BIOFUEL CO-PRODUCTS AS LIVESTOCK FEED

Opportunities and challenges

Chapter 13

Utilization of oil palm co-products as feeds for livestock in Malaysia

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ABSTRACT

Several oil palm industry co-products can be utilized as animal feed, notably oil palm fronds (OPF), oil palm trunks (OPT), palm press fibre (PPF), empty fruit bunches (EFB), palm kernel cake (PKC) and palm oil mill effluent (POME). These co-products are obtained either during the harvesting of the fruits, or the extraction and refining of crude palm oil (CPO) or palm kernel oil (PKO) Many of the co-products from the plantation (field residues) and processing mills need further processing before they can be used effectively in livestock diets

Information on chemical composition, nutritive values, improvement methods and feeding response of ruminants fed oil-palm co-product-based diets are widely documented Besides livestock feeds, some co-products are also utilized in the manufacturing of industrial products and organic fertilizers. OPF has been successfully utilized as feedstuffs either freshly chopped, as silage, or processed into pellets and cubes. Optimum inclusion level in beef and dairy animals is about 30 percent. Ensiled OPT produced reasonably good liveweight gain (LWG) of about 0.7 kg/day in beef cattle when fed at levels between 30 and 40 percent. PPF has a lower digestibility, which limits its inclusion in ruminant diets to less than 20 percent. PKC is a high-energy source and is a cost-effective ingredient in ration formulations for various livestock species Beef and dairy production utilizing PKC-based diets are more economical under local dietary and management systems than non-PKC-based diets. High content of fibre and shell can limit use in poultry and aquaculture. With biotechnological treatments, inclusion levels of PKC can be increased to 30 percent for poultry feeding. POME, the residue left from the purification of CPO, can be combined with PKC and OPF to provide a cost-effective and complete ration for feeding ruminant livestock. The use of EFB, the material remaining of fruit bunches after steaming, is very limited and is generally utilized only after irradiation and culture-substrate treatments. The utilization of other locally available oil-palm-based co-products is targeted at increasing dietary energy content and improving nutrient digestibility These include palm-fatty acid distillates (PFAD) and CPO, which are more suited for supplementing dairy animals, poultry, swine and aquaculture. The use of spent bleaching earth (SBE), another co-product from the oil-palm refineries, is very limited at present. Improvement in feed conversion efficiency (FCE) and maximizing the use of local feedstuffs represents a potential area of application to reduce the high cost of feed in Malaysia, especially in the non-ruminant subsector.

INTRODUCTION

The oil palm industry has become the backbone of Malaysia's economic and social development. It is developing rapidly to meet high global demand for palm oil, oleo-chemicals and biodiesel. In 2008, Malaysia produced about 17 74 million tonne of palm oil from over 4.49 million hectare of planted area. Palm oil and palm kernel oil (PKO) contributed about 30 percent of the total global production of oils and fats in 2008 (Oil World, 2009). The plantation area has increased from 97 000 ha in 1965 to 4.5 million ha in 2008 The planted area in Peninsular Malaysia, Sabah and Sarawak were 2 41, 1.33 and 0.74 million ha, respectively (MPOB, 2009) The private-estate sector occupied the largest area, amounting to about 60 percent of the total area. The rest of the estates were government and state-schemes (28 percent) and smallholders (12 percent) The government-owned plantations include the Federal Land Development Authority (FELDA), the Federal Land Consolidated Authority (FELCRA), the Rubber Industry Development Authority (RISDA) and the State Economic Development Corporation (SEDC). Of the government-owned plantations, FELDA is the largest owner of oil palm land. As of 2009, there were 252 oil palm mills and 36 refineries in Peninsular Malaysia, 117 oil palm mills and 11 refineries in Sabah, and 41 oil palm mills and 5 refineries in Sarawak. Over the period 1990–2005, the land area under oil palm increased by 6.6 percent per

MAIN MESSAGES

- **A large percentage of available palm kernel cake (PKC) should be efficiently used for domestic use as the main energy and protein sources for feeding ruminant and non-ruminant animals.**
- **Oil palm frond (OPF) is a good fibre source for ruminant feeding, and it is available in Malaysia throughout the year.**
- **Complete diets based on oil-palm co-products can be produced for various livestock species, including for aquaculture. Recommended levels of PKC feeding are 30–80 percent for growing beef cattle and 20–50 percent for goats, while for lactating dairy cattle it is 20–50 percent. Recommended levels of PKC in feed for poultry and freshwater fish are no more than 10 percent. The optimum level of OPF in feed for ruminant animals is 30 percent.**
- **Use of various oil-palm co-products as sources of feed for ruminants raised on the plantation itself is to be encouraged and maximized in order to reduce production costs.**
- **There is a huge potential – currently underestimated – for developing integrated oil palm-based ruminant production in Malaysia.**

year, compared with negative growth for rubber, cocoa and coconut areas (MPOA, 2005).

Oil palm, *Elaeis guinensis* Jacq, has an economic life of 20 to 25 years and annually bears 8 to 12 fruit bunches, each weighing between 15 and 25 kg. Each fruit bunch carries 1000 to 3000 fruits, and each palm tree produces about 40 kg of palm oil annually. In palm oil milling, when the fresh fruit bunches (FFB) are processed, the economic end products are crude palm oil (CPO) and palm kernel oil (PKO) In the oil palm industry, the co-products are obtained from two sources, namely from residues in the plantations (field residues) and from palm oil milling. The former produces two major co-products: oil palm trunks (OPT) and oil palm fronds (OPF), while the latter produces empty fruit bunches (EFB), palm kernel cake (PKC), palm oil mill effluent (POME), palm press fibre (PPF), and shell. After processing some of the co-products are suitable for use as animal feed ingredients. The availability of various type of biomass and wastes in the oil palm environment has been intensively reviewed (Zin, 2000). A more recent paper estimated yields of 0.62, 0 04, 0.96 and 0.23 t/ha/year for OPF, PKC, POME and PPF, respectively (Devendra, 2006).

This present paper describes the utilization of the biomass from plantation and milling activities as feeds for livestock. Emphasis is placed on resources with abundant supply and easy to collect and utilize for livestock feeding. Selected products from refining activities that are used as high-energy sources for dairy animals, poultry, swine and aquaculture are also highlighted.

CO-PRODUCTS FROM OIL PALM PLANTATIONS (FIELD RESIDUES)

Oil palm fronds

Availability

Oil palm fronds (OPF) are obtained during harvesting or pruning and felling of palms for replanting. As such, it is available throughout the year. On an annual basis, about 24 fronds are pruned per palm tree, and the weight of fronds varies considerably with age of the palm, with an average annual pruning of 82.5 kg of fronds per palm (Chan, 1999; Chan, Watson and Kim, 1981). At the time of felling during land clearing for replanting, each crown gives approximately 115 kg of dry fronds. It is estimated that about 30 million tonne of OPF is produced on a dry matter (DM) basis annually during the pruning and replanting operations (Ma, 2000) . Traditionally, most OPF is left to rot between the rows of palm trees, mainly for soil conservation, erosion control and ultimately for the long-term benefit of nutrient recycling. However, due to the need to increase the net return per hectare, OPF has been used as resource material for extraction of vitamin E, paper pulp and animal feed. The large quantity of fronds produced by a plantation each year makes this biomass a very promising source of roughage for ruminants.

Nutritive value

OPF comprises three main components: a petiole, rachis and leaflets About 70 percent of the DM in the OPF is from the petiole, and the rest from leaves and rachis. The leaves contain a higher percentage of crude protein (CP) and ether extract (EE) than the petioles. The DM content of OPF is about 31.0 percent and *in vitro* digestibility of DM of leaves and petioles is uniform throughout the length of the fronds, with a mean value of 35 6 percent (Ishida and Abu Hassan, 1992). OPF also contains between 15 and 26 percent hemicellulose, depending on its age. The moisture contents of chopped fresh OPF, solar-dried chopped OPF, steam-dried ground OPF and OPF pellets were 58 6 percent, 44.6 percent, 12.7 percent and 14 7 percent, respectively, with respective density values of 0.27, 0.08, 0.12 and 0.53 (Oshibe *et al.*, 2001). The chemical composition of OPF in comparison with other oil-palm co-products is shown in Table 1.

Rumen degradability is an appropriate assessment of the nutritive value of a fibrous feed for ruminants because

TABLE 1
Mean chemical composition (percent in dry matter, except for ME) and nutritive value of oil palm frond and other oil palm co-products

Co-products	CP	CF	NDF	ADF	EE	Ash	ME (MJ/kg)
Palm kernel cake (PKC)	17.2	17.1	74.3	52.9	1.5	4.3	11.13
Palm oil mill effluent (POME)	12.5	20.1	63.0	51.8	11.7	19.5	8.37
Palm press fibre (PPF)	5.4	41.2	84.5	69.3	3.5	5.3	4.21
Oil palm fronds (OPF)	4.7	38.5	78.7	55.6	2.1	3.2	5.65
Oil palm trunks (OPT)	2.8	37.6	79.8	52.4	1.1	2.8	5.95
Empty fruit bunches (EFB)	3.7	48.8	81.8	61.6	3.2	–	–

Notes: CP = crude protein; CF = crude fibre, NDF = neutral-detergent fibre; ADF = acid-detergent fibre, EE = ether extract; ME = metabolizable energy.
Sources: Wong and Wan Zahari, 1992; Wan Zahari *et.al.*, 2000.

TABLE 2
Rumen degradation parameters of whole and different fractions of oil palm frond (OPF) on incubation in nylon bags and using the equation $p = a + b(1-e^{-ct})$

Incubation (hours)	Petiole	Leaflet	Midrib	OPF
a (g/kg)	21.2	21.7	14.4	18.4
b (g/kg)	24.7	46.1	28.3	38.3
c (% per h)	2.8	1.2	1.5	2.5
(a+b)	45.8	67.8	42.7	56.7

Notes: p = actual degradation at time t; a = intercepts; b = insoluble but potentially degradable component at time t; c = rate of constant of b; (a+b) = total degradability. *Source:* Islam *et al.*, 1997.

it relates to the availability of nutrients. Table 2 shows the degradation characteristics of different fractions of OPF. A degradability value of 40 percent or more at 48 hours incubation indicates that OPF could be fed directly to ruminants. However, some improvement in terms of nutritive value is needed to increase the degradability level further. The characteristics of rumen degradation, digestibility, voluntary intake and palatability of several types of processed OPF have been reported by Kawamoto, Wan Zahari and Oshio (1999).

Nutritive value improvement

Several processing techniques have been developed to improve the feeding qualities of OPF. These include urea and molasses treatments, preservation as silage, alkali treatment, and steaming under high temperature and high pressure (Table 3), pelletizing and enzymatic degradation. Urea- and molasses-treated OPF can almost meet the maintenance requirements of ruminants for energy and protein. The optimum level of urea inclusion in the OPF based diet was 30 g/kg ration, and steaming was reported to increase OPF digestibility. Increasing the level of urea in the steamed OPF resulted in reduced dry matter intake (DMI) and dry matter digestibility (DMD). A recent study revealed that microbial fermentation of OPF mixed with rice bran and rice husk through microbial fermentation of Japanese koji (*Aspergillus oryzae*) enhanced the feeding value by improving the CP content, reducing the NDF and improving the DMD of the feed, particularly with *Aspergillus awamori* (Ramli *et al.*, 2010).

Freshly chopped

Freshly chopped OPF has been extensively used by local farmers for feeding to beef and dairy cattle in Malaysia. The growth performance and carcass composition of Brahman-Australian Commercial Cross (ACC) beef cattle fed iso-nitrogenous diets based on a freshly chopped OPF and PKC-based mixture is shown in Table 4. Diet 3 (40% OPF + 60% PKC) was the most economical as indicated by feed cost per weight gain value. Better feed conversion efficiency (FCE) and average daily gain (ADG) were obtained by diet 5 (20% OPF + 80% PKC), but it was not economical in terms of cost. Moreover, there were higher percentages of fat in the carcass. Carcass weight and dressing percentage improved with increasing levels of OPF in the diet.

TABLE 3
Chemical composition of oil palm fronds (OPF), untreated and steam-processed at various pressures (% in DM)

Treatment	NDF	ADF	HC	ADL	NDS	Ash	CP
Untreated	70.9	44.1	26.8	8.5	29.1	4.5	4.3
Fresh, steamed							
10 kg/cm²	60.7	52.2	8.5	18.9	39.3	4.4	4.3
12.5 kg/cm²	59.8	49	10.8	15.7	40.2	4.6	4.5
15 kg/cm²	65.8	51.2	14.6	17.7	34.3	4.7	4.5
Pre-dried, steamed							
10 kg/cm²	59.8	50.1	9.7	19.9	40.2	4.7	4.2
12.5 kg/cm²	58.3	48.3	10	18	41.7	4.7	4.3
15 kg/cm²	56.1	53.3	2.8	20.9	43.9	4.8	4.3

Notes: DM of the untreated and treated materials were almost similar, between 93.2 and 94.0, NDF = neutral-detergent fibre, ADL = acid-detergent fibre, HC = hemicellulose; ADL = acid-detergent lignin, NDS = neutral-detergent solubles (%NDS = 100 – %NDF); CP = crude protein. *Source:* Bengaly *et al.*, 2000.

TABLE 4
Growth performance and carcass composition of Brahman-Australian Commercial Cross beef cattle fed mixtures with varying ratios of fresh chopped oil palm frond (OPF) and palm kernel cake (PKC)

Parameter	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5
OPF	60%	50%	40%	30%	20%
PKC-based mixture	40%	50%	60%	70%	80%
Number of animals	24	24	24	24	24
Initial LW (kg)	289.8	279	284 4	279	278 9
Final LW (kg)	340.2	327.5	343	343.5	356.9
ADG (kg/day)	0.64	0.61	0.67	0.75	0.85
DMI (kg/head/day)	6.12	6.02	6.5	7.08	7 56
FCR	9.56	9 87	9.7	9 44	8.89
Feed cost	3.09	3.11	3 04	3.45	3.23
Carcass composition					
Dressing %	54	56.3	54.8	57.8	57 2
Meat to bone ratio	2.9	2.57	2.88	3 03	2.85
Meat (% carcass weight)	66 6	57	59.3	55.7	55.6
Bone (% carcass weight)	22.7	21.9	20.9	18.7	19 5
Fat (% carcass weight)	9.6	14.2	14.7	17.2	17 2

Notes: The diets were iso-nitrogenous diet (with about 16.4% CP). The PKC-based mixture contained soybean meal, vitamin-mineral premix and urea. All animals were fed palm fatty acid distillates (PFAD) at 3% of DMI as an energy source. Feed cost is based on Ringgit/kg gain over an 86-day experimental period (US$ 1 = Ringgit 3.8). CF percentages in diets 1 to 5 were 31.5, 28.6, 25.6, 22.2 and 19.2, respectively. The respective percentage total digestible nitrogen (TDN) values were 58 2, 60.2, 62.3, 65.3 and 67.3. CP = Crude protein; CF = Crude fibre; LW = Live weight; ADG = Average daily gain; DMI = Dry matter intake; FCR = Feed conversion ratio. *Source:* Mohd. Sukri *et al.*, 1999.

It is evident that the demand for processed OPF began to increase after the ensilation and pelletizing processes were introduced, especially when storage and ease of handling became necessary for commercial farms. However, in some locations, there was no urgent requirement to conserve OPF for silage as fresh OPF is abundantly available throughout the year.

Preservation as silage

Whole OPF can be chopped (to about 2–3 cm in length) and conserved as silage, and can be kept for several years when properly stored. Many trials were carried out to study the effect of additives on silage quality. These include treatment with water, molasses and urea (Table 5). The results indicate that good quality silage could be produced without no additives, provided that OPF was ensiled under anaerobic conditions. Urea addition at the rate of 1–2 percent prevented mould growth, and delayed the initiation of heat production by 28 hours. Inclusion of more than 3 percent of urea reduced the nutritive value of the silage However, no adverse effect on animals was observed when urea was used at 3 percent (Table 6). Current research shows that *Lactobacillus plantarum*, heterofermentative lactic acid bacteria, is the best isolate for OPF silage, based on its ability to decrease pH faster and attain the lowest pH compared with other isolates (Hussin and Wan Mohtar, 2010).

Processing of pellet and cube

Digestibility studies conducted using mature Kedah-Kelantan (KK) bulls indicated a DMD value of about 45 percent for OPF silage. It was significantly reduced when urea

TABLE 5
Effect of water, molasses and urea addition at ensiling on the fermentation characteristics of oil palm frond silage

Parameter	Treatment			
	Control	Water	Molasses	Urea
pH value	4.02 b	3.93 b	3.93 b	7.38 a
Organic acids (% DM)				
Lactic acid	1.89 bc	2.30 b	3.55 a	1.51 c
Acetic acid	0.89 b	0.65 b	0.78 b	8.99 a
Butyric acid	1.07 b	0.99 b	1.04 b	1.66 a
Percentage spoilage	13.9 a	9.0 a	1.6 a	0.0 b

Notes: Control had no additives. a, b, c = means with different letters in a row differ ($P <0.05$).
Source: Abu Hassan and Ishida, 1992.

was included at 6 percent of the total diet (Ishida and Abu Hassan, 1992). Further long-term feeding trials were conducted with growing and finishing beef cattle and with lactating cows (Abu Hassan *et al.*, 1993; Ishida *et al.*, 1994). In the trial without urea, the feed required for LWG and lean meat production was reduced with higher inclusion levels of OPF silage (Table 7). This is reflected in reduced feed cost.

The potential of OPF silage as a source of roughage for lactating dairy cows is shown in Table 8. The cows fed 30 percent OPF silage produced more milk than those fed 50 percent OPF silage There were no adverse effects on the animals, milk yield or flavour, even when the level of OPF silage was increased to 50 percent In a separate study, the LWG of swamp buffaloes fed 30 percent OPF silage was comparable to those fed 50 percent sago meal (Shamsudin, Mohd Sukri and Abdullah Sani, 1993). Studies with sheep indicated that OPF silage was better utilized compared with nipa palm (*Nypa fruticans*) frond silage. Additionally,

TABLE 6
Effect of urea level at ensiling on chemical composition, fermentation characteristics, voluntary intake and digestibility of oil palm frond silage

Parameter	Urea level (% in DM)		
	0	3	6
Chemical composition			
Dry matter (%)	30.1 ab	30.7 a	28.6 b
Percentage of dry matter			
Crude protein	6.7 c	11.4 b	17.2
Organic cell contents	20.8 a	20 0 ab	13 0 c
NDF	73 2 b	73.9 b	80.3 a
Fermentation characteristics			
pH value	3.78 a	4 89 b	7.81 c
Total acids (DM percent)	3.68 b	4 76 b	8 96 a
Composition of acids (%)			
Lactic acid	91.0 a	37.4 b	13.0 c
Acetic acid	6.1 c	25 8 b	72.9 a
Propionic acid	0.1 b	3.8 a	0.8 b
Butyric acid	0.9 c	30 9 a	6.7 b
Ammonia (% DM)	0.0 c	0.6 b	1.1 a
Voluntary DM intake (g/day)			
Digestibility (%)	39.9 a	32.1 a	24.0 b
Dry matter	45.3	46.8	35.7
Organic cell contents	100	91.7	86.1
NDF	29.1	37.5	30.2
TDN (DM%)	45 5	49.2	37.5

Notes: DM = dry matter; NDF = neutral-detergent fibre; TDN = total digestible nutrient; a, b, c = means with different letters in a row differ ($P < 0.05$). *Source*: Ishida and Abu Hassan, 1992.

TABLE 7
Effect of oil palm frond levels on growth performance and carcass characteristics of Australian commercial cross bulls

Parameter	Treatment			
	T1	T2	T3	T4
Live weight (kg)				
Initial weight	229.1	226.5	232.9	229.4
Final weight	396.3 a	336.4 ab	333.8 b	357.2 ab
Daily gain (kg/day)	0.75 a	0.62 ab	0.45 c	0.57 bc
Feed intake (kg DM/day)	7.02 a	6.10 ab	5.48 b	5.58 b
Carcass weight (kg)	237.2 a	210.2 ab	189.0 b	195.2 b
Weight of carcass components (kg)				
Meat	127.8	121.5	107	116.7
Fat	76.4 a	58.1 ab	45.8 b	46.0 b
Bone	37.6	33.4	33.2	36.1
% in carcass				
Meat	35.6	58.2	57.2	59.2
Fat	31.6 a	27 6 ab	24.2 b	23.7 b
Bone	16	16.1	17.7	18.4

Notes: T1 = 10% Urea OPF silage + 90% PKC-based concentrate T2 = 30% Urea OPF silage + 70% PKC-based concentrate T3 = 50% Urea OPF silage + 50% PKC-based concentrate. T4 = 50% OPF silage only + 50% PKC based concentrate a, b, c = means with different letters in a row differ ($P < 0.05$). PKC = Palm kernel cake. *Source*: Ishida *et al.*, 1994.

the provision of molasses was reported to increase the potential degradability of both nipa and oil palm fronds (Abdalla *et al.*, 2001). In this trial, ammonia-N in the rumen liquor of the animals fed OPF supplemented with 0 percent and 30 percent molasses were found to be conducive for

TABLE 8
Effect of feeding oil palm frond silage on performance of Sahiwal-Friesian lactating dairy cows

Parameter	Dietary treatment		
	T1	T2	T3
Number of cows	9	9	9
Body weight (kg)	417	451	450
Ingredient composition of diet (% DM)			
OPF silage	30	50	-
Fodder	-	-	50
Concentrates	70	50	50
Feed intake and milk production			
DM intake (kg/day)	6.46 b	5.86 c	8.28 a
Yield of 4% FCM (kg/day)	6.93	5.73	6 48
4% FCM to ME intake ratio (kg/MJ)	0.109 a	0.088 b	0.096 b

Notes: T1 = 30% OPF silage diet T2 = 50% OPF silage diet T3 = 50% fodder diet. FCM = fat corrected milk. ME = metabolizable energy. Concentrates contained 24.0% CP and 11.3 MJ/kg of ME a,b,c = Means with different suffixes differ ($P < 0.05$). *Source*: Abu Hassan *et al.*, 1993.

optimum rumen environment, with values of 141.5 mg/litre and 142.9 mg/litre, respectively. These values were, however, lower than suggested levels of 200–250 mg/litre for ruminants (Preston and Leng, 1997).

Feeding beef cattle

The effects of varying levels of OPF pellet on intake and growth performance of local beef cattle has been reported by Oshibe *et al.* (2000). The trial was conducted to evaluate the effect of OPF-based diets varying in CP content on intake and growth performance of growing Charolais × KK crossbred cattle. The animals were fed iso-caloric pelleted diets (containing about 9.13 MJ/kg DM) based on ground OPF at a 30 percent inclusion level. Over the 172-day feeding period, the LWGs achieved were 0.50, 0.52, 0.30 and 0.44 kg/day, respectively, when the animals were fed 10, 12, 14 and 15 percent CP (Table 9). The respective mean DMDs of the diets were 55.7, 68.6, 56.8 and 52.7. The LWGs obtained were comparable to those raised on 30 percent roughage and 70 percent concentrate. Provision of 12 percent CP improved DMD by about 23 percent compared with those fed 10 percent CP. Further addition of protein increased neither intake nor DMD, as shown in the groups fed higher CP levels. What contributed to the differences was not clear, as energy contents among the diets were very similar. It is unlikely that this is due to small differences in CF content as the values from the four diets only varied between 20.5 and 23.3 percent. Levels of EE for all of the diets were below 5 percent, and hence unlikely to cause any significant impairment in CF digestibility for pelletized diets based on OPF. Body scoring of cattle fed 30 percent OPF-based diets was from medium to good. Meat quality was excellent, with less deposition of fat in the carcasses. Irrespective of protein levels, the ranges for carcass weight and mesenteric fat were from 130.9 to

TABLE 9
Intake and growth performance of beef cattle raised on OPF pellet based diet

Treatment	Mean DMI (kg/day)	DM digestibility (%)	Initial LW (kg)	Final LW (kg)	LWG (kg)	Mid-abdomen (cm)
10% CP	6.40	55 7	242.5	328.5	0.50	181–214
12% CP	5.94	68.6	234.8	324 0	0.52	172–226
14% CP	5.88	56.8	231.5	283.4	0.30	182–192
15% CP	5.94	52.7	236.6	312.6	0.44	171–212

Notes: DMI = dry matter intake; LW = live weight; LWG = live weight gain, CP = crude protein
Source: Wan Zahari *et al*, 2000, 2002.

215.3 kg and 5.0 to 6.6 kg, respectively. The meat to bone ratio ranged from 0.7:1 to 3.1.

Distended rumen was reported in beef heifers fed pellets made from ground OPF at a 30 percent inclusion level (Wan Zahari *et al*., 2002). This is associated with the rapid rate of passage of finely ground materials from the pellet, which is unfavourable for optimum rumen fermentation. Faster passage of feed through the rumen is known to depress DMD. Hence, rumen retention time should be reduced to stimulate better digestibility. Longer particle size (>15 mm) should be considered for making complete diets based on OPF. One option to make OPF cube, a process that does not require grinding (Hayakawa and Ariff, 2000). Small particle size of the diet is also known to depress the population of protozoa in the rumen, but what particle size is best for the protozoa to stimulate optimum fermentation is another issue. A high protozoan population density could also increase requirements for supplementary protein. Additionally, reducing the protozoan population in the rumen generally increases animal productivity on low-protein diets. Moreover, an optimal ratio of nitrogen to sulphur is vital for efficient ruminal microbial growth for diets based on fibrous materials like OPF. Contrary to what has been thought, distension of the rumen was not associated with bolus formation, which has been found in growing sheep raised on OPF silage and urea molasses mineral blocks (Wan Zahari, unpublished). Irrespective of the treatments, there seemed to be large variations between animals for the weight of the rumen, intestine and other organs (Table 10). There were also no abnormalities with regard to the structural and physical appearances of organs and other body tissues. The meat and organs were safe for consumption and of superior quality due to less deposition of body fat (Wan Zahari *et al*, 2000, 2002). The average concentration of lead (Pb) residues in OPF feed was lower than the concentration specified for the maximum residual limit level (3000 ppb) (Faridah *et al*., 2002).

The LWG of Brahman × KK male cattle fed diets containing 70 percent OPF + 30 percent cassava fodder was significantly less than for those fed 70 percent OPF + 30 percent concentrate or 70 percent OPF + 15 percent cassava fodder + 15 percent grain concentrates (Tung *et al*., 2001). The

TABLE 10
Body composition of beef cattle raised on oil palm fronds based diet

Parameter	Bulls	Heifers
Live weight before slaughter (kg)	274.0–407 0	186.0–238 0
Carcass weight (hot) (kg)	130.9–215.3	98.7–136.4
Rumen weight (empty, kg)	7.5–10.4	4.2–5 8
Intestinal weight (full, kg)	10.85–13.30	8.0–11.0
Intestinal weight (empty)	6.0–9.0	3.8–7 0
Liver (kg)	2.15–4.40	1.92–3 96
Spleen (kg)	0.758–1 172	0.71–1.82
Kidney (kg)	0.508–0.714	0.175–0.304
Mesenteric fat (kg)	5.00–6.60	2.60–5.50
Fat in carcass (kg)	3.50–10.10	1.52–4.47
Sirloin (kg)	1 36–3.40	0.74–2.00
Loin (kg)	2.60–9.30	2.52–4.10
Meat:Bone ratio	2 70–3.10	2.42–3.10

Notes: The animals were Kedah-Kelantan × Charolais crosses. SOURCE: Wan Zahari *et al*., 2000, 2002.

values for DMI (kg/head/day), N retention (% of N intake) and LWG (g/head/day) for the respective treatments were 4.01, 4 78 and 4.66; 15.49, 19.04 and 17.93; and 277.8, 412.7 and 373.0 respectively.

Feeding dairy cattle

Research and development on OPF feeding for dairy cattle reflects the intensive system of rearing that is suitable for Malaysia, considering the high cost of pasture land. Several experiments have been conducted that were aimed at developing feeding programmes based on OPF pellets or OPF cubes.

A study was conducted to evaluate ground OPF-based diets as a complete ration for lactating Sahiwal-Friesians dairy cows. The lactation performance and LW change of the animals fed 30 percent OPF pellet ration is shown in Table 11. Milk yields of cows used in this experiment varied from 11 1 to 20.3 L/day for the duration of the trial. The highest recorded 28-day milk yield period was 609 litres, equivalent to an average daily yield of 21 75 litres. The overall milk fat was 3.5 percent, and daily supplementation with 100 g long hay was insufficient to increase the fat content to the level of 4.6–4.8 as obtained when feeding concentrate-grass mixture or dairy cattle pellets (Abu Bakar *et al*., 2001).

TABLE 11
Effects of oil palm frond (OPF)-based pellets on milk yield and milk composition

Ration	Milk yield (L/28 days)	Milk fat (%)	Milk protein (%)	Weight change (kg)
30% OPF pellets	366	3 5	3.5	22 5
30% OPF pellets + LG	375	3.5	3.5	16.5

Notes: LG = Unchopped guinea grass hay given at 100 g/cow/day as long fibre supplement. Four Sahiwal-Friesian cows per group, assigned to a treatment sequence in a 4x4 Latin square design involving four 28-day measurement periods following a 2-week adjustment period Daily ration fed to each cow was limited to 14 kg/day. *Source* Abu Bakar *et al.*, 2001.

In a separate study, Sahiwal-Friesian heifers fed molasses-treated OPF were observed to consume 30 percent more (P <0.05) total feed DM compared with untreated-OPF (Abu Bakar *et al*, 2000). The improvement in intake could be attributed to improvement in the palatability and digestibility of nutrients. There was no obvious advantage of brine treatment (salty water containing 39 12 percent sodium chloride by weight, commonly used for food preservation) in stimulating intake of OPF pellets. LWGs of the animals fed molasses-treated OPF were comparable to those fed brine-treated OPF, with values of 0.69 kg/day and 0.68 kg/day, respectively. In comparison, Sahiwal-Friesian heifers fed maize stover silage and guinea grass produced gains of 0.43 and 0.47 kg/day, respectively (Abu Bakar, Aminah and Mansor, 1990). In addition, Friesian heifers fed complete rations based on 70 percent sugarcane bagasse as roughage recorded mean LWG between 0.38 and 0.56 kg/day, depending on quality of the energy-protein sources used (Van Horn *et al.*, 1980). Dried grated coconut meal (containing 64 g CP/kg, 359 g CF/kg; 24 g EE/kg; and 10 8 MJ ME/kg) and PKC are equally good as supplemental feed with OPF pellets for growing Sahiwal-Friesian heifers diets, provided that the protein content is enriched (Abu Bakar *et al.*, 1999).

Oil palm trunks

Availability

Oil palm trunk (OPT) is only available after oil palms are felled for replanting at an age of about 25–30 years (Mohamad *et al.*, 1986). The main economic criteria for felling are the height of palms exceeding 13 m, and annual yield of bunches falling below 10–12 t/ha. The biomass consists mainly of vascular bundles and parenchyma tissues. The parenchyma recovery is about 38 percent (Oshio *et al.*, 1991).

Nutritive value

The nutritive value of OPT is similar to PPF. It contains about 3 percent CP. The vascular bundles contain less lignin than the parenchyma tissues and in digestibility studies with sheep the parenchyma tissue had higher DM and organic matter values.

Processing and livestock feeding

OPT can be collected and processed into chips (about 2–3 cm) and preserved in the form of silage Vertical or bunker concrete silo are recommended. OPT silage can be utilized for feeding after 21 days in the silo OPT silage results in excellent fermentation due to low pH (3.2) and good production of lactic acid. Without any treatment, the DM digestibility of OPT is comparable to rice straw. Feeding trials with ACC beef cattle showed that OPT silage produced better FCE than rice straw, with good rate of growth and eating quality (Oshio *et al.*, 1991). The DMD of OPF silage without urea was 45 percent, compared with 44.2 percent and 35.8 percent when urea was added at 3 percent and 6 percent, respectively Insecticide residues were not detected in the OPT samples (Ong and Abu Hassan, 1991).

The parenchyma is an excellent source of roughage for beef cattle in feedlots. The biomass was readily consumed by the animals, even at 50 percent level It can be integrated with OPT fibre processing where the fibre can be used for production of pulp, paper and composite panels. The nutritive value of the material can be further enhanced by physical, chemical or biological treatment. OPT-based ration can be formulated for feeding large ruminant animals and the maximum level of inclusion is suggested to be 30 percent.

CO-PRODUCTS FROM OIL PALM MILLING

Palm kernel cake

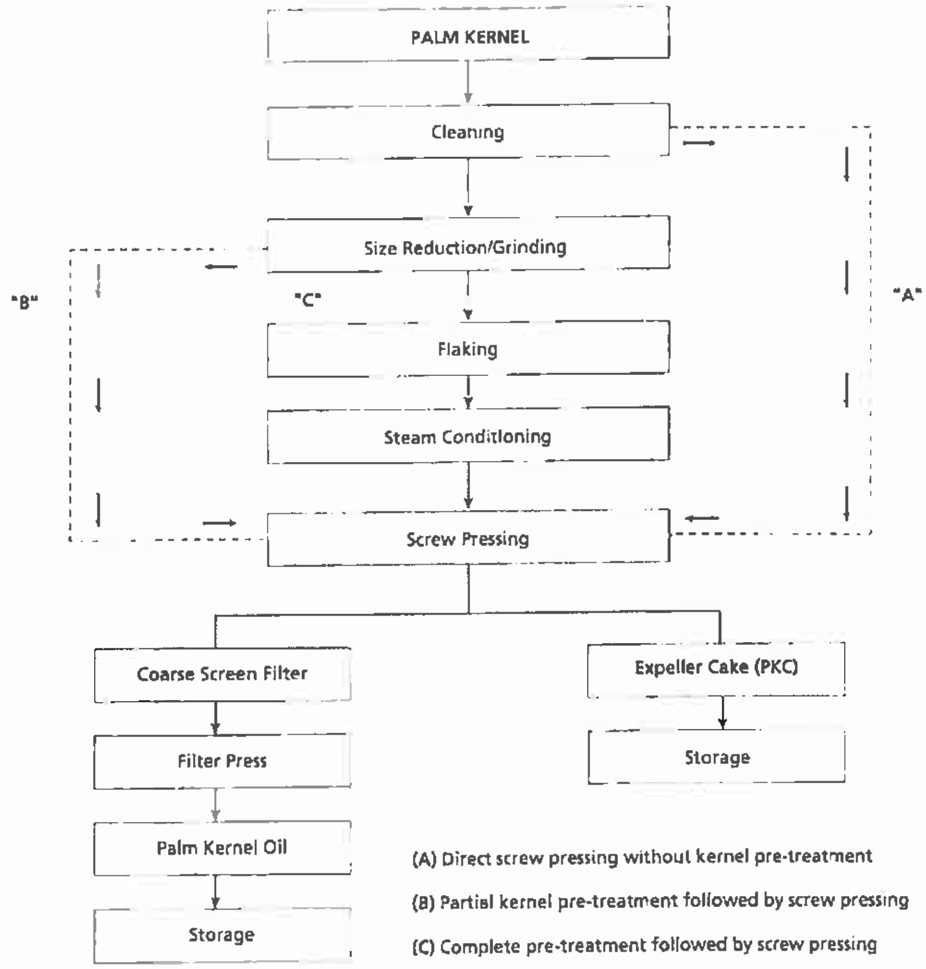
Availability

Palm kernel cake (PKC) is an important feed for livestock in Malaysia. It is produced after the extraction of PKO from the kernels of the oil palm fruits. PKC is also known as palm kernel meal (PKM), or palm kernel expeller (PKE) (Figure 1). Two types of oil extraction process are employed, either screw press (expeller) or solvent extraction. The oil milling industry differentiates PKC as the solvent extraction type, while PKE is the screw-pressed type. PKE is subject to heat damage during screw pressing. More than 99 percent – over 2 million tonne – of the meal produced is PKE, of which 95 percent is exported, mainly to the European Union. In this paper, the term PKC is used as it is accepted widely in Malaysia and other countries

Nutritive value

In general, the solvent extracted PKC has a lower oil content, ranging from 1.2 to 5.0 percent, while the expeller pressed PKC has 4 5 to 17.3 percent (Tang, 2000). Generally, PKC can be classified as an energy-feed (Table 12) and its chemical composition is somewhat similar to copra meal, rice bran or corn gluten feed. The ME values for ruminants and poultry are 10.5–11.5 MJ/kg and 5.9–7.0 MJ/kg, respectively (Yeong, 1985) The ME for swine is generally higher than for poultry, with the values between

FIGURE 1
Flow chart of the mechanical extraction of palm kernel oil



Sources: MPOB, 1992; Tang, 2000

10.0 and 10.5 MJ/kg The CP content is considered to be more than sufficient to meet the requirement of most ruminants. PKC has a good amino acid profile (Table 13), with availability between 62 and 87 percent (Yeong, Mukherjee and Hutagalung, 1981). Limiting amino acids are lysine, methionine and tryptophan. The protein quality of the MPOB-Q-PKC, recently introduced by the MPOB is superior to the existing PKC (Atil, 2009). This product is obtained after pre-processing the palm nuts to remove completely the shell and the fibrous testa of the kernels. However, this product is still under development. PKC also contains high residual fat (about 10 percent), carotene and vitamin E (about 0.3 IU/kg), which can act as a natural antioxidant Table 14 shows the fatty acid content in PKC. Its low content of unsaturated fatty acids also reduces rancidity problems.

PKC is high in minerals, with P and Ca contents of 0.48 to 0.71 percent and 0.21 to 0.34 percent, respectively (Table 15). The Ca:P ratio is very low (about 0.36:1) and

TABLE 12
Chemical composition and nutritive value of palm kernel cake

Parameter	
Dry matter (DM as %)	88.0-94.5
Chemical composition (% in DM)	
Crude Protein (CP)	14.5–19.6
Crude Fibre (CF)	13.0–20.0
Ether extract (EE)	2.0–8.0
Ash	2.0–10.0
Nitrogen-free Extract (NFE)	46.7–75.8
Neutral-detergent Fibre (NDF)	66.8–78.9
Oil content (%) +	4.5–17.3
Shell and dirt	3.6–21.4
Metabolizable energy (MJ ME/kg)	
Ruminants	10.5–11.5
Poultry	6.5–7.5
Swine	10.0–10.5

Notes. Oil content values adapted from from Siew, 1989

TABLE 13
The amino acid profile of palm kernel cake

Amino acid	Composition (%)
Alanine	0.92
Arginine	2.18
Aspartic acid	1.55
Cystine	0.2
Glycine	0.82
Glutamic acid	3 15
Histidine	0.29
Isoluecine	0.62
Leucine	1.11
Lysine	0.59
Methionine	0.3
Phenylalanine	0.73
Proline	0.62
Serine	0.69
Threonine	0.55
Tyrosine	0.38
Valine	0.93
Tryptophan	0.17

Notes: The concentration values are based on total protein content in palm kernel cake of 16.01%. *Source*: Yeong, 1983.

TABLE 14
The fatty acid content of palm kernel cake

Fatty acids	g/100 g oil
C6:0	0.2
C8:0	3
C10:0	4
C12:0	48
C14:0	16
C16:0	8
C18:0	3
C18:1	15.4
C18:2	2.4
C20:0	0.1

Source: MPOPC, 1995.

TABLE 15
The mineral content of palm kernel cake

Element	Level
Calcium (Ca) (%)	0.21–0.34
Phosphorus (P) (%)	0.48–0.71
Magnesium (Mg) (%)	0 16–0 33
Potassium (K) (%)	0.76–0.93
Sulphur (S) (%)	0.19–0.23
Copper (Cu) (ppm)	20.5–28.9
Zinc (Zn) (ppm)	40.5–50.0
Iron (Fe) (ppm)	835–6130
Manganese (Mn) (ppm)	132-340
Molybdenum (Mo) (ppm)	0.70–0.79
Selenium (Se) (ppm)	0.23–0.30

Source: Alimon, 2004.

diets based on PKC need to be supplemented with Ca to meet animal requirements. The level of Mg, K, S, Zn, Fe, Mn, Mo and Se are within acceptable ranges. However, Cu content in PKC (21-29 ppm) is higher than

TABLE 16
The digestibility coefficients of nutrients in palm kernel cake

Nutrient	Sheep	Cattle
Dry matter	0.70	0.76
Crude protein	–	0.78
Ether extract	0.91	0.84
Ash	–	0.67
Neutral-detergent fibre	0.52	0.76
Acid-detergent fibre	0.53	0.73

Source: Wong and Wan Zahari, 1997.

required by ruminants. More than 75 percent of PKC is cell wall component, which consist of 58 percent mannan, 12 percent cellulose and 4 percent xylan (Mohd. Jaafar and Jarvis, 1992). Table 16 shows the average digestibility coefficients of nutrients in PKC, based on studies with sheep and cattle. The digestibility values for ADF and NDF are much higher in cattle than in sheep, suggesting that sheep are less efficient than cattle in digesting fibre. The digestibility of NDF in forage hays are also higher in cattle than in sheep (Reid *et al.*, 1990). Earlier studies suggested that differences in the concentrations of urea and sulphur in blood, and lower excretion of N, P and Ca by the cattle, could have increased microbial activity in the rumen and digestion of fibre (Playne, 1978)..

PKC is normally free from aflatoxin, and therefore very safe for livestock feeding. It is also free from any chemicals, heavy metals, pesticides and dioxins. High DM content inherent in the PKC discourages growth of micro-organisms and mould, and it can therefore be stored for periods of up to three months without much problem.

Livestock feeding.

Feeding beef cattle and swamp buffaloes

PKC is widely used as the main ingredient in rations for feedlot cattle and buffaloes. In Malaysia, feedlot cattle are normally fed diets containing up to 80 percent PKC, with LWG of 0.6–0.8 kg/day for local KK cattle and 1.0–1.2 kg/day for crossbred cattle (Wan Zahari *et al.*, 2000) Diets containing almost 100 percent PKC have been fed to feedlot cattle with no negative effects, provided that the supply of Ca and vitamins (in particular A and E) are sufficient to meet requirements. Studies have shown that supplementing traditional rations of beef cattle with 30–50 percent PKC increased LWG (Wan Zahari and Alimon, 2004). It is common practice in Malaysia to produce complete feed based on PKC, either in the form of pellets, cubes or as total mixed ration (TMR) (Wan Zahari, Wong and Hussain, 2009). Apart from PKC, other common ingredients that are included in TMR include rice bran, brewers grain, palm oil mill effluent (POME), tapioca waste, urea, salt and minerals (Wan Zahari *et al.*, 2003). An example of the formulation for beef cattle feeding is PKC (80%) + grass/hay (17.5%) +

limestone (1.5%) + mineral premix (1.0%). A low cost fattening programme for beef cattle can be developed based on PKC and PPF, with LWG between 0.60 and 0.75 kg/day (Wan Zahari et al, 2000)

Owing to its small particle size, the level of PKC in beef cattle diets should not be more than 85 percent to avoid occurrence of metabolic problems such as acidosis and kidney stones. Grass or hay or other long-fibre sources should be included at at least 10 to 15 percent in the total ration. Addition of grasses or other forages will reduce the rate of passage of PKC in the gastro-intestinal tract of the animals, thus increasing retention and digestibility of nutrients (Oshibe et al., 2001; Wan Zahari et al., 2002). Moreover, when feeding PKC at high levels, attention should be given to Ca supplementation (Wan Zahari and Alimon, 2004). Limestone (calcium carbonate) is the most appropriate Ca supplement as it is cheap and easily available. It is important to ensure that the ratio of Ca to P in the rations is within the range of 1:1 to 3:1 in order to preclude skeletal deformities and mineral imbalances. Sodium chloride and vitamin A should be supplemented at the appropriate levels to meet requirements. Feeding PKC at 100 percent inclusion level may cause wet faeces and digestive disorders, and is contrary to principles of proper ruminant nutrition.

Feeding dairy cattle

In dairy cattle rations, PKC is used as a source of energy and protein at an inclusion level of 30–50 percent. PKC-based pellet is a common feed supplement for dairy cattle in Malaysia and it is usually fed together with grass and other concentrates (Abu Hassan, 2005; Abu Bakar et al., 2000). The grass to concentrate ratios fed are around 50–70 percent:30–50 percent (Abu Hassan et al., 1996). In the Malaysian environment, daily milk yields of 10–12 L/head can be achieved, and, with good formulation, higher yields can be expected (Wan Zahari et al., 2000). Other common ingredients in rations for dairy cattle are rice bran, brewers grain, palm oil sludge (POS) or POME, soybean waste, bakery waste, salt and minerals (Abu Bakar et al., 2001). In some areas, grass and other forages high in protein are given *ad libitum*. An example of a dairy cattle formulation is PKC (50%) + molasses (5%) + grass/hay (42%) + limestone (1.5%) + mineral premix (1%) + common salt (0.5%) (Alimon, 2004). Most of the PKC exported to the European Union is used in dairy cattle rations, but the level of inclusion is known to be limited to 15 percent

Feeding sheep and goats

Recommended maximum inclusion level of PKC in sheep rations is 30 percent. Long-term feeding of PKC at high inclusion level (>80 percent) can cause Cu toxicity in sheep, as sheep are known to be very susceptible to Cu poisoning (Hair Bejo et al., 1995; Al-Kirshi, 2004). Some sheep breeds (especially crossbreds) accumulate Cu in the liver, causing liver damage. Addition of 100 ppm of zinc sulphate or 5.2 mg/kg ammonium molybdate together with 440 mg/kg sodium sulphate in the rations can overcome the Cu toxicity problem (Hair-Bejo et al., 1995). Cu toxicity does not appear in cattle, buffaloes, goats and other animals, but long-term feeding of PKC can result in high levels of Cu concentrations in the liver. An example of a formulation for goats is PKC (50%) + grass/hay (30%) + rice bran (10%) + soybean meal (9%) + mineral premix (1%) (Wan Zahari and Alimon, 2003).

Feeding poultry

Owing to its high fibre content, non-starch polysaccharides and shell content, the use of PKC in poultry rations is very limited, with wide variation in the optimum inclusion level. The main difficulty is the origin and variation in the oil and shell content of the PKC used. Broiler chicken can tolerate up to 20 percent PKC in their diets without affecting growth performance and FCE (Yeong, 1987; Abu Hassan and Yeong, 1999. In layer rations, PKC can be included up to 25 percent without any deleterious effects on egg production and quality (Yeong, 1987; Radim et al., 2000). However, inclusion of PKC at levels greater than 20 percent was reported to reduce egg production and egg quality (Yeong et al., 1981), although in another study reduced egg production was only observed at levels exceeding 40 percent (Onwudike, 1988)

Muscovy ducks can be fed PKE at the 30 percent level without any deleterious effects on performance (Mustafa et al., 2001). Low-shell PKC with higher energy and CP content is important to maximize utilization in poultry. However, high inclusion levels of PKC require supplementation with high levels of fat, making the rations economically uncompetitive in comparison with conventional maize-soya-based diets.

Current research focuses on enhancing the nutrient content of PKC for poultry. Topics include enzyme treatment and solid-state fermentation of the PKC. Enzymic depolymerization of PKC releases digestible sugars that will be fully absorbed and metabolized by poultry. Supplementation with specific enzymes can improve nutrient digestibility and has worked efficiently to break down mannans in PKC (Noraini et al., 2002; Saenphoom et al., 2010). Broilers can be fed diets containing 30 percent fermented PKC without any adverse effect on performance (Noraini et al., 2008). Fermentation with *Aspergillus niger* was reported to increase the true metabolizable energy of PKC from 5.5 MJ ME/kg to 8.1 MJ ME/kg. *Aspergillus niger* up to generation F_6 can be used as inoculum for fermentation of PKC (Abdul Rahman et al., 2010). Chemical treatment using sodium hydroxide and formaldehyde have also been investigated, but with variable results. Further research is required to enhance the nutrient content of PKC for poultry (Wong *et al.*, 2009).

Feeding swine

PKC is also suitable for swine at an inclusion level ranging from 20 to 25 percent for growers and finishers. In some areas in Peninsular Malaysia, PKC is used at lower levels (between 5 and 10 percent). An example of a formulation for feeding swine is PKC (20) + maize (65.5%) + soybean meal (9.5%) + fish meal (3.0%) + dicalcium phosphate (1.5%) + mineral premix (0.2%) + common salt (0.3%) (Wan Zahari and Alimon, 2003). In Nigeria, PKC is fed to swine at levels ranging from 15 to 40 percent without no negative effects on performance (Codjo *et al.*, 1995).

Feeding in aquaculture

The availability of PKC in many tropical countries where aquaculture is practised has generated much interest in its potential use in fish diets. Early studies indicated that PKC can be tolerated up to 30 percent in catfish *(Clarias gariepinus)* and 20 percent in tilapia *(Oreochromis niloticus)* rations with no deleterious effects on growth and performance (Sukkasame, 2000). An example of a formulation for African catfish is PKC (30%) + fish meal (20%) + cassava flour (15%) + soybean meal (31%) + sago (1%) + mineral and vitamin (2%) + vegetable oil (1%). PKC pre-treated with commercial feed enzymes resulted in better growth and FCE than with raw PKC. The fermentation of PKC with *Trichoderma koningii*, a cellulolytic fungus, increased the CP content in PKC from 17 percent to 32 percent (Ng *et al.*, 2002). At a 40 percent feeding level of PKC, the rate of growth was reduced and this was not rectified with the addition of 1.2 percent dietary L-methionine (Ng, 2006). It is suggested that 30 percent is the maximum inclusion level for enzyme-treated PKC in tilapia diets. More R&D is needed to optimize the use of feed enzymes in PKC-based diets in order to reduce the cost of using imported maize as an energy source.

Table 17 shows the recommended levels of PKC in the feeds for beef cattle, dairy cattle, sheep, goats, poultry, swine and freshwater fish.

TABLE 17
Recommended levels of palm kernel cake in livestock feeds

Species	Recommended level (%)
Beef Cattle	30–80
Dairy Cattle	20–50
Sheep and Goats	20–50
Poultry – broiler	<10
Poultry – layer	<10
Swine	<20
Freshwater fish	<10

Source: Wan Zahari and Alimon, 2003.

Palm oil mill effluent and palm oil sludge

Palm oil mill effluent (POME) is a general description for the discharge from palm oil extraction in the mill. This is the residue left from the purification of the crude palm oil (CPO) and includes various liquids, dirt, residual oil and suspended solids, mainly cellulosic material from the mesocarp of the fruits. When fresh, it is in the form of a thick, brownish-yellow, colloidal slurry comprising about 95 percent water with an average pH of about 4.7 and biological oxygen demand of 25 000 mg/L (Ngan, 2000). Some mills may use decantation to complement the clarifier in order to reduce the volume of effluent by 10 to 20 percent. By using the decanter-drier system, a lighter co-product is recovered in the form of decanter solid. In order to avoid confusion, the term POME should be restricted to only the raw untreated effluent. The decanter solid is obtained when most of the solids in the effluent is removed before the waste water is discharged into the pond. The effect of different chemical treatments on the settling ability of POME has been reported (Hassan *et al.*, 2001).

Availability

The average production of POME is 670 kg for every tonne of FFB processed. In 1997, Malaysia produced about 32 million tonne of POME from 290 mills.

Nutritive value

The material is characterized by high content of ether extract (11.7%), ash (19.5%) and medium CP content (12.5%) (Table 1). Wide variability in ash content and CP digestibility in POME results in widely different feeding values (Gurmit Singh, 1994). The content of CF, cellulose, NDF and gross energy (GE) are 20.1 percent, 20 percent, 63 percent and 8.37 MJ/kg, respectively

POME is non-toxic as no chemical is added during the oil extraction process. It is rich in minerals and therefore suitable to be used as an organic fertilizer in crop cultivation. The average concentrations of Ca, P, K and Mg are 0.8, 0.3, 2.5 and 0.7 percent, respectively (Gurmit Singh, 1994). Ammonia N, B, Fe, Mn, Cu and Zn are 35, 7.6, 46.5, 2.0, 0.89 and 2.3 mg/litre, respectively (Ma and Ong, 1985)

Feeding ruminants

Feeding raw POME to growing sheep at levels ranging from 10–60 percent of the diet showed that the 10 percent level of inclusion gave the highest digestibility (Devendra and Muthurajah, 1976). However, an assessment of feeding value using sheep indicated that up to 40 percent POME can be used either alone in molasses-urea-based diets or when combined in equal proportions with PPF. Retardation in rate of growth and skeletal mineralization have been observed when POME was fed at the 100 percent level in dairy cattle. In this case, supplementation with protein, energy and minerals is necessary. The combination of POME and sago meal (40% POME + 45% sago meal) has successfully been used for feeding local sheep, with daily liveweight gains of 59.1–64.0 g in the males and 50.5–54.3 g in the females. Field trials with cattle on estates have shown improved LWG. Satisfactory gains of between 0.18–0.43 kg/day for buffaloes and 0.47–0.78 kg/day for cattle were obtained with POME, PPF and PKC-based diets (Dalzell, 1977).

Feeding non-ruminants

Most of the studies in poultry utilized the solid portion of POME, which was dehydrated mechanically in the raw or in fermented form, or in mixtures with other feed materials. Dehydrated POME was used to replace part of the protein and energy sources in poultry diets. LWG and FCE of birds were significantly lower when the POME level in the diet exceeded 15 percent. Supplementation of the diet with lysine and methionine did not reverse the situation. Meat to bone ratios were 3.1:1 to 3.4:1, whereas diets with 20 and 25 percent POME gave ratios of 2.6:1 to 2.8:1.

In a layer trial, the optimum dietary level of inclusion was 10 percent (Yeong, 1983). The average percent egg production, total egg mass and feed:gain ratio were 76.4 percent, 8.9 kg and 2.77:1, respectively, as compared with 77.9 percent, 9.2 kg and 2.52:1, respectively, for the maize-soybean control diet. Inferior results were apparent in those birds fed diets with more than 10 percent POME. The optimum POME levels in diets were 15 percent for broilers and 10 percent for layers. The levels have also been confirmed with studies with pigs. Local and Pekin ducks were able to utilize 10 percent POME efficiently without exhibiting any adverse effect on growth and FCE (Yeong, 1983).

There are several commercial feeds derived from POME, specifically developed to have a high protein content. Examples are Censor (Centrifugal solid recovery), Prolima and Central solids (Centriplus). Prolima was used in poultry diets as a protein source to replace soybean meal. This product contained 2.42 Mcal ME/kg, 43.3 percent CP, 7.6 percent CF, 12 percent EE and with an amino acid profile comparable to groundnut meal. The optimum level of Prolima inclusion in diets was 30 percent. At this level, the birds showed feed intake, LWG, FCE and carcass quality comparable to those fed with the maize-soybean control diet. The optimum level of Prolima inclusion in layer diets was 20 percent (Yeong *et al.*, 1980). The digestibility of lysine and methionine were 8.3 and 22.1 percent, respectively, for POME and 80.0 and 76.1 percent, respectively, for Prolima. POME has very low amino acid digestibility. Incorporating 14 percent of Centriplus solids in the diets of growing pigs resulted in a reduction in LWG, increased feed intake and poor FCE compared with pigs fed the control diet.

Two types of Censor meals, prepared by using cassava-PKC as absorbents or cassava-PKC-grass meal as absorbents for palm oil effluent, were used to replace maize at feeding levels of 25–100 percent for laying hens. Birds fed with both types of Censor meals showed adverse effects on egg production and feed efficiency. When Censor meals replaced 50 percent maize, the LWG and FCE were comparable to the control diet. Substitution of maize by 50 percent Censor in pigs increased feed intake without affecting LWG. No significant differences in carcass traits were found. Both Prolima and Centriplus were not commercialized due to high cost of production.

In a separate study, four types of processed oil palm slurry (OPS), using rice bran as an absorbent, were tested on the performance of broiler chicks. The dietary treatment did not have significant impact on feed intake, LWG or FCE. Carcass yields were similar and mortality was unaffected by the dietary treatments (Atuahene, Donkoh and Ntim, 2000). Improving the quality of POME in terms of uniformity and nutrient availability can help to upgrade its status as a feed ingredient for the poultry industry. A recent study revealed that through submergence fermentation and using selected yeast cultures, the CP value increased from 11.2 percent to 14.1 percent, with the highest digestible amino acid being phenylalanine (digestibility coefficient 0.705) and the highest percentage of digestibility improvement was for lysine (20.3 percent) (Jame'ah *et al.*, 2010).

Empty fruit bunches

Ripe fruit bunches are harvested at intervals of 10–14 days throughout the economic life of the palm. Each oil palm bunch usually weighs about 15–25 kg and, depending upon the age of the palm and variety, there is about 24 percent oil in the bunch. Empty fruit bunches (EFB) are the remains of the fruit bunches after the fruits have been stripped and sterilized, following the steaming process at the oil palm mill. It is in the form of stalks with empty spikelets, and is commonly used as a mulching material during the early stages of planting in the plantation, or as raw material for fibreboard.

Availability

The average production of fresh EFB is about 4.42 t/ha/year, which is equivalent to 1.55 t/ha/year of dried EFB (Chan, Watson and Kim, 1981). Burning of EFB is now prohibited by regulation to prevent air pollution.

Nutritive value

EFB contains about 50 percent CF, 3.5 percent lipid, 3.6 percent CP, 81.8 percent NDF and 61.6 percent ADF.

Processing and livestock feeding

Although large quantities of EFB are produced yearly, very limited research has been done on its use as feed for livestock. Early studies on the treatments of EFB by irradiation and substrate culture have met with limited success. EFB fermented by inoculating *Pleurotus sajor-caju* was found to be palatable to beef cattle (Mat Rasol *et al.*, 1993). At present, EFB is widely used as pulp for making paper, bunch ash after incineration, mulch and recycling of nutrients for oil palms, wood composite products and fibreboard. Intensive R&D is required to improve its value for feeding if EFB is to be utilized as a major ingredient in livestock rations. EFB is also used as a substrate for cellulose enzyme production by solid-state bioconversion.

Palm press fibre

Availability

Palm press fibre (PPF) is a fibrous co-product of crude oil extraction of the mesocarp. More than 12.2 million tonne of PPF is produced annually in Malaysia, at a rate of 2.70 t/ha.

Nutritive value

PPF has 5.4 percent CP, 41.2 percent CF and 26 percent lignin (Table 1).

Processing and livestock feeding

Due to its poor nutritive value, PPF is commonly used as fuel to generate heat for boilers, for making pulp and paper, roof tiles and fibreboard. Being highly lignified and fibrous, it is not commonly used as feed for livestock, and when fed to cattle its intake by the animal is low because of the poor digestibility (24–30 percent).

Based on balance trials on sheep, optimum DMD of PPF was obtained when it was fed at 30 percent level of inclusion. Several treatments have been applied to PPF to improve its digestibility and palatability. Alkali treatments using sodium hydroxide and calcium hydroxide have been used, but had little effect in enhancing the digestibility of PPF. Steaming at 15 kg/cm^2 for 10 minutes improved the organic matter digestibility (OMD) of untreated PPF from 15 percent to 42 percent. Higher OMD levels were achieved by explosive depressurization at 30 kg/cm^2 for 1 minute (OMD reaching 51.6 percent). Other researchers found no benefit from sodium hydroxide treatment and steaming in improving the digestibility of PPF.

Formulated feedlot rations containing 30 percent PPF fed to LID × Red Dane male calves produced an average LWG of 117 kg per animal during the 251-day feeding. Rations containing 50 percent PPF and 30 percent PKC for dairy cattle provided the cheapest source of energy compared with cattle pellets based on starch equivalent.

The widespread use of PPF is still constrained by its low digestibility and the potential problem of rumen impaction. Farmers operating in the vicinity of oil palm mills can utilize PPF, either fresh or ensiled, to some extent for feeding cattle, and thus reduce cost of feeding. However, it is advocated that the feeding level should be maintained at less than 30 percent. Further research on chemical and physical treatments are necessary to improve its utilization in livestock.

Crude palm oil

Availability

Crude palm oil (CPO) is extracted from the mesocarp of the fruit of the oil palm tree (Figure 2). The mesocarp comprises about 70–80 percent by weight of the fruit, and about 45–50 percent of this mesocarp is oil. Two co-products produced during the refining of CPO are palm fatty acid distillates (PFAD) and spent bleaching earth (SBE).

Nutritive value

Like all natural fats and oils, CPO comprises mainly mono-, di- and triglycerides. There are free fatty acids, moisture, dirt (about 0.25 percent) and minor components of non-oil fatty matter, collectively referred to as unsaponifiable matter. CPO has a deep orange-red colour due to the high content of carotenoids, and is a rich source of vitamin E (300–600 ppm), consisting of tocopherols and tocotrienols. The content of palmitic acid (C16:0, saturated) and oleic acid (C18:1, unsaturated) are quite high (about 37.0 percent and 47.0 percent, respectively). The B-carotene content is 54 g/100 ml of oil, and maximum fatty acid content is 5 percent. The pro-vitamin A activity is about 640 IU/g. CPO does not contain n-3 highly unsaturated fatty acids, which are required by marine species. The GE value is about 8500 Kcal/kg, equivalent to about 34 MJ/kg.

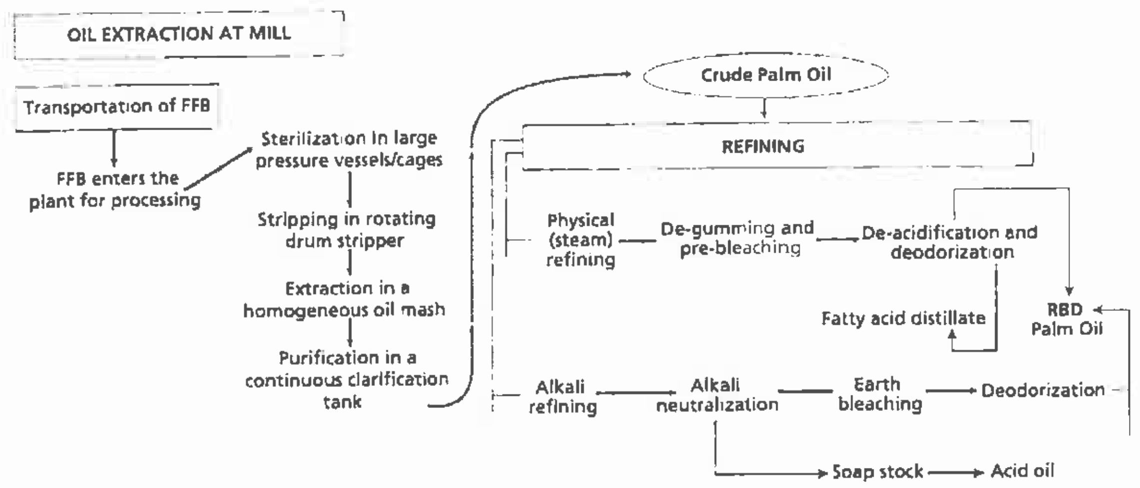
Livestock feeding

Palm oil is traditionally used at about 3 percent level in diets for pigs and poultry as a source of vitamins A and D, as well as to reduce dustiness of the diets. Higher levels of dietary palm oil of up to 10 percent have also been used successfully in diets for growing and finishing pigs in Malaysia. The percentage of lean cuts and backfat thickness increased with increasing levels of palm oil. In lactating cattle, supplementation with 2–8 percent of CPO increased both milk yield and milk fat content. The digestibility of CPO determined in balance trials with sheep gave a value of 85.4 percent. Information on the use of palm oil products in fish diets is currently limited to a few species only (Ng, 2010). About 90 percent of fish oil in the diets of catfish, *Hemibagrus bongan* (Popta 1904) (syn. *Mystus nemurus* (Valenciennes 1840)), could be replaced by CPO without affecting growth, FCE or body composition (Ng *et al.*, 2002). In another study, African catfish, *Clarias gariepinus*, was observed to show better growth when fed semi-purified diets containing 10 percent palm oil as the sole dietary lipid (Ng *et al.*, 2004).

Palm fatty acid distillate (PFAD)

Palm fatty acid distillate (PFAD) is a co-product from refining of CPO at very high temperature (240–260 °C) under

FIGURE 2
Palm Oil Process Flow Chart



Source: MPOB, 2000

reduced pressure (2–6 mm Hg). Normally, the refinery mixes all the distillates, irrespective of whether from refining of CPO, crude palm olein or crude palm stearin (Figure 2). The final product is generally called PFAD. It is a light-brown solid at room temperature, melting to a brown liquid on heating.

Nutritive value

PFAD is composed of free fatty acids (81.7%), glycerides (14.4%), squalene (0.8%), vitamin E (0.5%), sterols (0.4%) and other substances (2.2%) (Ab Gapor, 2010). It is used in the animal feed, oleo-chemical and soap industries. Vitamin E, squalene and phytosterols are valuable constituents that can be extracted from PFAD and are of potential value for the nutraceutical and cosmetic industries.

Livestock feeding

Most of today's market for by-pass fats consumption is for dairy cow feed. High producing cows, especially in early lactation, are typically in negative energy balance. The loss in appetite and the effect on live weight caused by insufficient dietary nutrient intake to meet the demands of milk output subjects the high yielding cow to considerable weight loss over the first 60–80 days of lactation, and this can have substantial effects on subsequent performance. Consequently, the cow mobilizes body reserves such as body fat to meet the energy demand. Fats in their crude form have only limited application in ruminant feeds because they become hydrolyzed in the rumen into free fatty acids, which may cause many problems. The major problem is the tendency to reduce the rate and level of fibre digestion in the rumen. The maximum efficiency of milk production is achieved when fat contributes between 16 percent and 18 percent of the dietary ME intake.

There are several protected fats based on PFAD or calcium soaps that are marketed worldwide under various trade names. Most of the products are in the form of hydrogenated triglyceride with energy content of about 9000 Kcal/kg and a digestibility above 90 percent. The products can be absorbed in the small intestine and have a very low stearic acid (C-18:0) content of between 1 and 5 percent. Improved PFAD specifically derived from palm oil increased milk production and the total SNF of lactating cows (Farah Nurshahida *et al.*, 2008). The digestibility of fatty acids in hydrogenated distillate was lower than for Ca salts of fatty acids, but intake and production responses were similar or greater for diets containing hydrogenated distillate (Elliott, Drackley and Weigel, 1996). Calcium soaps of PFAD were satisfactorily stable till pH 5.5 in the rumen (Sukhija and Palmquist, 1990). Increasing dietary intake of Ca salts of PFAD resulted in increase ratio of $C_{18:1}$:$C_{18:0}$ in Holstein cows, but not in Jersey cows (Beaulieu and Palmquist, 1995). The use of PFAD is a practical and cost-effective way to produce high-energy diets without causing side effects due to increased lipids (Ng *et al.*, 2004).

Spent bleaching earth

In refining the CPO and PKO, Bleaching Earth is used to remove colour, phospholipids, oxidized products, metals and residual gums from the oil, impurities that can cause the oil to have an unattractive colour and taste. The residue is termed Spent Bleaching Earth (SBE). It absorbs approximately 0.5 percent by weight of the oil in the process. The SBE generated annually by Malaysian palm oil refineries is estimated to be approximately 120 000 tonne. Disposal of SBE by incineration, inclusion in animal feeds, as land fill or in concrete manufacturing is generally practised (Kheang *et al.*, 2006).

Nutritive value

The free fatty acid content of SBE ranges from 14 to 31 percent, with an unsaturated to saturated ratio of 46 5:53.5 (Lai, 1987) Apart from the original bleaching earth, the SBE also contains residual water, inorganic acids, organic acids, silicates and active carbon used in the refining process. The content of the output varies greatly, depending on the type of bleaching agents used and the method applied. Two main methods are chemical and physical refining. Chemical refining uses alkali to neutralize the free fatty acids, which are then removed as soap. Physical refining subjects the oil to steam distillation under high temperature and vacuum Table 18 outlines the nutritive value of the SBE collected from a CPO refinery in Selangor, Malaysia (Wan Zahari, Mohd Sukri and Wong, 2004). Ash content is excessively high, while the protein content is low (CP <6 percent). The heavy metal contents are within normal ranges and therefore SBE is considered safe for livestock consumption.

Livestock feeding

There is no published report on the utilization of SBE for ruminant livestock, even though the material is known to be used by small-scale farmers in certain areas in Peninsular Malaysia. Supplementation of protein is required if SBE is to be use as a main ingredient for ruminants The high level of residual oil in SBE could be exploited for dairy feeding. Reflecting its high Ca content, SBE is suitable for combining with PKC in order to achieve a better Ca.P ratio. More studies need to be carried out to evaluate the effect of SBE on animal performance, especially on broiler and layer poultry. These should include studies to determine ME values and optimum inclusion levels SBE can be further fortified or enriched with addition of certain nutrients or compounds to increase the feeding value. Apart from blending into animal feed, SBE can also be used as binder in feed processing, especially in diets with high fibre content, such as OPF-based diets. The free-flowing characteristic of SBE is very well suited for feed processing purposes and it can be pneumatically conveyed via a vacuum line.

TABLE 18
Nutritive value and elemental composition of spent bleaching earth

Parameter	Value
Energy value	
Gross Energy (MJ/kg)	10.9
Proximate analysis (% DM)	
Ash (%)	57.9
CF (%)	1.0
CP (%)	0.44
EE (%)	14.6
ADF (%)	34.6
Heavy metal	
Cd (ppb)	44.35
Co (ppb)	4277
Cr (ppb)	43310
Mo (ppb)	Trace
Ni (ppb)	12229
Pb (ppb)	2001
Se (ppb)	Trace
Hg (mg/kg)	–
Major elements	
Ca (%)	6.28
K (%)	0.72
Mg (%)	2.44
Na (%)	0.70
P (ppm)	57.07
S (%)	0 42
Trace elements	
B (ppm)	2143
Cu (ppm)	8.61
Fe (ppm)	13.42
Mn (ppm)	217.50
Zn (ppm)	25.86

Source. Wan Zahari, Mohd. Sukri and Wong, 2004.

MAXIMIZING LIVESTOCK PRODUCTION IN AN OIL PALM ENVIRONMENT

Of the land area under oil palm, only 2 1 percent is currently used for integration with ruminants, emphasizing the enormous potential for expanding this system (Devendra, 2011). The concept of integrating ruminants with tree crops is not new and has been practised with varying degrees of success. Grazing the undergrowth and providing supplementary feeding with feeds such as PKC and POME is economically feasible. The basic model for integrated systems involving cattle and oil palm has been intensively reviewed (Devendra, 2006; Devendra, 2007). Based on this model, theoretical calculations for a 500 000 ha oil palm plantation gives the following results:

- Carrying capacity utilizing native herbage alone at 4 kg DM/head/day = 214 286 head
- Carrying capacity utilizing native herbage plus co-product feeds at 4 kg DM/day = 736 581 head (an increase of 245% over grazing alone).
- Using a 50 percent dressing percentage and a liveweight at slaughter of 420 kg, the quantity of beef produced using oil palm co-product feeds is 154 682 tonne.
- Annual gross revenue based on US$ 1260/t live weight = US$ 194.9 million.
- Rate of return on investment is from 8 1 percent for indigenous cattle to 16.3 percent from exotic cattle.

Lack of feeder cattle is one of the limiting factors in beef production in Malaysia. This is mainly associated with the high cost of rearing, as most of the feeder cattle are imported. It is estimated that about 1.8 million head of breeding females could be produced were the available feeds from 4.0 million hectare of oil palm to be effectively used, contributing about 0.5 million feeders per year Based on these figures and assuming a 30 percent concentrate + 70 percent roughage ration is used for feeding, the total requirement for concentrate would be about 1.6 million tonne per year. About 78 percent of locally available PKC would be needed annually for beef production were it to be used in this way as the concentrate in the above feeding regimen, with OPF utilized as the main roughage source.

CONCLUSIONS

The rapid expansion of the palm oil industry in Malaysia has generated large quantities of wastes from the field and palm oil mill. Most of the wastes and residues are basically cellulosic and organic biomass with high nutrient content. Most of the resources can be used as feeds for livestock.

At the plantation site, potential feedstuffs include OPF and OPT, while co-products from the milling and refining activities include EFB, PPF, PKC, POME and SBE. The availability of these resources provides potential for more practical and cost-effective feeding systems, as feeding values and outcomes from the previous and current R&D activities are known. Significant development in the processing of these feedstuffs, either as an ingredient for total mixed rations or as complete and balanced feeds, would encourage further growth in the local goat, sheep, beef and dairy industry. Intensive rearing of beef cattle on oil palm plantations also offers tremendous potential for beef production in view of the availability of OPF, PKC, POME and SBE for use as feedstuffs. With changes in livestock production systems towards semi-intensive and fully intensive systems, the demand for feed is growing in Malaysia. Growth of the local livestock sector aims to meet the self-sufficiency level for beef and milk over the next decade, and this creates further demand for feed. It is also evident that these fibre sources are in high demand in markets in Japan, South Korea, Taiwan and the Middle East, in addition to the Malaysian domestic market. Promotion and marketing of the agro-industrial co-products from the oil palm industry should be intensified to further expand their use and commercial potential. CPO, PFAD and other specialty fats, though not usually categorized as oil palm co-products *per se*, have great potential to be utilized as energy sources for dairy animals, poultry, swine and in aquaculture. The utilization of oil palm co-products thus aims to convert the large plantation biomass not only into animal feed, but also into other commercially viable value-added products.

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Climate change and predicted shortages of fossil fuels present major challenges. Currently, biofuel production is from agricultural crops grown primarily on arable land. Conflict with the traditional use of arable land, itself a limited resource, to produce food and animal feed must be avoided and economic sustainability assured. At present cereals, especially maize and wheat, and sugar cane are used for ethanol production, with soybean, oil palm and rapeseed for biodiesel production.

The expanding transport industry requires increasing amounts of biofuels, and an increasing market for co-products has generated a need for new feedstocks. Cellulosic material, often available from sub-prime land with minimal inputs, and other non-conventional sources are being investigated. Before being used as feeds, some seeds and cakes will require detoxification. The contribution of micro-algae, production of which can be achieved in coastal waters, is likely to grow in importance. These developments are mirrored the broadening of the animal species receiving the co-products, from ruminants, especially cattle, and pigs to poultry and fish (aquaculture). Further developments include enhancement of the use of existing co-products and the introduction of new ones.

This publication collates, discusses and summarizes state-of-the-art knowledge on the use as livestock feed and future availability of co-products from the biofuel industry. The levels at which the co-products could be safely used in livestock diets are also presented. Throughout the book, gaps in knowledge and research topics needed to address them have been identified. These include standardization of product quality to assist ration formulation; testing of new products; development of detoxification procedures; research on micro-algae; and life cycle analysis linked to traditional nutritional appraisal.

This publication covers a wide array of co-products and is a timely contribution, as people's aspirations are rising, evident from the increasing demand for livestock products and an ever greater reliance on transport, coupled with the challenge of maintaining agricultural production when faced with global warming. We hope that the information here synthesized will be useful to policy-makers, researchers, the feed industry, science managers and NGOs, supporting them in making information-based decisions on issues such as food-feed-fuel competition. Hopefully it will help confront the emerging challenges of global warming, in addition to making efficient use as livestock feed of a wide range of currently available and future co-products from the biofuel industry.

ISBN 978-92-5-107299-8

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I3009E/1/07.12