89.5	90.1	38.4	85.5	13.92	

*** Negative Protein Digestibility refers to the affect of this dietary component on total digestibility due mostly to thepresence of lignin and tanins in green bananas**

Using bananas and plantains

Bananas can be fed to pigs either fresh, ensiled (Le Dividich *et al.*, 1976a; Le Dividich *et al.*, 1976b), or in the form of a dry meal, even though the latter is extremely difficult to achieve. Ripe bananas are very palatable and their degree of ripeness affects performance. If fed non-peeled ripe bananas *ad libitum*, the pig

will first eat the pulp leaving part of the peel; however, fed on a restricted basis, both the pulp and peel are eaten. If fed high levels of green bananas, palatability will affect voluntary intake and a lower consumption will affect the performance. Both bananas and plantains can, however, be sliced when green, dried in the sun, and in this way consumption will improve.

Although cooking green bananas improves consumption, growth performance does not equal that of ripe bananas. Table 5.4 shows that when growing/finishing pigs were fed relatively low amounts of ripe or green bananas, approximately one-third of total dietary dry matter, with a restricted amount of protein supplement, they had similar average daily gains and feed conversions.

Table 5.4. Performance of growing/finishing pigs fed bananas in different forms (30–90 kg).

% DM				

in diet	Form	ADG (g)	DM feed conversion	Source
0	cereal (control)	680	3.41	Hernández and Maner (1965), cited by Clavijo and Maner (1974)
45	fresh green	460	4.16	
59	cooked green	500	4.26	
71	ripe	560	4.44	
34	green	450	3.55	Viteri, Oliva and Maner(l971), cited by Clavijo and Maner (1974) Solis *et al.* (1985)
36	ripe	460	3.55	
59	green	510	4.29	
66	ripe	570	4.63	

Calles *et al.* (1970) studied the performance of growing/finishing pigs fed free-choice ripe bananas with a restricted amount of

either a 30 or 40% protein supplement. Growth performance, which significantly improved (660 *vs.* 770 g) when the 30% supplement was used, was assumed to be the effect of the additional intake of energy. It was suggested that the significant increase in the daily consumption of bananas during the first two to three weeks of the experimental period might have been associated, not only with the adaptation to a new feed, but also to the development of a larger stomach capacity.

Table 5.5 shows the performance of growing/finishing pigs fed different levels of green banana meal. When fed at increasingly higher levels, Celleri *et al.* (1971) found a reduction in average daily gain and a deterioration in feed conversion. Similar studies by Zamora *et al.* (1985) confirmed that pigs fed green banana meal at levels higher than 20–25% had lower performance.

Table 5.5. Performance of pigs fed different levels of green banana meal (30–90 kg).

%DM in diet	ADG (g)	DM feed conversion	Source
0	670	3.66	Celleri *et al.* (1971)
25	650	3.88	
50	630	4.04	
75	610	4.19	
0	620	4.09	Zamora *et al.* (1985)
20	620	4.12	
40	580	4.40	

Fresh ripe bananas can be used as a basic feed for the gestating sow; the farrowing performance, i.e. the number and average piglet birth weight, did not differ from the control group fed cereals. In fact, one group of gestating sows fed fresh, ripe bananas showed an improved liveweight gain compared to a similar group fed cereals; upon farrowing there were no

observed differences in the piglets. On the contrary, for the lactating sow, fresh, ripe bananas do not meet energy requirements, and fed ad libitum they may cause diarrhea which can affect performance (Clavijo and Maner, 1971).

Green banana meal can supply 50% of the ration for lactating sows with no significant difference in litter size at weaning but with a loss of sow body weight due to less digestible energy. This could be important because a loss of sow body weight can affect future reproductive performance. When used at the same level in the diet of 5-week old weaned piglets, the green meal controlled diarrhoea and produced a growth performance comparable to that obtained with the same level of cassava flour (Le Dividich and Canope, 1974).

Finally, banana leaf meal has been used to replace up to 15% of total dietary dry matter for growing pigs (Garcia *et al.*, 1991b); performance was satisfactory both from the point of view of

average daily gain and feed conversion (Table 5.6).

Table 5.6. Use of banana leaf meal for growing pigs (14–28 kg).

% DM in diet	ADG (g)	DM feed conversion
0	506	2.63
5	496	3.00
10	505	2.91
15	483	2.99

Source: Garcia *et al.* (1991b)

CASSAVA

Cassava (*Manihot esculenta Crantz*) is one of the major sources of carbohydrates for humans in Latin American and Africa. Recently, there has been increased interest in the feeding value of cassava for pigs. Although in most developing countries, the average yield is 10 t/ha (FAO, 1991) recent data from Brazil have

shown that it is possible to obtain 68 t/ha by using improved varieties, reasonably fertile soil and good management (Chandra, 1986).

Chemical composition

Cassava roots contain 30 to 40% dry matter, more than most roots and tubers. This depends on factors such as variety, soil type, moisture, climatic conditions and the age of the root at harvest. Starch and sugar are the predominant components of the dry matter, approximately 90%, with starch being the most important (Table 5.7).

Although the crude protein content of cassava root is 2 to 4% in dry matter, the true protein content is less than half this amount, due to the fact that 50% of the nitrogen in the roots is in the form of non-protein-nitrogen. Furthermore, the available true protein is deficient in the sulphur-containing amino acids (Table 5.8). The

roots contain significant amounts of vitamins, particularly vitamin C, thiamine, riboflavin and niacin.

Table 5.7. Chemical composition of cassava roots and leaves (% DM).

	Roots		Leaves	
	Dominguez, 1985	**Ravindran *et al.*,1982**	**Eggum, 1970**	**Ravindran *et al.*, 1982**
Crude protein	3.5	2.9	34.1	20.2
Ether extract	0.8	1.4	6.3	6.2
Crude fibre	4.2	5.0	10.7	29.0
Ash	4.1	2.3	6.2	7.8
Nitrogen free extract	87.4	88.4	42.7	36.8

Table 5.8. Amino acid composition of cassava

roots and leaves (g/16g N).

Amino acid	Roots	Leaves
Threonine	2.08	3.52
Valine	2.78	5.30
Methionine	0.70	1.29
Isoleucine	2.08	4.06
Leucine	3.80	7.43
Phenylalanine	2.80	4.81
Lysine	0.35	4.81
Total	59.11	84.90

Source:Ravindran *et al.* (1982)

The yield of cassava leaves, depending on the variety and soil fertility, can vary from 2 to 8 tons of dry matter/ha/year (Oke, 1978). Cassava leaves have a relatively high crude fibre and

crude protein content; values ranging from 17 to 34% crude protein in dry matter have been reported for cassava leaf meal (Ravindran *et al.*, 1983). Unlike the roots, approximately 85% of the crude protein in the leaves is true protein, however, owing to their high crude fibre content, the digestibility is only 70 to 80% (Eggum, 1970). The amino acid pattern shows that cassava leaf protein is deficient in methionine but rich in lysine (Table 5.8). Since harvesting the leaves every two months does not affect root yield, and does increase leaf yield (Luteladio and Egumah, 1981), an interesting alternative might be to treat the leaves and roots as two distinct crops; the roots for carbohydrates and the foliage for protein, vitamins and minerals.

One of the major factors which has limited the more widespread use of cassava roots for pigs is its content of the cyanogenic glycosides, linamarin and lotaustralin. These glycosides, upon contact with the endogenous enzyme, linamerase, produce hydrocyanic acid. The reaction is initiated when the roots are

crushed or the cellular structure is otherwise damaged. Presently, interest is centered on using varieties naturally low in glycosides and in the development of processing methods which reduce the danger of hydrocyanic acid toxicity.

Maner (1973) and Tewe (1992) outlined some of the processing methods used to reduce or eliminate the toxicity of cassava roots. Boiling destroys the enzyme, linamerase, removes the free cyanide and also the glycosides. Chopping or crushing, followed by sun drying, removes both the glycosides and the hydrocyanic acid; while drying with hot air removes the free hydrocyanic acid and destroys the enzyme, but leaves the glycosides largely intact. Ensiling can cause the destruction of the intact glycosides, thereby reducing the content of cyanide. In some varieties, the leaves contain even more cyanogenic glycosides than the roots; however, Rajaguru *et al.* (1979) pointed out that this should not be a serious problem since sun-drying can eliminate most of the cyanide in the leaves.

Digestibility

Several studies have emphasized the high digestibility of cassava root diets for pigs, and their comparison to cereals (Table 5.9). Sonaiya and Omole (1977) reported that digestibility was not effected by using up to 15% cassava in the diet, however, earlier studies had shown that with piglets (Aumaitre, 1969; Arambawela *et al.*, 1975) and older pigs (Maust *et al.*, 1972) the digestibility of cassava-based diets was superior to that of cereals. Likewise, no effect on the nutrient uptake was reported by Chicco *et al.*, (1972) when cassava completely substituted maize. Tillon and Serres (1973), in support of this same observation, found that the digestibility of cassava root was not significantly modified by grinding, heating or drying and that the digestible energy of cassava root was comparable to that of maize and other cereals.

Table 5.9. Comparison of the digestibility of cassava root and cereal-based diets for pigs (%).

	Cassava root[a]	Cassava root[b]	Cereal[c]
Dry matter	93.8	92.4	87.7
Crude protein	40.5	36.4	82.5
Ether extract	51.7	44.3	76.40
Crude fibre	48.8	54.5	58.2
Nitrogen free extract	98.5	95.6	83.7
Gross energy	-	89.2	84.6
Digestible energy, MJ/kgDM	15.72	15.73	

[a] **Mesa and Maner (1970), cited by Pond and Maner (1974);**

[b] **Totsuka *et al.* (1978);**

[c] **Zamora and Veum (1979)**

Eggum (1970) studied cassava leaf amino acid availability which ranged from 55% for valine and isoleucine to 84% for serine. He found that only 59% of the methionine was biologically available. The low values were attributed to the high crude fibre content and the presence of tannins in the leaves. Although cassava leaves are not a common source of energy, Allen (1984) has reported a value of 9.0 MJ/kg of dry matter.

Use For Pigs

Fresh cassava roots

Raw cassava, as seen by the data in table 5.10, can supply the major source of energy for growing/finishing pigs. Fed *ad libitum*, on a ration of chopped raw cassava roots and a protein supplement, growing/finishing pigs gained weight less rapidly but as efficiently as those fed a maize-soya bean meal ration. The consumption of chopped fresh cassava roots by

growing/finishing pigs varies according to the protein content of the supplement. The voluntary daily intake of cassava roots was reported to increase throughout the growing/finishing period when the amount of protein supplement increased (Job *et al.*, 1975, cited by Maner *et al.*, 1977). Trials have shown that fresh cassava, of low cyanide content and properly supplemented with a source of protein, minerals and vitamins, can be used as a major source of energy throughout the entire swine life cycle. However, if they are fed bitter roots, performance will suffer: consumption will decrease and they will exhibit a lower average daily gain, and in some cases even lose weight (Gomez *et al.*, 1976).

Table 5.10. Performance of growing/finishing pigs fed fresh cassava roots.

% DM in diet	Liveweight (kg)	ADG (g)	DM feed conversion	Source
0	18–99	840	3.43	

68	"	790	2.80	Maner *et al.* (1977)
0	21–86	750	2.81	Job *et al.* (1975), cited by Maner *et al.*(1977)
60	"	650	3.02	
0	20–54	680	2.84	Buitrago *et al.* (1978)
51	"	630	2.76	

Cassava root silage

In the humid tropics, sun drying is difficult, often resulting in a low quality product with severe *Aspergillus* mould and related aflatoxin contamination. Artificial drying of cassava roots is expensive, therefore ensiling, in addition to diminishing the content of hydrocyanic acid, is often a more viable means to store cassava for use as a feed resource (Gómez and Valdivieso, 1988).

Buitrago *et al*. (1978) compared cassava root silage to fresh

chopped cassava roots for growing/finishing pigs and found that the average daily gain and dry matter feed efficiency were similar. However, when the silage material was prepared from the entire plant, roots and foliage, performance was affected. This was possibly the result of either the low palatability or the high fibre content of the silage material. Although there is limited data with respect to the use of chopped cassava root silage for sows, its use for growing/finishing pigs indicates that performance is comparable to that of chopped fresh cassava roots (Table 5.11).

Table 5.11. Performance of growing/finishing pigs fed * different forms of cassava: fresh, chopped, chopped root silage and root and foliage silage.

Treatment	% in diet	Liveweight (kg)	ADG (g)	DM feed conversion
Maize control diet	0	20–54	680	2.84
Fresh chopped				

cassava	51	"	630	2.76
Chopped cassava root silage	50	*	650	298
Fresh Chopped cassava	61	18–98	750	3.43
Chopped cassava root silage	60	"	770	3.25
Root and foliage silage	53	"	640	3.52

Source Buitrago *et al* (1978);* plus a protein supplement

Cassava root meal

Comprehensive studies on cassava meal for pigs have been conducted by researchers from the Colombian Agricultural Institute and the International Center for Tropical Agriculture (CIAT). Cassava meal was prepared by chopping the whole root

and drying it in a forced air oven at 82°C. The dry cassava meal substituted maize in a 16% crude protein concentrate ration. There was a slight decrease in average daily gain as the level of cassava meal increased, however, feed intake was similar for all groups indicating that palatability was not a problem (Table 5.12). Adding 10% molasses increased consumption and improved average daily gain in all groups. A second experiment evaluated various protein supplements with high levels of cassava root meal. Performance was again satisfactory. Doubling the vitamin trace supplement improved performance, but in this instance, the addition of molasses produced no effect.

Table 5.12 Cassava root meal for growing/finishing pigs (% DM)

% DM in diet	Liveweight (kg)	ADG (g)	DM feed conversion	Source
0	19–105	770	3.47	Maner *et al.* (1977)
69	"	710	3.49	

0	16–95	710	3.30	CIA T (1978)
68	"	650	3.40	
0	21–96	720	2.67	Lougnon (1979)
50	"	680	2.93	

Aumaitre (1969) compared iso-nitrogenous diets containing 50% cassava root meal to diets with the same amount of barley, oats, wheat or maize. The average daily gain of weaner pigs from 5–10 weeks of age was higher on the cassava diet; liveweight gains were reported of 416, 386, 380, 360 and 354 g/day, respectively. Feed per unit of gain was similar for all groups. More recently, data from studies at the University of Hawaii (Gómez, 1992) have shown that piglets from weaning to between 20–25 kg, fed diets containing 20 to 25% cassava meal, performed similarly or slightly better than those fed a maize-soya bean meal ration.

When cassava root meal was fed at levels of 22, 44 and 66%

(Shimada, 1970) from 30 to 90 kg, performance was lowered, only, with the group fed the highest level. Cresswell (1978) found that diets based on cassava root meal may benefit from 0.2% methionine; its addition improved feed consumption and growth, and increased urinary thiocyanate excretion.

Researchers at CIAT have studied the effects of cassava/soya bean meal or maize/soya bean meal diets on swine reproduction. A consistent trend to produce smaller litters (8.4 *vs.* 10.0) when sows were fed on cassava meal (Maner, 1973; Gómez *et al.*, 1976; Gómez, 1977) was attributed to a deficit of methionine. More recently, however, Gómez *et al.* (1984) showed that supplementation with 0.3% methionine did not improve reproductive performance and suggested that incorrect handling of the meal might have explained the difference (Table 5.13). Interestingly, piglet survival rate at 56 days on the methionine treatment was similar to that of maize.

Table 5.13. Cassava root meal* for pregnant-lactating gilts.

Performance parameters	Maize	Cassava meal	Cassava meal plus 0.3% methionine
Gilts farrowed	14	10	10
Average number piglets born	8.5	9.1	9.4
Average birth weight, kg	1.09	1.06	1.07
Piglets weaned/litter at 56 days	7.1	8.2	8.0
Average piglet weaning weight, kg	16.9	16.2	16.5

Source: Gómez *et al*. (1984); * soya bean meal as protein supplement

Cassava leaves

Growth performance was lowered as the proportion of fresh cassava leaves was increased in the ration of growing/finishing pigs (Mahendranathan, 1971). This adverse effect was evidently due to the high level of hydrocyanic acid present in the fresh leaves, which affected the palatability. Additional attempts to use cassava leaf meal as a substitute for other protein supplements in swine diets have been less encouraging. CIAT (1978) and Alhassan and Odoi (1982) reported lower gains and poorer feed efficiency when cassava leaf meal was included at 20 and 40%, or at 20 and 30%, in diets for growing/finishing pigs, respectively (Table 5.14).

Ravindran (1990) substituted 10,20 and 30% cassava leaf meal in a maize/soya bean meal diet for growing pigs and found that the average daily gains and feed efficiency decreased linearly with increasing levels of leaf meal. The performance of pigs fed a diet containing 10% cassava leaf meal was improved by the addition of methionine and additional energy supplementation. This same

author emphasized that the relatively high crude protein level and lysine content of cassava leaves (See Tables 5.7 and 5.8) might justify the development of processing methods that would make this feed resource more competitive for swine production.

Table 5.14 Cassava leaf meal (CLM) as a supplement for swine rations

	0% CLM	20% CLM	40% CLM
Initial liveweight, kg	15.1	15.1	15.3
Final liveweight, kg	101.1	98.3	96.8
ADG, g	720	570	550
DM feed conversion	3.20	4.30	4.70

Source: CIAT (1978)

SWEET POTATO

The productive potential of the sweet potato (*Ipomoea batatas*

(L.) Lam.) varies from 24 to 36 t/ha of fresh roots (Morales, 1980) and from 4.3 to 6.0 tons of dry matter/ha of foliage. It is also possible to obtain up to three harvests, yearly (Ruiz *et al.*, 1980). Although, the main nutritional importance of sweet potato is in the starch content of the root, it is also a source of important vitamins, such as; vitamin A, ascorbic acid, thiamine, riboflavin and niacin. Recently, it has been shown that the fresh vines can provide up to 27% of the dry matter and 40% of the total dietary protein for growing/finishing pigs (Table 5.20).

Chemical composition

The chemical composition of sweet potato roots and vines is shown in Table 5.15. The roots contain low amounts of crude protein, fat and fibre; carbohydrates make up between 80 to 90% of the dry matter in the roots. The uncooked starch is very resistant to hydrolysis by the enzyme amylase, however, when cooked, the hydrolizable starch fraction increases from 4% to

55% (Cerning-Beroard and Le Dividich 1976).

Table 5.16 shows the nutritional quality and deficiencies of sweet potato roots and vines in total sulphur-containing amino acids and lysine in terms of an ideal protein for pigs (Fuller and Chamberlain, 1982). The typsin inhibitors in raw sweet potato roots decrease protein digestibility, but they can be destroyed by cooking (Martinez *et al.*, 1991).

Table 5.15 Chemical composition of sweet potato roots and vines (% DM)

	Roots		**Vines**	
	Noblet *et al.*, 1990	**Dominguez, 1990**	**Godoy and Elliot, 1981**	**Dominguez, 1990**
Dry matter	-	29.2	15.0	14.2
Crude protein	4.4	6.4	18.2	18.5
Ash	3.1	5.3	17.7	12.5

Acid detergent fibre	4.2	5.5	22.3	23.5
Neutral detergent fibre	6.9	-	26.2	-
Lignin	0.7	-	5.7	-
Ether extract	0.6	-	-	-
Gross energy MJ/kg DM	17.1	16.5	-	14.4

Table 5.16. Amino acid content of sweet potato roots and vines (g/100 g protein).

	Roots			Vines
	Ideal* protein	Purcell *et al.* 1972	Li 1982	Walter *et al.* 1978
Isoleucine	3.8	4.2–10.1	3.9–5.1	4.9

Leucine	7.0	7.8–9.2	6.2–7.9	9.6
Total sulphur	3.5	2.8–3.8	3.0–3.9	2.8
Phenylalanine + tyrosine	6.7	11.9–13.6	6.2–10.1	10.6
Threonine	4.2	5.5–6.3	5.1–6.1	5.3
Trytophan	1.0	0.8–1.2	-	-
Valine	4.9	6.8–8.3	4.9–8.2	6.3
Lysine	7.0	4.2–7.2	4.3–4.9	6.2
Chemical score: total sulphur	100	80–109	85–110	80
lysine	100	60–103	61–70	88

*** Fuller and Chamberlain (1982)**

Digestible nutrients

Sweet potato roots, raw or cooked, and peeled or non-peeled, have been evaluated in digestibility trials. Peeling significantly increases crude protein digestibility but has no effect on digestible or metabolizable energy, or on the total digestibility of nutrients. Although cooking increases the digestibility of nutrients, it does not affect the utilization of energy (Table 5.17). Wu (1980) found that the net energy of the sweet potato, 8.5 MJ/kg dry matter, was only 79% that of maize, while Noblet *et al*. (1990) showed that net energy was the same, 12.3 MJ/kg of dry matter. Canope *et al.* (1977) reported that cooking improved the digestibility of all nutrients, especially nitrogen. Rose and White (1980) fed raw sweet potato roots to pigs and associated a low intake with a high digestible energy value, 15.8 MJ/kg dry matter.

Table 5.17. Digestibility of sweet potato root diets (%)

Table 5.17. Digestibility of sweet potato root diets (%).

	DM	OM	N	GE	DE (MJ/kgDM)	Source
Raw	90.4	92.1	27.6	89.3	14.1	Canope *et al*. (1977)
Cooked	93.5	94.5	52.8	93.0	14.5	
Raw	95.3	96.1	49.8	94.2	15.8	Rose and White (1980)
Cooked	85.5	-	76.0	89.2	14.7	Domínguez (1992)
Silage	90.1	91.0	32.0	89.0	16.3	Tomita *et al*. (1985)
Chips	-	91.8	52.3	89.3	15.3	Noblet *et al*. (1990)

Tomita *et al*. (1985) evaluated silage made from sweet potato roots and found that the high digestible energy value was related to the high gross energy value of the silage. Lin *et al*. (1988) reported that poorer nitrogen digestibility was probably due to antitryptic factors, which although lowered, were not entirely eliminated by this method of conservation. Dominguez (1992) found that the inclusion, in dry matter, of 10% of fresh sweet

potato vine to a diet of cooked sweet potatoes and soya bean meal lowered the digestibility of all nutrients. An increase in fibre was assumed to be the cause. However, the same author stated that the digestible energy value was acceptable, and even higher, compared to the value of 4.1 MJ/kg dry matter reported by Takahashi *et al*. (1968) for this foliage. Although in this diet the retention of nitrogen was low, it increased when 10% foliage was added, from 14.1 to 16.4 g/day, which suggests that sweet potato foliage is an acceptable protein source for pigs when included at moderate levels in the diet.

Use for Pigs

Watt (1973) summarized the results of feeding sweet potato roots to pigs. He concluded that the use of cooked, as opposed to raw sweet potatoes, increased the average daily gain and that 500 g/day of a protein supplement supported optimal growth. Corring and Rettagliati (1969) also found that in rations for

growing/finishing pigs cooked sweet potatoes were superior to the raw form. The data in the following table show, that as raw sweet potatoes progressively replaced maize, the daily feed intake and average daily gain decreased, however, there were no significant changes in feed conversion (Table 5.18).

Table 5.18. Raw sweet potato roots (% DM) as an energy source for growing/finishing pigs (32–90 kg).

Maize/raw sweet potatoes *	88.2/0.0	46.8/42.4	22.4/69.5	8.5/84.3
DM feed intake, kg/d	2.29	2.05	1.91	1.92
ADG, g	740	650	580	570
DM feed conversion	3.16	3.23	3.31	3.37

Source: Marrero (1975); * with a protein supplement

Sweet potatoes can also be chopped, sun-dried, and used as an energy source for pigs. The data in Table 5.19 show that the

performance of pigs fed dried sweet potato chips, although inferior to pigs fed on maize, offers an additional and interesting option for feeding pigs in the tropics.

Table 5.19. Dried sweet potato chips as an alternative energy source for finishing pigs.

Sweet potato chips, % DM	ADG (g)	DM feed conversion	Source
0	650	3.36	Tai and Lei (1970)
54–88	560	3.81	
0	840	2.92	Cornelio *et al*. (1988)
46	720	3.38	
0	640	3.79	Manfredini *et al*. (1990)
40	600	4.01	

Table 5.20 shows the performance of pigs fed a basal diet of

cooked sweet potato, with or without the addition of fresh sweet potato foliage, to replace 25 and 50% of the soya bean meal in the basal diet. A maize/soya bean meal diet was used as the control. The results suggest that, providing an adequate protein supplement is used, cooked sweet potato may totally replace maize for finishing pigs. The use of the fresh vines at both levels, decreased total dry matter intake. This was probably due to their low dry matter content, 12 to 15 percent. With the lower level of substitution, which implied the use of fresh vines at a level of 13.6% of total dietary dry matter, the feed conversion was similar to that obtained with the sweet potato/soya bean meal basal diet. The higher level of fresh vines, 27% of dietary dry matter, resulted in a poorer gain and increased feed conversion. In an earlier experiment, when Kohn *et al.* (1976) substituted sweet potato vines for part of a maize/soya bean meal ration for pigs weighing 26–90 kg, it was also reported that the average daily gain decreased and the feed conversion increased.

The complete substitution of maize by cooked sweet potatoes for weaned piglets of 7 to 15 kg decreased the average daily gain from 329 to 284 g and increased the dry matter feed conversion from 1.95 to 2.48 (Mora *et al*., 1990). When the fresh vines were used to replace 10% of total dry matter, Mora *et al*. (1991) found that performance of 6 to 12 kg weaners tended to improve, both from the point of view of average daily gain (186 *vs.* 202 g/day) and feed conversion (2.80 *vs.* 2.50).

Table 5.20. Use of sweet potato roots and vines for growing/finishing * pigs.

Constituent:	%DM			
Ground maize	83.8	-	-	-
Soya bean meal	16.2	18.4	13.8	9.2
Cooked sweet potato	-	81.6	72.6	63.8
Fresh sweet potato vines	-	-	13.6	27.0
Initial liveweight, kg	29.2	28.6	29.2	29.2

Final liveweight, kg	90.4	90.4	84.4	80.2
DM feed intake, kg/d	2.30	2.71	2.46	2.43
ADG, g	770	770	690	640
DM feed conversion	3.01	3.51	3.55	3.81

Source: Domínguez *et al.* 1991: * (30–90 kg)

OTHER TUBER CROPS

Yam (*Dioscorea* spp.) is a tropical or semitropical root crop that grows extensively in West Africa and to a lesser extent in other tropical areas. Although there are many types of yam, the most economically important are the white yam, (*D. rotundata*), the yellow yam (*D. cayenensis*) and the water yam (*D. alata*). The nutritional composition of yam (Table 5.21) varies among species and cultivars. The major carbohydrate component is amilopectin and only a small proportion of the total carbohydrate fraction

consists of mono and disaccharides. Although the percentage of tryptophan in yam is rather high, 1.0%, it is deficient in lysine and the other sulfur-containing amino acids.

Taro or cocoyam (*Colocasia esculenta Schott*), which originated in India and South East Asia, is presently cultivated in many tropical and subtropical countries. The starch grains of the corms are very small which makes taro highly digestible. The level of crude protein, although slightly higher than that in yam, cassava or sweet potato, contains low amounts of the amino acids: histidine, lysine, isoleucine, tryptophan and methionine.

Table 5.21. Chemical composition of other tuber crops (% DM).

	Discorea sp		***Colocasia esculenta***	
	tubers	**leaves**	**tubers**	**leaves**
Dry matter	34.2	24.1	26.2	8.2
Crude protein	8.1	12.0	8.7	25.0
Crude fibre	2.6	25.3	1.7	12.1

Ash	5.2	7.9	4.0	12.4
Ether extract	0.8	2.3	0.4	10.7
Nitrogen free extract	83.3	52.5	85.2	39.8

Source: FAO (1993)

Table 5.22. Performance of growing pigs fed yam or taro.

Tuber	Liveweight (kg)	ADG (g)	DM feed conversion	Source
Cooked yam	20–56	580	3.25	Esnaola (1986)
Raw yam	20–43	510	3.40	CIAT (1978)
Cooked yam	20–43	760	2.53	
Cooked taro	30–59	590	3.20	Anon (1986)

The taro leaf contains 25% crude protein in dry matter, in addition to calcium, phosphorus, iron, vitamin C, thiamine, riboflavin and niacin. Although, some results of feeding trials using these tuber crops are presented in Table 5.22, normally both yam and taro are too expensive to be used as livestock feed.

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Chapter 6 Organic wastes

Recycling organic wastes for commercial pig production is not a new idea (Williams and Cunningham, 1918; Hunter, 1919; Ashbrook and Wilson, 1923; Hultz and Reeve, 1923). The utilization of kitchen wastes from institutions such as hospitals, schools or hotels, and the use of distillery wastes, fish-processing, abattoir wastes and agricultural residues, if used to feed livestock, would help to reduce the increasingly important, problematic question of environmental pollution. Organic wastes are subject to rapid deterioration and contamination by microorganisms, some of which are extremely pathogenic. However, it has been shown that by ensiling, or by thermal treatment, preferably complete sterilization, organic wastes can be completely decontaminated and safely used as alternative feedstuffs. This chapter discusses different alternatives for

processing organic wastes as well as their nutritional value when fed to pigs.

KITCHEN WASTES

The nutritive value of kitchen wastes for pigs is adequate with respect to protein and energy, however, its low dry matter content tends to affect growth due to a reduction in total dry matter intake, principally in younger animals, fed *ad libitum* (*González et al.*, 1984). The digestibility of the nutrients contained in kitchen wastes is variable and somewhat related to the source. Kornegay *et al*. (1970) in reviewing the performance of pigs fed heat-treated garbage residue from different sources concluded that it should be supplemented with a 15 to 18% crude protein concentrate in order to improve the daily liveweight gain (to more than 600 g/day) and feed efficiency. No marked difference in carcass quality was observed when garbage residues were fed to pigs. The chemical composition and the

digestibility of kitchen wastes is given in Table 6.1.

Table 6.1. Composition and digestibility of kitchen wastes.

	Medium composition (% DM)		Digestibility (%)	
	(a)	(b)	(a)	(b)
Dry matter	31.6	13.2	80.5	87.3
Organic matter	92.1	93.5	85.1	-
Ash	7.9	6.5	38.0	-
Crude protein	17.5	19.7	61.0	83.1
Ether extract	20.1	34.1	77.0	94.1
Crude fibre	3.6	5.3	56.6	72.5
Nitrogen free extract	50.9	35.0	95.8	88.6
Gross energy, MJ/kg DM	-	23.1	-	87.8
Digestible energy, MJ/kg DM	-	-	-	23.9*

Sources: (a) Woodman and Evans (1942);
(b) Balazs *et al*. (1971); * Differs from the mean value for gross energywhich suggests a higher energy content for this sample

INDUSTRIAL SWILL

The experience during the 1970s of one sub-tropical country, Cuba, to consolidate a nationwide pig feeding strategy based on the collection of organic wastes from all major institutions will serve to illustrate the concept of industrial swill used throughout this chapter. Private kitchen wastes are excluded; however, all institutionally-produced organic wastes, including agricultural residues and fish wastes are collected daily in specially designed trucks and brought to the processing plants, generally adjacent to the pig units. Once in the processing plant, any undesirable material, particularly metal objects, are removed and the wastes

are ground in a hammer mill to a particle size of 80 mm. Following that, they are sterilized in an autoclave at 121°C and 1.0 to 1.5 atmospheres for 30 minutes (del Rio *et al*., 1980). This process converts the organic wastes into a heterogeneous feeding material known as "processed" swill which is mixed with molasses to produce a final product called "terminal" swill.

The "terminal" swill is pumped directly from the processing plants to the feed troughs in the nearby feedlots. Each ten thousand head feedlot requires 80 tons of organic wastes, daily.

Nutritional value of industrial (processed) swill

Industrial swill, known in Cuba as "processed" swill, contains between 14 and 19% dry matter, and contains in dry matter: 18–22% crude protein, 6– 12% crude fibre, 6–10% fat and 10% ash. It has a gross energy value of about 18.0 MJ/kg dry matter (Dominguez, 1985). The mineral composition of processed liquid

swill is offered in Table 6.2.

Table 6.2. Mineral composition of processed liquid swill.

	% DM		**ppm**
Calcium	1.1–4.5	Copper	32–48
Phosphorous	0.4–1.0	Iron	650–2170
Magnesium	0.03–0.9	Zinc	15–97
Sodium	0.23–0.93	Manganese	21–52
Potassium	0.57–1.36		
Cloride	0.23–0.74		
Sulphur	0.12–0.48		

Source: Dominguez *et al*. (1983)

The composition of the essential amino acids of processed swill is presented in Table 6.3. The level of methionine is insufficient and although the amount of lysine appears to be suitable, its

precise availability is unknown due to the technology used in treating the organic residues, particularly the effect of heat. Even though tryptophan was not determined, Maylin (1983) has reported a level of 0.3% in processed swill.

Table 6.3. Amino acid composition of "processed" Cuban swill, %.

Amino acids	Grau *et al* (1978)	Maylin (1983)	Amino acids	Grau *et al*. (1978)	Maylin (1983)
Lysine	1.49	0.80	Cystine	ND	ND
Histidine	0.60	0.37	Isoleucine	0.99	0.61
Arginine	1.31	0.90	Leucine	1.71	1.18
Threonine	0.92	0.59	Tyrosine	0.63	0.51
Valine	1.26	0.78	Phenylalanine	1.06	0.73
Methionine	0.28	0.27	Tryptophan	ND	ND

ND: Not determined

ND: Not determined

The digestive utilization of the main nutrients of processed swill is slightly lower when compared to cereals (Table 5.9). Nevertheless, the digestive indice of nitrogen, gross energy and digestive energy, the latter with an average value of 15.3 MJ/kg dry matter, shows that processed swill offers considerable potential as an alternative feed resource for pigs in the tropics (Table 6.4).

Table 6.4. Digestibility of processed swill.

Digestibility (%)				Digestive energy (MJ/kg DM)	Source
Dry matter	Organic matter	Nitrogen	Gross energy		
79.8	84.0	83.7	-	16.16	Grau *et al*. (1976)
85.3	87.9	83.6	85.4	16.15	Maylin and Cervantes

					(1982)
81.6	-	82.2	82.3	15.25	Maylin (1983)
80.7	-	76.8	79.7	14.37	González *et al*. (1986)
78.4	-	76.0	77.1	14.60	Domínguez *et al.* (1987)

It has been shown (González *et al.*, 1984) that for growing/finishing pigs processed swill can be used to substitute up to 50% of the dry matter of cereals. There was no affect on feed conversion; however, it was emphasized that due to its low dry matter content, 14 to 19%, younger animals could not obtain sufficient nutrients (Table 6.5).

Table 6.5. Performance of growing/finishing pigs fed different proportions of cereal and "processed" liquid swill in ad *libitum* rations (% DM).

Processed swill/cereal	0/100	25/75	50/50	75/25	100/0
Initial liveweight, kg	26.0	26.6	26.8	27.1	26.1
Final liveweight, kg	95.1	95.8	94.3	94.3	92.4
DM feed intake, kg/d	2.06	2.07	1.89	1.97	1.75
ADG, g	590	550	550	520	430
DM feed conversion	3.47	3.75	3.45	3.76	4.04

Source: González *et al*. (1984)

Supplementation of swill

When Cuba first began to develop a national pig feeding only treated organic wastes, known at that time as "processed" swill, was used for feeding grower/finishers. The average daily amount fed to pigs weighing between 25 and 90 kg was 12 kg. It contained 18 to 22% dry matter depending on the quality of the product in each processing plant. The average daily gain was never more than 450 g and the dry matter feed conversion was

approximately five tons of "processed" swill to one ton of liveweight gain (Pérez *et al*, 1987).

The idea of using molasses in "processed" swill for pigs caught on quickly after ruminants, in Cuba, were successfully fed diets containing in dry matter up to 70% C molasses (see Chapter 3). However, the addition of C molasses diluted the energy and the protein in the final mixture, known as "terminal" swill, and this resulted in increased, therefore poorer, feed conversions (Domínguez, 1985). The immediate solution was to mix a dry cereal concentrate with the "terminal" swill before it was pumped to the feedlot, or add it directly to the "terminal" swill in the trough.

Gradually, therefore, the major commercial pig feeding system used in Cuba from 1975–1985 for pigs from 25 to 90 kg consisted of (dry matter basis): 37% organic wastes, 33% C molasses and 30% concentrates (Pérez *et al*., 1982). Depending on the quality

of the product produced in each of the more than 20 processing plants, the daily ration was 8 to 10 kg of "terminal" swill and 0.8 kg of a dry concentrate ration Eventually, between 400 and 500 thousand pigs were fed on this system, daily.

After a time, it was noted that the addition of C molasses, followed by the addition of a cereal-based concentrate produced no major change in feedlot performance. Moreover, in a review of eleven experiments to determine the effect of supplementing "terminal" swill with concentrates, Domíguez (1988) showed that there was no positive effect on performance: the average daily gain remained unchanged while the dry matter conversion fluctuated from 4.14 to 6.88 with an average value of 5.17.

An effort was made to improve the performance traits of pigs fed this system and different additives were studied; however, none of them caused sufficient improvement to merit their commercial application, even the experimental results of Domínguez and Lan

(1985) which had shown that the addition of copper sulfate would improve gains by some 50 g/day, as well as improve dry matter feed conversions by 10% (Table 6.6). As mentioned, the problem involved almost half a million growing/finishing pigs, daily.

During this same period, 1980–1985, that Cuban researchers studied different additives to improve the performance of pigs fed "terminal" swill, another type of molasses, B molasses, was first extracted from the sugarmills and promoted as an energy feed resource for swine, particularly for use with processed swill (Table 6.7).

The data in Table 6.8 show the performance of pigs fed processed swill and C or B molasses, with or without additives as growth promoters. The utilization on an experimental basis of these additives significantly improved performance; however, the conversion to B molasses, besides improving the average daily gain and feed conversion by 17 and 15%, respectively, was seen

from a commercial perspective as easier to implement since it only involved the extraction of a different type of molasses from the sugarmills. The infrastructure was already in place, therefore, by the mid-to-late 1980s, the major commercial pig feeding system in Cuba based on "processed" swill was converted to B molasses (see Chapter 3). Most interestingly, as observed in this same table, the performance of pigs fed the swill/concentrate ration with B molasses, and additives, differed little from that of the performance obtained with a typical maize/soya bean meal ration!

Table 6.6. Performance of growing/finishing pigs fed a ration of: processed swill/C molasses/ cereal concentrate and different additives.

Additive/level	Initial LW, kg	FinalLW, kg	ADG(g)	DM feedconversion	Source
Zeolite (%)					
					Castro

0.0	41.0	95.0	460	5.19	(1976)
10.5	40.0	96.0	490	4.92	
Sodium bicarbonate (%)					
0.0	26.0	93.0	500	4.78	Domínguez *et al.*
0.25	27.0	94.0	510	4.72	(1980)
Copper (ppm)					
0.0	26.0	95.0	500	4.91	Domínguez and Lan
250–170[b]	26.0	101.0	550	4.51	(1985)
Copper + vitamin E (ppm)					
0.0+0.0	25.0	96.0	510	4.42	Domínguez *et al.*
250–22	25.0	98.0	580	4.05	(1981)

a as $CuSO_2$. $5H_2O$. b Variable level

Table 6.7. Performance of pigs fed processed swill and different types of cane molasses.

Type of molasses	% DM	Initial LW (kg)	Final LW (kg)	ADG (g)	DM conversion	Source
C molasses	32	46	87	450	7.00	Figueroa *et al.*
B molasses	33	48	100	570	5.40	(1985)
C molasses	27	29	58	510	4.90	Pérez *et al.*
B molasses	27	30	61	550	4.70	(1987)
Syrup-off*	27	31	65	610	4.20	

*** Syrup-off = end product produced upon centrifuging the final massecuite in a raw sugar refinery**

Table 6.8. Performance of pigs fed processed swill, cereal concentrate and C or B molasses, with or without additives.

	C molasses		B molasses	
	no additives	additives*	no additives	additives*
Initial liveweight, kg	26.3	26.4	26.2	26.3
Final liveweight, kg	88.7	95.3	94.5	96.7
DM intake, kg/d	2.47	2.71	2.52	2.75
ADG, g	530	680	620	710
DM feed conversion	4.78	4.01	4.07	3.89

Source: Dom�nguez *et al.*, (1988) * additives= 200 ppm of copper sulfate and 1% of a vitamin/mineral premix toprovide requirements according to NRC (1979)

SLAUGHTER HOUSE BYPRODUCTS

Meat meal and meat and bone meal

Meat meal, and meat and bone meal, byproducts from slaughter houses contain: hair, hoof, hide, trimmings, blood, intestinal tracts and condemned carcasses. If the dry rendered product contains more than 4.4% of phosphorus, it is designated as meat and bone meal. The processing method is important, since high temperatures can cause the destruction of sulphur-containing amino acids and reduce the availability of lysine (Atkinson and Carpenter, 1970). The chemical composition of meat and meat and bone meal is given in Table 6.9.

Table 6.9. Chemical composition of meat meal and meat and bone meal (% DM).

Parameters	Meat meal	Meat and bone meal	Parameters	Meat meal	Meal and bone meal
Dry matter	93.0	94.0	Calcium	8.3	9.4
Crude protein	55.6	50.9	Phosphorus	4.1	4.6

Ether extract	8.7	9.7	DE (MJ/kg DM)	10.1	9.5
Crude fibre	2.3	2.40			

Source: NRC (1988)

Table 6.10. Composition of essential amino acids in meat meal and meat and bone meal (%).

Amino acid	Meat meal	Meat and bone meal	Amino acid	Meat meal	Meat and bone meal
Arginine	3.79	3.65	Cystine	0.68	0.46
Histidine	1.04	0.96	Phenylalanine	1.91	1.65
Isoleucine	1.84	1.47	Tyrosine	0.96	0.79
Leucine	3.51	3.02	Threonine	1.78	1.60
Lysine	3.09	2.89	Tryptophan	0.38	0.28
Methionine	0.73	0.68	Valine	2.61	2.14

Source: NRC (1988)

Jorgensen *et al.* (1984) studied the digestibility of various nutrient components of meat and bone meal. The digestibility of dry matter, 87%, and organic matter, 91%, was satisfactory, while that of nitrogen, 79%, was inferior to that of soya bean meal, 92 percent. The apparent ileal availability of the essential amino acids averaged 72% for meat and bone meal as compared to 80% for soya bean meal. Likewise, the ileal availability of lysine in meal and bone meal, 65%, was significantly lower than that of soya bean meal, 80 percent. The amino acid composition is given in Table 6.10. Meat meal is of lower quality than fish meal or soya bean meal (Atkinson and Carpenter, 1970; Beames and Daniels, 1970) and should not be used as the only source of protein in diets where the source of energy is sugar cane products, roots, bananas or oil palm derivatives. Perhaps, a level of meat meal similar to that proposed when "protein paste" is used would be adequate (See below).

Blood meal

Although blood represents approximately three percent of total liveweight, loss during slaughter can reduce the total amount saved to less than one percent. Fresh blood contains approximately 20% dry matter of which 80% is crude protein; the essential amino acids are given in Table 6.11. Blood meal produced by conventional vat-cooking and drying processes has been found to be of limited use in pig rations because of poor palatability and the low availability of lysine. Spray and flash drying procedures have significantly improved palatability and more importantly, lysine availability, increasing its potential value for swine (Miller and Parsons, 1981; Parsons *et al.*, 1985). The concentration of isoleucine remains a limiting factor; however, with proper supplementation flash-dried blood meal can be used at a level of 5-6% for adult and growing/finishing pigs (Wahlstrom and Libal, 1977). The chemical composition of spray-dried (NRC, 1988) and flash-dried (Miller and Parsons, 1981) blood meal is, in % air-dry: dry matter, 93 and 90; crude protein, 86 and 83; ether extract, 1.2 and 1.5; crude fibre, 1.0 and 1.5 and digestible

energy, 12.5 and 15.1 MJ/kg, respectively.

Table 6.11. Essential amino acids in spray and flash-dried blood meal (%).

Amino acid	Spray-dried*	Flash-dried**	Amino acid	Spray-dried*	Flash-dried**
Arginine	3.6	4.0	Cystine	1.0	1.0
Histidine	5.2	5.3	Phenylalanine	5.9	7.5
Isoleucine	0.9	1.0	Tyrosine	2.3	3.0
Leucine	11.0	12.5	Threonine	3.6	4.4
Lysine	7.4	9.7	Tryptophan	1.0	1.1
Methionine	1.0	1.0	Valine	7.5	9.0

Source: * NRC (1988);
**** Miller and Parsons (1981)**

Barbosa *et al.* (1983) substituted blood meal for soya bean meal in a sorghum-based diet with no difference in average daily gain but with an increase in the conversion (Table 6.12). When Itori *et al.* (1984) substituted soya bean meal for combinations of peanut meal and flash-dried blood meal in maize-based diets, the average daily gains and feed conversions were similar, suggesting similarity in the apparent biological value of the protein sources.

Table 6.12. Performance of growing/finishing pigs * fed flash-dried blood meal.

	Level of blood meal (% DM)			
	0	2	4	6
ADG, g	690	710	710	710
DM intake kg/d	2.14	2.14	2.28	2.38
DM feed conversion	3.06	3.21	3.22	3.39

Source: Barbosa *et al*. (1983); * liveweight 25–95 kg; basic diet: sorghum/soya bean meal

Feather meal

Although feather meal is one of the most protein-rich feedstuffs available, more than 90% crude protein, it is poor in some essential amino acids like methionine, lysine, histidine and tryptophan (Table 6.13). Therefore, the proportion of feather meal that can be used in the ration will depend on the content and the quality of the protein in the other components of the diet. Whereas steam cooking at 3.2 atmospheres can produce a good quality product, Eggum (1970) reported that acid hydrolysis (HCl at pH 6 for 20 hours) can also be used to produce a meal of high digestibility and similar biological value. The chemical composition of feather meal, in % dry matter, is: crude protein, 92.7; ether extract, 2.7; ash, 4.7; crude fibre, 0.1 (Boda, 1990). This same author also reported that feather meal had a dry

matter content and in vitro digestibility of 96 and 46%, respectively.

Table 6.13. Composition of the essential amino acids in steam and acid-treated feather meal (g/16 g nitrogen).

Amino acid	Steam-treated	Acid-treated	Amino acid	Steam-treated	Acid-treated
Arginine	2.08	2.23	Cystine	6.29	6.06
Histidine	0.72	0.63	Phenylalanine	4.61	4.85
Isoleucine	4.82	5.55	Tyrosine	2.48	3.11
Leucine	8.05	8.27	Threonine	4.84	4.87
Lysine	2.08	2.23	Tryptophan	0.73	0.62
Methionine	0.72	0.76	Valine	7.25	7.73

Source: Eggum (1970)

Although different feeding trials have shown that 5 to 7%

hydrolyzed feather meal can replace soya bean or fish meal for growing/finishing pigs (Hall, 1957; Lavorenti *et al.*, 1983), when Combs *et al.* (1958) used 10% to supplement a maize diet, all major performance parameters were affected. Table 6.14 shows that feather meal should not be regarded as a full-value protein feed and its use should be restricted to low levels if maximum growth and efficiency of feed utilization by pigs is the objective.

Table 6.14. Performance of growing/finishing pigs fed hydrolyzed feather meal.

Level (%)	ADG (g)	DM feed conversion
0.0	737	3.41
2.5	725	3.42
5.0	685	3.34
7.5	691	3.58

Source: Lavorenti *et al.* (1983)

Protein paste

In many tropical countries, the slaughter of livestock is accompanied by the loss of a considerable amount of raw material which could be used as a protein supplement for feeding pigs. The most important sources are: blood, hair, viscera and bones, and sometimes even the entire carcass. In the more developed countries, animal slaughter is often associated with processing plants and slaughter residues are generally converted into tankage and meat meal. However, frequently in the tropics, because such procedures are often complicated or expensive, these products are simply discarded. And in most cases, dead animals are simply buried or incinerated.

In Cuba, a system has been designed to process abattoir wastes and dead animals into a high-quality protein paste-like material (Pineda *et al.*, 1986). The technology is simple; the processing plants are integrated with the “terminal” swill processing plants

adjacent to the commercial pig fattening units (see 6.2). The main equipment needed is a horizontal autoclave designed for interior mechanical movement. An average temperature of 130 °C and a pressure of 2 atmospheres during 60 minutes can convert all of this material, including sectioned, large, dead animals, into a feed resource for pigs of substantial biological value, known as "protein paste".

The chemical composition of "protein paste", which can be preserved several days using either inorganic acids, or molasses, is given in Table 6.15. Preserved in molasses (20%), it has the disadvantage of a slightly reduced protein level, however, it is more palatable than that which is preserved with inorganic acids (Domínguez, 1990).

The digestibility of the nutrients in protein paste preserved with inorganic acids was evaluated in diets using cane refinery "syrup-off" (see Chapter 3) as the sole energy source. The

protein digestibility was similar to that of soya bean meal and superior to that of meat meal or torula yeast. In addition, nitrogen retention was higher than that of the other protein sources studied (Table 6.16).

Table 6.15. Chemical composition of protein paste (% DM).

	Conserved with:	
	Sulphuric acid	**type C molasses (20%)**
Dry matter	30.5	41.60
Crude protein	40.2	23.50
Ash	25.8	21.20

Source: Domínguez (1990)

Table 6.16. Digestibility of nutrients in diets * supplemented with

conventional sources of protein compared to "protein paste" (%).

Parameter	Source of protein:			
	soya bean meal	torula yeast	meat meal	protein paste
Dry matter	94.6	94.2	89.1	91.4
Organic matter	95.8	95.3	93.9	91.8
Crude protein	90.2	85.4	87.4	90.9
Nitrogen retention	54.4	53.6	52.8	57.5

Source: Domínguez *et al*. (1986); * cane refinert "syrup -off" as energy source

Table 6.17 shows the performance of two groups of growing/finishing pigs fed protein paste preserved with C molasses. The paste contributed 25 or 50% of total dietary

protein in a basal diet of cooked sweet potatoes. The control group was fed a diet of cooked sweet potatoes and torula yeast, only. At a level of 25% of dietary protein in the form of "paste" there was no significant difference in performance compared to the control ration. It was emphasized, that even though the pigs fed 50% protein in the form of "protein paste" showed an inferior performance, the average daily gain and feed conversion were still very satisfactory when compared to the average performance of pigs in the tropics fed the more conventional cereal diets (Domínguez *et al.*, 1990).

Table 6.17. Use of protein paste to replace torula yeast in basal diet of cooked sweet potatoes for pigs (30–90 kg).

	% crude protein from:		
	control	**25% level**	**50% level**
Torula yeast	62.9	40.9	19.1
Protein paste	-	26.5	52.8

DM intake, kg/d	2.36	2.30	2.33
ADG, g	780	780	700
DM feed conversion	3.03	2.95	3.33

Source: Dominguez *et al*. (1990)

DISTILLERY BYPRODUCTS

Grain distillery byproducts

The production of distilled liquors and alcohol from cereal grains includes grinding, cooking and the addition of enzymes to hydrolyze the starch to simple sugars prior to the addition of yeast, which is used to ferment the sugars to alcohol. After fermentation, the alcohol is distilled and a residue remains that can be used for livestock feeding. It contains yeast and other unidentified nutrients and is known as “stillage”. The coarse grain fraction, usually removed from the whole stillage and

dehydrated, is called dried distillers' grains. The water soluble materials and remaining fine particles, upon dehydration, form dried distillers' solubles. Another variant, following the removal of ethyl alcohol by distillation, is to produce distillers' dried grain with solubles. Currently, this is the major grain distillery byproduct used as a commercial feedstuff for swine.

Chemical composition The nutritional value of distillers' feeds may be influenced by the type or form of cereal employed in the fermentation process. The chemical composition of maize distillery byproducts compared to ground maize is shown in Table 6.18.

Table 6.18. Chemical composition of grain distillery byproducts (% AD).

	DDG[a]	DDS[b]	DDGS[c]	Maize
Dry matter	94.0	91.0	91.0	88.0

Crude protein	27.0	28.5	27.0	8.50
Ether extract	9.8	8.4	9.3	3.60
Crude fibre	12.1	4.4	9.1	2.30
Ash	2.4	7.0	4.5	-
Digestible energy (MJ/kg DM)	14.2	13.9	15.2	14.8
Calcium	0.11	0.30	0.14	0.03
Phosphorus	0.43	1.44	0.66	0.28

Source: NRC(1988); [a] DDG=dried distillers' grains:[b] DDS=dried distillers' solubles,

[c] DDGS=distillers' driedgrain with solubles

Distillery feeds are relatively high in crude fibre which could limit their use as an energy source. However, their relatively high content of fat means that the amount of digestible energy compares favorably to that in maize. Generally, distillery feeds are a good source of phosphorus, water-soluble vitamins and

vitamin E, but they are low in calcium. The composition of the essential amino acids in several sources of distillery byproduct feedstuffs, compared to maize, is presented in Table 6.19.

Feeding distillers' dried grain with solubles

"Distillers' dried grain with solubles" has been used in rations for both weaners and grower/finishers. For weaners, the feed intake and average daily gain were slightly improved by the addition of 2.5% in the diet, while at a level of 5% no additional benefit was observed (Orr *et al.*, 1981). Harmon (1975) fed a maize-soya bean meal ration to 10 kg weaners in which "distillers' dried grain with solubles" substituted 9, 18 and 27% of the control diet. The average daily gain decreased as the level of "distillers' dried grain with solubles" increased. The data in Table 6.20 suggest that this residual material can serve better as an alternative source of energy and protein for growing/finishing pigs.

Table 6.19. Composition of the essential amino acids in distillery

byproduct feeds compared to maize (% AD).

	DDG[a]	DDS[b]	DDGS[c]	Maize
Arginine	1.10	0.96	0.96	0.43
Histidine	0.60	0.66	0.64	0.27
Isoleucine	1.00	1.30	1.38	0.35
Leucine	3.00	2.31	2.21	1.19
Lysine	0.60	0.91	0.70	0.25
Methionine	0.50	0.55	0.49	0.18
Cystine	0.20	0.44	0.29	0.22
Phenylalanine	1.20	1.46	1.47	0.46
Tyrosine	ND[4]	ND	ND	ND
Threonine	0.90	1.00	0.92	0.36
Tryptophan	0.20	0.86	0.69	0.09
Valine	1.30	1.52	1.48	0.48

Source: NRC (1988); [a] DDG=dried distillers' grains:

[b]DDS=dried distillers' solubles;

[c] DDGS=distillers' driedgrain with solubles; [d]ND = not determined

Table 6.20. Performance of growing/finishing pigs fed "distillers' dried grain with solubles".

% DM in diet	ADG (g)	DM feed conversion	Source
0	830	3.12	Cromwell *et al*. (1984)
10	820	3.09	
0	632	3.38	Livingston and Livingston (1966)
25	578	3.56	

"Distillers' dried grain with solubles" were used at levels of 17.7 and 44.2% in substitution of a maize-soya bean meal diet for

feeding pregnant gilts. Litter size and average piglet weight at birth were similar for all three treatments (Table 6.21). During lactation, the sows received a fortified 16% crude protein ration. Litter size, average piglet weaning weight and sow weight changes were similar for all groups and it was suggested that “distillers'dried grain with solubles” can partially replace, on a lysine equivalent basis, a diet of maize-soya bean for pregnant sows (Thong *et al.*, 1978).

Table 6.21. Reproductive performance of gilts fed “distillers' dried grain with solubles” (DDGS).

Production parameters	DDGS (% DM in diet)		
	0.0	17.7	44.2
Average no.piglets born alive	8.8	8.6	8.2
Average piglet birth weight, kg	1.4	1.4	1.4
Average no. piglets weaned	7.3	7.4	7.3
Average piglet weaning weight, kg	6.5	6.7	6.6

Source: Thong *et al.*(1978)

Cane molasses distillery byproducts

Rum is produced by the fermentation by yeast of the sugars in cane C molasses into alcohol. After the alcohol is distilled, a residue, known as “molasses distiller's solubles” remains; it contains only 7% dry matter. Molasses distiller's solubles are a good source of vitamins and are reported to contain unidentified growth factors (FAO, 1993); however, due to their low dry matter content they are generally discharged, untreated, into the surrounding ecosystem. If concentrated or dehydrated to 45–50% dry matter, they are known as “concentrated distillers' solubles” (Table 6.22). In either case, the yeast, which converts the sugars to alcohol, tends to settle as a thick sludge at the bottom of the fermentation vats. It tends to spoil quickly, therefore, most often, it is dried and bagged for use in

concentrate feeds.

Table 6.22. Chemical composition (% DM) of molasses distillers' solubles (MDS) and concentrated molasses distillers' solubles (CMDS).

	MDS*	CMDS**
Dry matter	7.0	49.8
Crude protein	16.6	13.3
Crude fibre	0.6	-
Ash	21.6	22.5
Ether extract	0.2	-
Nitrogen free extract	60.8	-

Sources: * FAO, (1993),
**** Gorni *et al*. (1987)**

"Concentrated molasses distillers' solubles" can serve as an alternative source of energy and protein for growing/finishing pigs. Gorni *et al*. (1987) added 12% of concentrated molasses distillery solubles, of 50% dry matter, to a sorghum/soya bean meal diet and obtained identical performance. Garcia *et al*. (1991) used dehydrated molasses distillery solubles in a cereal-based feeding system, while Sarria and Preston (1992) improved performance by adding, on a dry matter basis, up to 20% of concentrated molasses distillery solubles, containing 60% dry matter, to a sugar cane juice-soya bean meal feeding system (Table 6.23).

The major problem with fresh molasses distillers' solubles relates to its extremely low dry matter content, about 6 percent. The author has used the same sun-dried filter-press mud, three times, in an attempt to absorb the nutrients present in this material, prior to mixing the filter-press mud in a concentrate ration.

Table 6.23. Performance of growing/finishing pigs fed different forms of molasses distillery solubles (MDS): concentrated or dehydrated.

% MDS	ADG (g)	DM conversion	Source
0	860	2.96	Gorni *et al*.(1987)*
12	860	2.97	
0	630	4.01	Sarria and Preston (1992)**
20	650	3.62	
0	768	4.51	Garcia *et al*. (1991)***
15	938	4.26	

*** MDS of 50% DM and level in sorghum/soya bean meal diet as % AD.**

**** MDS of 60% DM and level in sugarcane juice/soyabean meal diet as % DM,**

*** dehydrated MDS of 94.95% DM and level in sorghum/soyabe anmeal diet as % AD

FISH SILAGE

The technique for making fish silage is cheap and simple. It can be made from by-catch (scrap fish) or fish wastes (offal), preferably chopped or ground prior to the addition of acids (Cervantes. 1979), or carbohydrates (Tibbets *et al.*, 1981). The action of the endogenous enzymes break down the protein causing the tissue to liquefy. The presence of mineral or organic acids, or the result of the fermentation of the added carbohydrate, decreases the pH, which in turn inhibits the growth of bacteria enabling long term storage of the material. An additional way to preserve fish wastes is to mix and store it directly in molasses. A brief description of all three methods follows:

Acid silage

Acid fish silage is one in which by-catch or fish wastes, preferably chopped or ground and placed in non-metallic vats, are mixed with an acid solution and stirred several times daily, three to five days, until liquefied. The lowered pH prevents bacterial putrefaction permitting the fish tissue to be stored for several months, preferably in protected or closed vats. Reportedly, the best acids to use in this process are the organic acids, propionic and formic (Wiseman *et al*., 1982; Rattagool *et al*., 1980, cited by Green *et al*., 1983), and certain mineral acids, either sulphuric (Cervantes, 1979), or hydrochloric (Machin, 1990).

In Cuba, Alvarez (1972) used a concentrated solution of sulphuric acid and water (1:1 ratio by volume) in order to determine the optimal proportion of acid solution to use in preserving fish wastes obtained from a processing plant. The residues were not

chopped and the quantities of acid solution used were: 20, 30, 40, 50, 60, 70, 80 and 90 ml/kg of fish residue. The amount of 60 ml of acid solution/kg of fresh fish waste (residue) was selected as optimum. The final pH of the material was 1.8 and prior to use it was neutralized to a pH 5 by the addition of calcium carbonate. Following that, Cervantes (1979) observed that if fish wastes were ground prior to the addition of the acid solution, then the amount of 30 ml/kg of raw material was sufficient. Domínguez (1988) stated that one general rule using other types of acid might be to adjust the pH to below four.

As earlier mentioned, during storage, the protein of fish silage is broken down by enzymes to low molecular weight peptides and amino acids and this results in high levels of free, soluble amino acids which appear to be stable (Green *et al*., 1983). In fact, it has been shown that less than 8% of the amino nitrogen is released as ammonia in fish silage stored for up to 220 days. Degradation under normal storage conditions does not appear to

be of great importance; however, at temperatures exceeding 30° C, tryptophan, methionine and histidine are most likely to decompose (Gildberg and Raa, 1977).

Fermented silage

The principle of fermented fish silage is similar to that of acid silage, however, in the case of fermented silage, preservation is due to the acidity arising from the growth of lactic acid producing bacteria. By-catch or fish wastes, preferably chopped or minced, are placed in nonmetallic vats and mixed with a carbohydrate source such as, cassava, sweet potatoes or molasses, or a mixture of them, and stored airtight. The immediate addition of a small amount of molasses, 20% (Domínguez, 1988), or 30% (Green *et al.*, 1983) is recommended in order that fermentation begins rapidly. However, if the objective is to produce a balanced or complete silage ration, using roots as the principal source of carbohydrates and fish wastes as the source of protein, then the following proportions, in air-dry, should be used: roots, 50–30%; molasses, 10% and fish wastes, 40–60% (Domínguez, 1988).

Molasses preservation

Molasses, alone, can be used for the preservation of by-catch or fish offal which have preferably been chopped or ground, and drained, prior to mixing in a minimum 1:1 ratio, by weight, with molasses. A weighted wire netting should be placed on the surface of the fish/molasses mixture in order that the raw material is kept completely submerged in molasses. This is particularly important if whole by-catch is used. Although the osmotic pressure of the molasses causes an initial dehydration of the raw fish residue, an acidic fermentation also occurs which tends to preserve this material. The mixture should be stirred daily until the p^H lowers to below five (Domínguez, 1988).

Chemical composition

The chemical composition of fish silage prepared from different substrates is presented in Table 6.24. This information suggest that fish silage produced using by-catch, surprisingly, does not exhibit a higher nutritional value than that produced from only wastes (offal). Although fish silage is considered primarily a protein supplement, it can also contain energy provided by residual oil.

The amino acid composition of fish silage is presented in Table 6.25. Lysine, threonine and sulphur-containing amino acids are present in high levels, as they are in fish meal, and as a consequence fish silage would appear to be an excellent protein supplement in the pig diet. In fact, Whittemore and Taylor (1976) reported that the digestible energy and digestible nitrogen were higher in diets containing fish silage than in those of fish meal.

Feeding fish silage

The results of substituting the protein in fishmeal for that of acid fish silage for growing/finishing pigs, where processed swill and C molasses were the major components of the ration, are presented in Table 6.26. It was stated that at the highest level of substitution, the palatability (acidity) of the ration was probably responsible for the reduction in feed intake which undoubtedly affected growth performance. Emphasis was placed on the need to neutralize this material to a pH of five prior to use, particularly when used in rations based on processed swill which, in themselves, tend to be acidic (Cervantes, 1979).

Table 6.24. Chemical composition of different types of acid fish silage (% DM).

Substrate	Origin/type	CP	Oil	Ash	Source
By-catch (scrap)	Thailand	58.1	4.2	30.0	Rattagool *et al*. (1980)
	Britain	66.5	16.6	11.7	Green *et al.* (1983)

	Cuba	52.6	10.4	11.9	Cervantes (1979)
		69.1	15.3	10.8	Tatterton & Windsor (1974)*
Fish wastes	hearing	48.3	28.2	12.5	Whittemore and Taylor
	white fish	71.1	2.4	19.9	(1976)
	tuna	69.9	12.2	10.5	Tatterton & Windsor (1974)*
	cod	68.1	2.1	19.0	Disney *et al.* (1978)*
	various	67.7	14.2	4.2	Green *et al.* (1983)
	various	38.9	4.4	9.9	Alvarez (1972)
					Cervantes (1979)
	Cuba: by-catch &	37.0–	6.1–	4.0–	Penedo *et al.*

Mixture	fish wastes	70.2	12.3	11.1	(1986)

* **cited by Green *et al.* (1983)**

Table 6.25. Amino acid composition * of fish silage (%).

Amino acid	Smith and Adamson 1976	Whittemore and Taylor 1976	Amino acid	Smith and Adamson 1976	Whittemore and Taylor 1976
Arginine	3.7	5.1	Cystine	0.3	0.8
Histidine	1.2	1.7	Phenyalinline	2.4	3.5
Isoleucine	1.9	2.8	Tyrosine	1.1	1.6
Leucine	3.7	5.2	Threonine	2.2	3.0
Lysine	4.2	6.2	Tryptophan	-	-
Methionine	0.8	1.8	Valine	2.4	3.3

*** Penedo *et al.* (1986) reported the presence of lysine, methionine and cystine in the leftover liquid portion (6% DM)as 3.3, 1.3 and 0.6 g/kg, respectively**

Table 6.26. Replacement of protein in fishmeal (FM) for acid fish silage (AFS) * in diets based on processed swill and C molasses for growing/finishing pigs (% DM).

	FM 100%	FM/AFS (75:25)	FM/AFS (50:50)	AFS 100%
Processed swill	46.6	46.2	45.8	45.0
C molasses	44.3	43.9	43.5	42.7
Fishmeal	9.1	6.8	4.5	-
Fish silage		3.1	6.2	12.30
Initial liveweight, kg	25.5	25.3	25.5	25.20
Final liveweight, kg	78.2	78.8	77.9	68.9
ADG.g	538	545	535	438

DM feed consumption, kg/d	2.1	2.1	2.1	1.9
DM feed conversion	4.10	4.00	4.00	4.40

Source: Cervantes (1979).

*** fish wastes, ground, preserved with 30 ml/kg acid solution (see 6.5.1)**

Information related to the feeding of low-fat, by-catch fish silage to both weaners and grower/finishers is shown in Table 6.27. Similar to the results in the previous table, a reduction in feed intake could have caused lowered average daily gains when the highest level was fed. Smith (1977) reported that when fish silage with a low oil content was used, it was possible to include levels as high as 10% dry matter in the diet for growing/finishing pigs without negative effects on performance or carcass quality; however, herring fish silage fed at the same rate reduced

performance and produced an unacceptable carcass. Although the use of fish silage in growing/finishing rations sometimes results in "off-flavors" in the pork, this can be easily controlled by reducing the amount fed or removing the silage from the ration 20 days prior to slaughter.

**Table 6.27. Performance of weaner and grower/finisher pigs fed diets containing fermented fish silage.*

% DM in diet	Weaners			Grower/finishers		
	DM feed intake, kg/d	ADG (g)	DM feed conversion	DM feed intake, kg/d	ADG (g)	DM feed conversion
0	0.87	420	2.07	2.30	730	3.10
3	0.89	400	2.22	2.50	730	3.40
6	0.91	430	2.12	2.60	740	3.50
9	0.80	390	2.07	2.10	680	3.80

Source: Tibbetts *et al.* (1981); *
fermented silage by-catch, 60%, ground maize, 30%, molasses, 5% andlactobacillus culture, 5 percent

More recently, in Vietnam, the nutritional value of fermented silage made from shrimp heads, blood and molasses was compared to fishmeal in 17% crude protein rations for growing pigs (AHRI, 1993). The silage material and fishmeal had similar protein contents in dry matter, 46.2 and 45.8%, respectively. The objective was to study the effect of replacing 10% fishmeal (dry matter basis) by silage, which after a period of ten days' fermentation had a pH of 4.3–4.5 (Table 6.28). A reduction in growth, when the silage replaced 100% of the fishmeal, was assumed to be related to a reduction in feed intake, possibly caused by lowered palatability. Acidity might have been the factor responsible for the reduction in consumption. It was concluded that silage could replace 75% of the fishmeal and that other protein-containing materials, such as, small fish, crabs, silk

worms and animal offal might be similarly processed for use as animal feeds.

Fish silage, neutralized to a pH of five prior to feeding, should be an excellent source of protein to complement energy feed resources such as sugar cane juice or molasses, bananas, cassava, sweet potatoes or the African oil palm. In this regard, Perez (1993) even suggested that the preservation of whole or chopped by-catch or fish wastes directly in B molasses, in a proportion of two parts by weight of molasses (air-dry basis) to one of fish, would constitute a complete ration consisting of between 8 and 10% protein in dry matter for fattening pigs.

Table 6.28. Replacement of fishmeal (FM) with shrimp's head, blood and molasses fermented silage (SHS) for pigs (% DM).

	FM (100%)	FM/SHS (50:50)	SHS (100%)
Initial liveweight, kg	13.9	15.2	14.50

Final liveweight, kg	72.8	76.0	73.0
DM feed intake, kg/d	1.95	1.89	1.74
Average daily gain, g	491	523	487
DM feed conversion	3.97	3.61	3.57

Soure: AHRI (1993), basic diet (% DM) ground maize. 58; rice bran, 20; fried soya bean meal, 5;fishmeal, 10; minerals and vitamins,2.

Finally , Green *et al.* (1983), in their review of the use of fish silage in pig diets, emphasized that the major cause of discrepancy amongst researchers in defining performance has been attributed to diversity with respect to both the type of fish tissue and the silage method employed. They concluded that in experiments where the same amount of lysine, and in which the levels of other essential amino acids were adequate, fish silage diets have produced better feed conversions than soya bean

meal diets. Perhaps, one of the problems, not mentioned, is the need to put more of these ideas into practice!

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