Plant Toxins and Detoxification Methods to Improve Feed Quality of Tropical Seeds* - Review -

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ABSTRACT : Many antinutritional and toxic factors abound in tropical seeds, which are also generally rich in nutrients and therefore more prone to attack from herbivores. Antinutritional and toxic factors are considered to defend seeds against environmental vagaries and thus help to protect them. These factors though good for the plant, cause deleterious effects or are even toxic to animals and man. The conventional seeds cultivated for oil or non-oil purposes, and general aspects of antinutritional factors are not presented here as these have already been discussed widely by many workers. Deficits in conventional protein and energy sources in the tropics have stimulated a quest for alternative feeds both for animals and humans. This article attempts to highlight two new oilseed crops, *Jatropha curcas* and *Moringa oleifera*, and in addition deals with some under-utilized seeds with potential as animal feed. Most of these seed plants are adapted to various marginal growing conditions in the tropics and can help to mitigate the prevailing deficit in protein and energy sources. Antinutritional and toxic factors in seed or seed meal, various approaches to detoxify seed meal, and future research and development priorities for their exploitation as animal feeds are presented. (*Asian-Aus. J. Anim. Sci. 1999. Vol. 12, No. 3 : 467-480*)

Key Words : Antinutritional, Toxic, Defence Compounds, Oilseeds, Unconventional Feeds

INTRODUCTION

Many varieties of seeds are cultivated for their oil. Some are also used as animal feeds but more commonly, the residue left after removal of the oil is used for feeding to animals. The protein content of the residue is usually high and the carbohydrate content low. The fat content depends on the method used to remove the oil. The production of oil plants takes third place in world agricultural production in terms of value, after starch plants and fruits, and ahead of beverages and other drinks (tea, coffee, tobacco), and sugar. More than 90% of the oil plants are produced in the tropics and subtropics, a far higher percentage than with the other group of food plants. About a third of the crop is exported from tropical countries at a value only exceeded by non-food goods. The cultivation of oil plants, therefore, is considered to play a major role in development politics (Rehm and Espig, 1991).

In economically developed regions, livestock products such as meat, milk, eggs and hides, account for more than one-half of the value of total agricultural production. Most of the countries in the tropics and subtropics are developing countries, and in most developing regions the proportional value of livestock products is lower. As a proportion of total agricultural production, livestock products amount to about 22% in Southeast Asia, 25% in sub-Saharan Africa (not including the Republic of South Africa), 26% in China, 31% in West Asia and North Afica and 38% in South America (Fitzhugh et al., 1992). The primary constraint to livestock production in developing countries is the scarcity and fluctuating quantity and quality of the year-round feed supply. These countries experience serious shortages in animal feeds of the conventional type. The grains are requred almost exclusively for human consumption. The introduction of new or relatively lesser-known seed-bearing plants, capable of growing in poor soils, can play a vital role in bridging the wide gap between supply and demand for animal feeds. In most tropical countries, there are vast areas of degraded, barren and/or marginal land where the propagation of these crops can bring economic benefits to farmers, control soil erosion and create jobs. In addition, diversification in traditional agriculture and conservation of biodiversity through the sustainable utilisation of harvests can be expected. Oilseeds have the advantage over other seeds that the oil with a high nutritional and economic value can be extracted first. The protein-rich fraction left after extraction of the oil can be exploited as a protein supplement for animal diets, thus reducing costs as protein is the most expensive component of animal diets.

The seeds usually contain a large amount of stored materials such as starch, storage-proteins, oil and minerals required for seed growth and early plant growth. These stored materials make seeds highly susceptible to attack by microorganisms, insects, birds and animals so that protection against predators is necessary. Protective mechanisms are present in the form of toxins and antinutritional factors. Antinutritional factors and toxins commonly present in seeds are protease inhibitors, amylase inhibitors, lectins, goitrogens, cyanogens, vicine and convicine, phytate, tannins, alkaloids and flatulence factors. The presence of these

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deleterious substances and their detoxification in conventional oil and non-oil seeds (soyabean, rapeseed, cottonseed, groundnut, lupin, common beans and peas) have been dealt with in several reviews (Huisman et al., 1989; Liener, 1994; D'Mello, 1995a,b), and will therefore not be presented here. The purpose of this paper is to highlight some unexploited seed plants, adapted to various marginal growing conditions in the tropics, with immense potential as a source of protein for feeding tomorrows world.

To evaluate an unknown seed or seed meal, it is imperative to have a detailed description of its chemical and nutritional properties, to obtain knowledge on acceptability and utilization by livestock, to investigate the presence of toxins and antinutritional factors and to develop processes to detoxify deleterious factors if present, and finally to utilize the detoxified product for animal diets.

JATROPHA CURCAS

Jatropha curcas, a multipurpose tree, is of Mexican and Central American origin. Presently, it is cultivated in large areas in many other Latin American, Asian and African countries. The genus *Jatropha* belongs to tribe Joannesieae of Crotonoideae in the Euphorbiaceae family and contains approximately 170 known species. The genus name *Jatropha* is derived from the Greek *iatrós* (doctor) and *trophé* (food) which implies medicinal uses. In 1753, Linnaeus was the first to name this plant *Jatropha curcas* L. according to the binomial nomenclature of Species Plantarum. *Jatropha curcas* is also commonly called physic nut or purging nut (English), pourghère or pignon dInde (French), purgeernoot (Dutch), Purgiernuß, Brechnuß (German), purgueira (Portuguese), habel meluk (Arab), kanananaeranda, parvataranda (Sanskrit), bagbherenda, jangliarandi, safed arand, ratanjyoti (Hindi), yu-lu-tzu (Chinese), sabudam (Thailand), pinoncillo (Mexico) and tempate (Costa Rica) (Heller, 1996).

J. curcas is a small tree or shrub which is drought-resistant (requires a minimum of 250 mm rainfall per year) and survives on poor, stony soils. It can easily be propagated by cutting or seeding, grows rapidly and can reach a height up to 8 m. The plant is cultivated mainly for the production of seeds as their oil content is 55-60%. For optimum production of seeds, between 900 and 1200 mm of precipitation is required per year. The plant starts producing seeds within 12 months but reaches its maximal productivity level after 4 to 5 years of plantation. A seed yield of about 5 tons per year from one hectare plantation has been achieved (Raina and Gaikwad, 1987; Makkar and Becker, 1997a), which can produce 2 tons of oil and 1 ton of protein-rich seed meal. The oil can serve as fuel for diesel engines, indicating its potential as a renewable energy source. The potential impact for countries with no indigenous fossil fuel or in regions remote from a source of fuel supply is immense. The oil has a strong purgative action and is also widely used for skin diseases and to alleviate pain such as that caused by rheumatism. Extracts of the leaves produce potent cardiovascular actions. The latex from the stem is used to control bleeding of wounds and also has antimicrobial properties. The extract from the fruits can terminate pregnancy, and the extract of the seeds has molluscicidal activity (Makkar and Becker, 1997b). As the bark is rich in tannins and dyes, it can be used for various industrial applications. The possible major uses of the plant are presented in Figure 1. For more details, readers are referred to Heller (1996). The seed meal left after extraction of the oil is presently used as a fertilizer and is not suitable as animal feed as it is toxic to fish, monogastrics and ruminants.

Toxicity

Most researchers studying the toxicity of *J. curcas* have utilized rodents (rats and mice) in the main, and food animals (sheep, goats, calves and chicks) only to a limited extent.

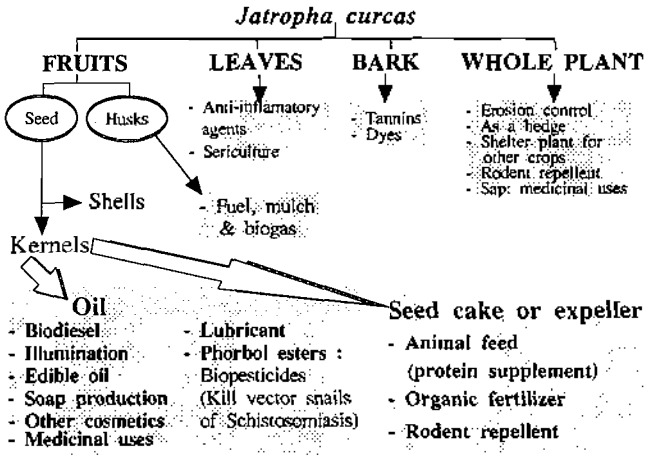

Figure 1. Parts of *Jatropha curcas* and their possible uses

A high mortality was found in mice given a diet containing 40 and 50% finely ground jatropha seeds; mice died within 3-16 days of dosing with a high mortality rate (> 67%). At lower concentrations (20, 10, and 5%) of the seeds, the mortality rate was reduced and the time of death extended, thus suggesting a dose response. This relationship was also evident in the degree of pathological changes observed in the small intestine, liver, heart and lungs of the mice (Adam, 1974). Similarly, Liberalino et al. (1988) also reported a high degree of toxicity in rats fed a diet consisting 37% of powdered decorticated jatropha seeds; the rats died within 2- 3 days after consuming the diet, and mortality was 100%. Adverse effects and mortality have also been reported for chicks fed a diet containing jatropha seeds alone or in combination with *Ricinus communis*. The lesions observed were necrosis of scattered hepatocytes, erosion of the intestinal mucous membrane, degeneration of the cells of the renal proximal convoluted tubules and

congestion of the blood vessels of the heart. High activities of dehydrogenases and transaminases in serum suggested liver damage (El Badwi et al., 1992).

Goats which received 1 g seeds/kg live weight/day or more (5 and 10 g), suspended in water and given by drench, died within 2-9 days (Adam and Magzoub, 1975). In another study (Ahmed and Adam, 1979a) where finely ground corticated jatropha seeds were mixed with water and given by drench to male goats at doses ranging from 1-0.05 g/kg live weight/day, mortality occurred within 6-25 days of dosing. Post-mortem findings revealed large areas of diffuse haemorrhage on rumen and reticulum mucosa, haemorrhagic or catarrhal abomastitis and enteritis, small ulcers in the small intestine and necrosis of the liver. Serum glucose and liver glycogen levels decreased by 25-50% and 51-77% respectively. Sheep seem to be more susceptible to toxic effects than goats. Ahmed and Adam (1979b) reported toxicity to calves at single doses of 0.025 g/kg live weight/day and above. The calves tolerated the lowest dose and no untoward clinical signs were observed during the first day of dosing. However, the ingestion of the seeds at this dose level eventually caused toxic signs and death occurred within 14 days.

Lippmann (1913), Abdu-Aguye et al. (1986), Joubert et al (1984) and Mampane et al. (1987) have described poisoning in humans by accidental ingestion of jatropha seeds. Symptoms were giddiness, vomiting and diarrhea. Recently, we observed reduction in body mass and mucus in the faeces of fish (carp, *Cyprinus carpio*) fed a diet containing 32% completely defatted jatropha meal. No fish died during the 14-day experimental period (Makkar and Becker, 1997b).

It is reported in literature that seeds from a provenance of *J. curcas* are consumed by humans in certain regions of Mexico, suggesting the presence of an edible or a non-toxic provenance (Cano et al., 1989). Seed meal of this provenance was fed to rats and fish (carp, *Cyprinus carpio*). The protein efficiency ratio of heat-treated meal for rats was 86% of the casein-containing diet. The fish also consumed and grew on a diet containing this jatropha meal. On the other hand, under similar experimental conditions, feeding of a diet containing heat-treated jatropha meal from a toxic variety to rats produced 50% mortality in 4 days and severe loss in body mass in the remaining rats. These results suggested that meal from seeds of the *J. curcas* provenance from Mexico (Veracruz state) is non-toxic (Makkar and Becker, 1997b). The term non-toxic means that consumption of seeds from this provenance does not lead to the death of animals as is the case with the toxic varieties. It does not mean that the non-toxic provenance is free from all antinutritional factors and is safe for animal feeding.

Nutritional value of the seed

The dry fruit weighed on average 2.1g with a 71 : 29 (w/w) seed to husk ratio. Thus, the seeds form a large proportion of the fruit. The average seed weight from 18 different seed provenances was 0.64g and the kernel formed a large proportion of the seed (61.3% by weight). The kernel to shell ratios of toxic varieties and the non-toxic provenance from Mexico were the same (Makkar et al., 1997).

The chemical composition of kernel and shell of jatropha varieties is shown in table 1. Jatropha kernel is composed mainly of lipid and protein, with very little moisture and ash. A seven-year-old seed sample from a toxic variety had a similar kernel : shell ratio (63 : 37) and similar contents of crude protein (25.6%), lipid (57%) and ash (3.4%) in the kernel as for fresh seeds. The low moisture content of the kernel (3-6%) and shell (*c.* 10%) could partly be responsible for the non deterioration of seeds over a long period. The presence of antinutritional factors/toxins is also likely to increase the shelf-life of the seeds. The shell of jatropha seed is composed mainly of fiber (84-89% neutral detergent fiber). The high acid detergent lignin (*c.* 45%) and very low protein (*c.* 4%) contents in the shell indicate its poor nutritional value. However, the shell can be a good source of fuel as it has a high gross energy content.

Table 1. Chemical composition of kernel and shell of *Jatropha curcas*

	Toxic variety (Cape Verde)		Non-toxic provenance	
	Kernel	Shell	Kernel	Shell
Constituents (% in DM)				
Crude protein	22.2	4.3	27.2	4.4
Lipid	57.8	0.7	58.4	0.5
Ash	3.6	6.0	4.3	2.8
Neutral detergent fiber	3.8	83.9	3.8	89.4
Acid detergent fiber	3.0	74.6	2.4	78.3
Acid detergent lignin	0.2	45.1	0.0	45.6
Gross energy (MJ/kg)	30.7	19.3	31.1	19.5

The crude protein content of meal (defatted kernel) was 56.4% in the toxic variety (Cape Verde) and 63.8% in the non-toxic Mexican provenance, both values higher than that of commercial soyabean meal. The buffer-soluble nitrogen (BSN) and non-protein nitrogen (NPN) in different varieties ranged from 7.4-8.0g crude protein/100g DM and 4.7-5.0 g crude protein/100g DM, respectively. The NPN represented about 62-64% of the BSN. Only 7.8-9.0% of the total nitrogen in the jatropha meals was as NPN suggesting the presence of a high level (*c.* 90%) of true protein, which is comparable to that for soyabean, sunflower and rapeseed meals (Makkar et al., 1998a).

The essential amino acid composition of meals from the non-toxic provenance and toxic variety (Cape Verde) are similar (table 2). The levels of essential amino acids except lysine are higher than for the FAO reference protein. The levels of essential amino acids, except

Table 2. Essential amino acid composition of *Jatropha curcas* seed meals as compared to castor bean, the FAO Reference protein (for a 2-5 year old child) and soyabean (data from Makkar and Becker, 1997c, 1998a)

Amino acids	Amino acid composition (g/16 g N)					
	Toxic variety (Cape Verde)	Non-toxic provenance	Castor bean	FAO Reference protein	Soyabean	Extracted-meal (Moringa)
Lysine	4.28	3.40	3.86	5.80	6.08	1.48
Leucine	6.94	7.50	4.48	6.60	7.72	5.84
Isoleucine	4.53	4.85	6.27	2.80	4.62	3.49
Methionine	1.91	1.76	1.65		1.22	2.13
Cystine	2.24	1.58	1.42	2.50	1.70	4.72
Phenylalanine	4.34	4.89	4.04		4.84	4.29
Tyrosine	2.99	3.78	2.65	6.30	3.39	1.41
Valine	5.19	5.30	5.53	3.50	4.59	3.63
Histidine	3.30	3.08	2.19	1.90	2.50	2.28
Threonine	3.96	3.59	3.35	3.40	3.76	2.28
Tryptophan	1.31	-	-	1.10	1.24	-

isoleucine, in the jatropha meals are higher or similar compared to *Ricinus cummunis* (castor bean) meal (castor bean also belongs to the Euphorbiaceae family). A comparison between the amino acid composition of jatropha meal and soyabean reveals an almost similar pattern for all essential amino acids except lysine and sulphur-amino acids; lysine and sulphur-amino acid levels are respectively lower and higher in jatropha meals. Compared with casein, the levels of essential amino acids, except sulphur-amino acids, are lower in jatropha meals; the sum of methionine and cystine in jatropha meals is higher than in casein (Makkar et al., 1998a).

In vitro digestible organic matter (DOM), metabolizable energy (ME) and rumen degradable nitrogen ($IVRDN_{24h}$) of jatropha meals and soyabean meal are shown in table 3. The DOM and ME values are high (about 78% and 10.8 MJ/kg, respectively) and similar for the different jatropha meals. These values are lower than those for soyabean meal, but are comparable with those for cottonseed, rapeseed and sunflower meals. The $IVRDN_{24h}$ for the jatropha meals are low, ranging from 28.9% in the non-toxic to 43.3% in the Cape Verde variety, indicating that jatropha meal proteins are not easily degraded by reticulo-rumen microorganisms. This observation together with high values for pepsin soluble nitrogen (94-95% of the total N; Aderibigbe et al., 1997) suggest that jatropha meals have a significant amount of rumen undegradable protein which will be available to animals post-rumen for production purposes. The $IVRDN_{24h}$ for soyabean meal (80.9%) was much higher than for jatropha meals.

Table 3. Digestible organic matter (DOM), metabolizable energy (ME) and 24h in vitro rumen degradable nitrogen (IVRDN24h) of *Jatropha curcas* and soyabean meals

	Toxic variety (Cape Verde)	Non-toxic provenance	Soyabean meal
DOM (%)	78.0	77.3	87.9
ME (MJ/kg DM)	10.9	10.7	13.3
IVRDN24h (%)	43.3	28.9	80.9

The PER value of the seed meal from the non-toxic provenance and the above chemical parameters suggest that the seed meal from the non-toxic provenance is of high quality and that the seed meal from the toxic variety after detoxification has a high potential for use as a protein supplement. A pre-requisite for development of detoxification processes is to know the toxin and the antinutritional factors present in seeds of the toxic variety.

Toxic and antinutritional factors

In order to identify the factor(s) responsible for jatropha toxicity, toxic and antinutritional factors in seeds from the toxic variety and the non-toxic provenance were compared, which lead to the identity of the toxic factor. There was no evidence of the presence of anti-fermentative factor(s) in the meal. Tannins, cyanogens, glucosinolates and amylase inhibitors were not detected in the meal samples (Makkar et al., 1998a). Table 4 shows levels of some antinutritional and toxic factors.

Table 4. Some antinutritional and toxic factors in *Jatropha curcas*

	Toxic variety (Cape Verde)	Non-toxic provenance
Phorbol esters[a] (mg/g kernel*)	2.70	0.11
Lectin [1(mg meal/ml assay which produced haemagglutination)]**	102	51
Trypsin inhibitor activity (mg trypsin inhibited/g meal)**	21.3	26.5
Phytate (% in meal)**	9.4	8.9
Saponins (% diosgenin equivalent in meal)**	2.6	3.4

* DM content of kernel 96.6%.

** on dry matter basis.

[a] Equivalent to phorbol-12-myristate 13-acetate.

Lectin activity (inverse of minimum amount of meal in mg/ml assay mixture which produced heamagglutination) is lower in meal from the non-toxic compared to the toxic (51 vs 102) variety. The lectin assay used was based on haemagglutination of two-fold serially diluted extracts of the sample. This implies that values of 51 and 102 by the haemagglutination method are separated by only one dilution and are therefore not very different from one another. Toxicity of *J. curcas* seeds is generally attributed to the presence of lectin (curcin) in these seeds (Mourgue et al., 1961; Stirpe et al., 1976; Cano et al., 1989). However, almost similar lectin values in the non-toxic provenance and the toxic variety suggest that lectin is not the main toxic principle in jatropha seeds (Aregheore et al., 1998). Trypsin inhibitor activity in seed meal from the non-toxic provenance was higher than for the toxic variety. Saponin and phytate levels in the meals were of similar order. The phytate content of jatropha meals is high (*c.* 9%), and a major portion of the total phosphorus is present as phytate-phosphorus. A major difference between the two meals is a high level of phorbol esters in the toxic variety and a virtual absence in the non-toxic provenance. In some provenances, phorbol esters were not detectable (Makkar et al., 1998b). Phorbol esters are known to have purgative, skin-irritating and tumor promoting effects (Adolf et al., 1984; Hirota et al., 1988). Ingestion of plants from the Euphorbiaceae and Thymelaeaceae families that biosynthesize diterpene esters of the phorbol type causes severe toxic symptoms in livestock (Kingsbury, 1964). These results suggested that phorbol esters elicit jatropha toxicity.

In order to determine the role of phorbol esters in causing toxicity unequivocally, the typical symptoms of jatropha toxicity were reproduced in fish (Makkar and Becker, 1997b) by incorporation of purified phorbol esters obtained from jatropha oil using HPLC (Makkar et al., 1997). Based on reduction in body mass and mucus production in faeces, a method for detection and possible measurement of phorbol esters in a feed was also developed using fish (carp; *Cyprinus carpio*) (Becker and Makkar, 1998). The above observations confirm that the toxicity of *J. curcas* seeds is due to phorbol esters present in the toxic variety. Lectins and trypsin inhibitor do not seem to be responsible for short-term toxicity but might enhance the toxic symptoms of phorbol esters.

Detoxification

The values for trypsin inhibitor activity in jatropha meal (table 4) are of similar order of magnitude as in raw soybean meal (Smith et al., 1980). It is known that consumption of unheated soyabean meal produces adverse effects in monogastrics. Trypsin inhibitors and lectins are heat labile and were destroyed by heat treatments. Heat treatments had no effect on saponin, phytate and phorbol ester levels (Aderibigbe et al., 1997). Some treatments which decreased trypsin inhibitor activity to the levels generally found in the commercially available steam-treated (toasted) soyabean meal and eliminated or reduced the lectin activity drastically were: 120°C for 30 min at 67% moisture, 100°C for 60 min at 67% moisture and 130°C for 30 min at 80% initial moisture. Dry heating was less effective (Aderibigbe et al., 1997, Aregheore et al., 1998).

Extraction of the meal (4 times) using aqueous ethanol (80%) or aqueous methanol (92%) [1 : 5 , w/v] removed approximately 95% of both saponins and phorbol esters. The untreated jatropha meal has a phorbol ester level of about 1.78 mg/g (about 72% of the total phorbol esters was extracted with the oil using petroleum ether (bp 40-60°C) and the remaining 28% was still present in the meal free of oil, probably bound to proteins and complex carbohydrates such as starch, pectin, cellulose, and xylan; Makkar and Becker, 1997a; Winkler et al., 1997).

The meal from the toxic variety after heat treatment (67% moisture, 120°C for 30 min) followed by the aqueous methanol treatment was found to be innocuous to rats (Makkar and Becker, 1997b). The solvent and phorbol esters can be recovered by distillation. The solvent can be re-used and the phorbol esters can be used as insecticidal and molluscicidal agents.

Phorbol esters are generally unstable under alkaline conditions. The seed meal treated with various levels of sodium hydroxide (2 to 4%, w/w) and sodium hypochlorite (1 to 2.5% active chlorine) alone or in combination, followed by heat treatment (67% moisture, 120°C for 30 min) decreased the phorbol ester level from 1.78 mg/g to 0.14 mg/g seed meal. Although a diet containing 16% of this treated meal was not fully accepted by rats, no animal died (Makkar, Aregheore and Becker, unpublished observations). Poor acceptability of the diet containing this chemically treated meal could be due to presence degraded moieties of phorbol esters. This treatment might have potential for ruminants. It may be noted that these chemical treatments together with the heat treatment have been reported to detoxify *Ricinus cummunis* (castor bean) meal by inactivating the lectin (ricin) and allergen (Rhee et al., 1987).

MORINGA OLEIFERA

The Moringaceae is a single genus family with 14 known species. Of these, *Moringa oleifera* Lam (synonym: *Moringa pterygosperma* Gaertner) is the most widely known and grows throughout most of the tropics. It is native to sub-Himalayan tracts of north-west India, Pakistan, Bangladesh and Afghanistan, can grow on bad soil, and is commonly referred to as drumstick tree (describing the shape of its pods) or horseradish tree (describing the taste of its roots). It is a drought-tolerant, multipurpose tree of significant economic importance as it has several industrial and medicinal uses. It is a small (7-12 m high), fast growing tree with thick grey bark, fragrant white flowers

and long green pods which produces seeds at about 18 months. It can also be cultivated for forage production under intensive farming systems. Initial trials in Nicaragua have shown a high biomass production of up to 120 tons dry matter/ha per year, in eight cuttings, after seeding 1 million seeds per ha. The fruits, seeds, leaves and flowers are also eaten in some countries as nutritious vegetables. The leaves are rich in carotene, iron and ascorbic acid and the pods in free leucine. The leaves are free from antinutritional factors and high in crude protein (26%), and amounts of all essential amino acids are higher than the amino acid levels of the FAO reference protein and comparable to those in soyabean. Oil is extracted from the seeds or the seeds are used for curry powders. The pods (brown, triangular, splitting lengthwise into 3 parts when dry) contain about 20 seeds (dark brown in colour, with 3 papery wings) embedded in the pith. Application of an ethanol extract (80%, v/v) of *M. oleifera* leaves has been shown to increase nodulation of black-gram (*Vigna munga* L.) and to increase growth of plants such as *J. curcas*, maize, soyabean and peanut, suggesting the presence of some growth factors in leaves. The kernels of *M. oleifera* can be crushed and its water extract used to purify water. The water extract is considered to be a viable replacement coagulant (biodegradable and environment friendly) for chemicals such as aluminium sulphate (alum) in developing countries. As moringa oil can be used for human consumption, the water extract of seed meal has been used to purify water. The possible major uses of *M. oleifera* tree have been shown in Figure 2; details can be obtained from Morton (1991) and Makkar and Becker (1996a). The de-shelled seeds (kernels), water-extracted kernel (residue left after removal of water-soluble coagulants from kernels), seed meal (defatted kernels) and water-extracted meal (residue left after removal of water-soluble coagulants from meal) could be potential sources of animal feed. On average, *M. oleifera* seed weighs 0.3 g and the kernel to shell ratio is 75:25 (Makkar and Becker, 1997c).

Nutritional value

The crude protein and lipid contents of the kernel are approximately 37% and 42% respectively. The residues left after water extraction of kernel or meal have crude protein contents of 35 and 70% respectively. The shells are low in crude protein (10%) but high in fiber (neutral detergent fiber: 84%). The non protein nitrogen content of kernel and meal is *c.* 9% of the total crude protein and nil in the residues (extracted-kernel and extracted-meal) left after extraction of water coagulants. The rumen degradable crude protein of kernel, meal, extracted-kernel and extracted-meal has been reported to be 64, 61, 36 and 28% respectively. The low values of rumen degradable crude protein (28-36%), high pepsin soluble nitrogen (82-91%) and low acid detergent insoluble nitrogen values (1-2%) suggest that most of the protein in the extracted-kernel and extracted-meal samples would be available postruminally. The values of protein potentially digestible in the lower intestine (post-rumen) of *c.* 62-69% of the total protein in these samples is much higher than in other protein supplements such as coconut, sunflower, cottonseed, groundnut and sesame meals (Makkar and Becker, 1997c). The kernel, meal and their water-extracted residues are deficient in lysine, leucine, phenylalanine + tyrosine and threonine when compared to the standard FAO protein. The contents of sulphur-containing amino acids in these samples are higher (table 1 presents values for the extracted-meal; almost similar values have been reported for kernel, meal and extracted kernel; see Makkar and Becker, 1997c).

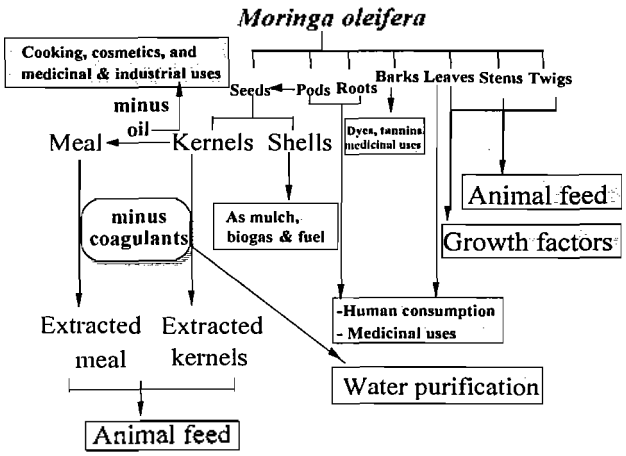

Figure 2. Parts of *Moringa oleifera* and their possible uses

Antinutritional factors

Tannins, trypsin inhibitors and amylase inhibitors were not detected in the seed samples. The saponin content of kernels, meal, extracted-kernel and extracted-meal is negligible (0.5-1.4%). The water treatment of kernels and meal, used for extraction of active moieties to purify water, removes *c.* 50% of the saponins (table 5). Only the kernel and extracted-kernel samples showed haemolytic activity; haemolytic activity was higher by extracted kernels in spite of its lower saponin level, suggesting that the haemolytic activity is not due to saponins. Some other moieties, probably associated with the oil fraction (as haemolytic activity was not detected in the meal or extracted-meal), produce haemolysis. The nature of these haemolytic factors and their possible effects on the nutritional value and shelf-life of the oil are not known.

Haemagglutination activity has been observed in kernel and meal samples but not in their extracted samples (table 5). Kernel and meal contain several proteins that possess a net positive charge at a pH < 8.6 (pKa > 8.6). These positively charged proteins are considered to be the active moieties for flocculation of impurities. These act as a natural cationic polyelectrolyte in the water purification process (Bart et al., 1982). It is

Table 5. Antinutritional factors in untreated and treated kernels of *Moringa oleifera*

Sample	Total phenols[a] (%)	Saponin[b] (%)	Cyanogens[c] (mg/100g)	Gluco-sinolates[d] (μmol/g)	Phytate[e] (%)	Haem-agglutination	Haemolytic activity
Kernel	0.02	1.1	0.5	46.4	2.6	+	+
Meal	0.04	1.4	1.3	65.5	4.1	+	nd
Extracted-kernel	0.07	0.46	1.5	4.4	3.0	nd	+
Extracted-meal	0.06	0.64	3.1	nd	6.7	nd	nd

nd, not detected.
[a] as tannic acid equivalent; [b] as diosgenin equivalent; [c] as HCN equivalent; [d] as glucose equivalent; [e] as phytic acid equivalent.

not known whether the haemagglutination activity observed in kernel and meal samples is due to electrostatic interaction between these proteins and erythrocytes and/or to true lectin activity (Carratù et al., 1995).

Cyanogens are present in kernel, meal, extracted-kernel and extracted-meal samples (table 5). These levels are much lower than those considered safe per EC regulations i.e. < 10 mg HCN equivalent/100 g for cassava and almond cakes, and < 25 mg HCN equivalent/100 g for linseed meal. Furthermore, according to EC regulations for livestock, the cyanogen level in a compounded feed should not exceed 50 mg HCN equivalent/kg except for the chicks whose safe level is fixed at 10 mg HCN equivalent/kg. For human consumption, a safety limit of 10 mg HCN equivalent/kg flour has been fixed by FAO/WHO (1991).

The levels of glucosinolates observed for kernel and meal samples (table 5) are of the same order as for rapeseed meal (Saini and Wratten, 1987; Smith and Dacombe, 1987) and *Camelina sativa* seeds (Lange et al., 1995). For swine, the limiting value above which sows' fertility may be impaired is 4 μmol of total glucosinolates/g diet and 8 mmol of daily intake of these compounds. In rats, a diet with glucosinolate levels > 2.7 μmol/g feed might increase the mortality of pups which could be due to transfer of glucosinolate breakdown products to milk, and in cows, a significant increase in days from calving to conception was observed when daily intake of glucosinolates was approximately 75 mmol/cow (see review: Mawson et al., 1994). The extracted meal sample is free of glucosinolates (table 5). One of the glucosinolates isolated from *M. oleifera* seeds is 4(alpha-L-rhamnosyloxy) benzyl gluco-sinolate which in presence of water seems to get converted to 4(alpha-L-rhamnosyloxy) benzyl isothiocyanate by myrosinase activity in seeds (Eilert et al., 1981). This isothiocyanate has a strong antibiotic activity, the presence of which-along with coagulants in the seed or meal extract used for purification of water-will have an effect on microrganisms in the water. While some glucosinolates may make an important contribution to the flavour and aroma of the feed/food, others have been shown to be potentially harmful and it is generally accepted that high levels of glucosinolates are undesirable in food for human and animal consumption (Heaney and Fenwick, 1980). These glucosinolates can undergo chemical and enzymatic hydrolysis to produce a range of products which possess antinutritional properties leading to reduced growth and impaired reproduction. The 4(alpha-L-rhamnosyloxy) benzyl isothio-cyanate, a converted product of moringa seed glucosinolates, has been observed to be toxic to mice even at a low dose of 0.55 mg/25 g mouse (Eilert et al., 1981). Thermal degradation of moringa seed glucosinolates produces 4(alpha-L-rhamnosyloxy) phenylacetonitrile which is mutagenic (Villasenor et al., 1989).

At least three alkaloids are present in the meal. A substantial amount of these alkaloids is removed from the meal following extraction with water, i.e. extracted-meal is free of alkaloids (Makkar and Becker, 1997c).

Phytate levels of about 30 g/kg and 67 g/kg observed for extracted-kernel and extracted-meal are similar in magnitude to those for many other conventional protein supplements (soyabean meal 32-38 g/kg, rapeseed meal 60-73 g/kg, sunflower 62-92 g/kg, peanut meal 32-43 g/kg; Pointillart, 1993). Phytate present to the extent of 1 to 6% is known to decrease the bioavailability of minerals in monogastrics (Reddy et al., 1982). Decrease in the digestibility of starch and protein by phytate has also been reported (see Thompson, 1993).

Detoxification

The main antinutritional factors in kernel and meal samples which are likely to produce adverse effect on animal health and production are glucosinolates, haemagglutinins and alkaloids. All these three components were virtually absent in residues left after treatment with water (see above). Therefore, an attractive approach to detoxify kernel or meal for animal feeding is the soaking of samples in water for 20 to 30 min, followed by sieving to recover the residue for animal feeding. Although kernel and meal samples are bitter in taste, the residues left after extraction with water were almost free of bitter taste. The bitter taste is generally attributed to alkaloids, saponins, cyanogens and glucosinolates which were removed by the treatment, suggesting that the bitter taste would not limit the use of this material in animal diets (Makkar and Becker, 1997c). Our preliminary studies have shown good acceptability of the water-extracted meal by rats. Detoxification of another glucosinolate-rich *Cramble abyssinica* (cramble) meal by water-washing has been

achieved. After detoxification using water-washing treatments, this meal was found to be suitable for monogastrics (Liu et al., 1994a, b). Another tropical seed meal (mustard, *Brassica* spp.), which in addition to erucic acid contains high levels of glucosinolates, could be detoxified using this treatment. However, a major disadvantage of this treatment is that other soluble fractions are lost too. For detoxification of moringa seed meal, water-washing is an attractive proposition as other water-soluble components have the utility for water purification. For locations where moringa coagulants are not required, solid-state fermentation of the seed meal using *Rhizopus oligosporus* sp. could be considered, as this mould degraded glucosinolates in defatted rapeseed meal (Bau et al., 1994).

OTHER TROPICAL SEEDS WITH POTENTIAL AS ANIMAL FEED

Some tropical seeds have been systematically evaluated for their feeding value in India. The details on their nutritional potential, possible adverse effects and safe limits for incorporation are available in Punj (1988). Seeds of *Acacia nilotica, Madhuca indica, Garcinia indica, Shorea robusta* and *Tamarindus indica*, seed kernel of *Mangifera indica*, and pods *of A. nilotica, Theobroma cacao* and *Quercus* spp. have been reported to be very high in tannins (Makkar et al., 1990; Negi, 1985; Makkar and Becker, 1996b). These tannin-rich agro-forestry byproducts can be detanninified by using hydrogen peroxide (a strong oxidising agent) in presence of sodium hydroxide. A decrease in tannin content as high as 99% has been observed which is due to inactivation of tannins as a result of their oxidation (Makkar and Becker, 1996b). The use of oxidising agents holds promise for a large scale detoxification of tannin-rich feedstuffs because of their low cost. These approaches are very simple, do not require complex equipment and have the potential to be adopted by the feed industry. Seeds, pods or seed meal of *Prosopis juliflora, Pithecolobium saman, Cassia tora, Guizotia abyssinica, Pongamia glabra, Schleichera oleosa, Hevea brasiliensis* and *Hibiscus cannabinus* are very low in tannins (Makkar et al., 1990). Their incorporation in livestock feed may be considered, subject to absence of other deleterious factors. *P. glabra* seeds are toxic due to the presence of karanjine. As this toxin is fat soluble and is removed during solvent extraction, the solvent extracted meal can be used with impunity in ruminant diets (Punj, 1988). *P. glabra* seed meal has also been found to be rich in trypsin and chymotrypsin inhibitors which can be removed by heat or acid treatment (Rattansi and Dikshit, 1997). Seed cakes of *S. oleosa* and *H. brasiliensis* have been observed to contain low levels of HCN which do not seem to produce any adverse effects. *Madhuca indica* seed cake is rich in saponins (mowrin). Its consumption produces adverse effects in monogastrics but not in ruminants. The seeds of *C. tora* contain a toxic factor, crysophanic acid, which can be removed by washing with water (Punj, 1988). Besides high amounts of tannins, cyanogenic glucoside content of 64 mg/kg has been reported for *Mangifera indica* seed kernels. Soaking and boiling of kernels have been reported to decrease a substantial amount of cyanogenic glucosides, but these treatments did not overcome the adverse effects of the seed kernel incorporation in chick diets (Ravindran and Sivakanesan, 1996). The adverse effects observed on chicks appear to be due to tannins.

In another systematic study (Grant et al., 1995), the nutritional potential of a number of raw tropical seeds was assessed in a series of feeding trials with rats. Lectin activity was also monitored. Seeds of *Artocarpus altilis, Canavalia ensiformis, Canavalia maritima, Dioclea grandiflora, Phaseolus acutifolius, Phaseolus coccineus* and some cultivars of *Phaseolus vulgaris* contained high levels of toxic lectins, and these seeds were toxic to rats. On the other hand, seeds of *Albizia adinocephala, Albizia lebbeck, Bauhinia violacea, Cassia nodosa, Cassia tora, Dioclea sclerocarpa, Entada phaseoloides, Enterolobium cyclocarpum* and *Leucaena leucocephala* had low lectin activities but were toxic, suggesting presence of other antinutritional/toxic factors. Low levels of lectins were also observed in seeds of *Bauhinia reticulata, Macrotyloma uniflorum* and *Tamarindus indica*. Feeding of these seeds showed no toxicity but the digestibility of protein was very low in rats. The results also suggested that seeds of *Abelmoschus esculentus, Chenopodium quinoa, Delonix regia, Macroptilium lathyroides, Papaver somniferum, Parkia biglandulosa, Sesbania arabica, Terminalia catappa, Vigna subterranea, Vigna umbellata* and *Vigna unguiculata* have a potential as protein supplement in animal diets.

The toxicity of *Canavalia ensiformis* (jackbean) seed has been partially overcome by extrusion cooking which destroys lectin (Cocanavalin A) (Melcion et al., 1994). The remaining adverse effects could be due to the presence of heat-stable factors such as canavanine and/or antigenic proteins (Melcion et al., 1994; D'Mello, 1995a,b). Canavanine can be removed from the extruded jack bean meal using acid extraction (Tepal et al., 1994). *Prunus persica* (peach) and *Prunus armaniaca* (apricot) kernel meals contain HCN and amygdalin (a cyanogen) as the main antinutritional factors. These can be removed to a substantial extent by microbial treatment (Nout et al., 1995), soaking in water and soaking followed by cooking (El-Adawy and El-Kadousy, 1995; Tuncel et al., 1995), and soaking in ammoniacal water (El-Adawy et al., 1994). Similarly, mimosine present in *Leucaena leucocephala* seeds can be eliminated by soaking split seeds in water for 24 h (Soedarjo and Borthakur, 1996). Water-washing has also been found to detoxify *Azadirachta indica* (neem) seed meal (Verma et al., 1995). *In vivo* studies are required to evaluate the nutritional value most of these residues obtained after soaking treatments.

Seeds of Jojoba, *Simmondsia chinensis* (an oilseed

shrub that grows on arid land in the Southwest United States and Mexico) contain antinutritional factors such as 5-demethylsimmondsin,4,5-didemethyl-simmondsin, simmondsin and 2-ferulate, trypsin inhibitors and tannins. Ruminants are less prone to jojoba meal toxicity compared to monogastrics as simmondsin is degraded by rumen microbes. Although various detoxification processes, for example water extraction, enzyme processes, microbiological treatments, solvent extraction and ammoniacal hydrogen peroxide have been suggested (Verbiscar et al., 1980, 1981; Abbott et al., 1991), isolation of protein isolate would provide the most valuable byproduct from the seed meal.

The consumption of *Crotalaria* spp. seeds produces adverse effects which are attributed to pyrollizidine alkaloids. Removal of toxic principles from these seeds by boiling in water has been suggested (Mkiwa et al., 1994). Cyclopropionic fatty acid present in *Ceiba pentandra* (kapok) seed or seed meal could produce deleterious effects (Sebedio and Grandgirard, 1989). The seeds of *Indigofera spicata* contain non-protein toxic amino acids, canavanine and indospicine (arginine analogues) and those of *Robinia pseudoacacia* (black locust) canavanine (D'Mello, 1995a). Systematic studies are required for detoxification of these seeds. In *Cyamopsis tetragonoloba* (guar) seeds, the primary antinutritional factor is a galactomannan gum (guaran). This polysaccharide inhibits enzyme-substrate interactions and also reduces nutrient absorption by increasing viscosity of digesta. Proteinase inhibitors and saponins are also present in guar meal. Various detoxification treatments (heat, dietary additives, solvent extraction and micobiological) and the performance of farm animals fed diets containing the upgraded guar meal are well documented in D'Mello (1995b).

Toxic effects of feeding *Ricinus communis* (castor) and *Shorea robusta* (sal) seed meal have been neutralized by mixing both these seed meals in rats diets. The alleviation of toxic effects was attributed to the detoxification of castor seed meal by neutralization of its toxicants by tannins present in salseed meal (Gandhi et al., 1994). It has also been shown: i) that simultaneous presence of saponin and tannin in the diet of mice abolishes adverse effects of both these factors (Freeland et al., 1985), ii) interactions between lectins and tannins remove the inhibitory action of tannins on amylase (Fish and Thomson, 1991), and iii) tannins may interfere with the release of HCN from the hydrolysis of cyanogens thus reducing their deleterious effects in certain ecological situations (Goldstein and Spencer, 1985). On the other hand, studies on antinutrient-antinutrient interactions, *in vitro*, with special reference to tannin-saponin interactions reveal that the effects of both tannins and saponins on decrease in various rumen fermentation parameters were additive, and that the hypothesis "the simultaneous presence of tannins and saponins might alleviate the adverse effects of each other" does not hold true for the tannins (tannic acid and quebracho tannins) and saponins (Quillaja saponins) (Makkar et al., 1995). The results could be different for saponins and tannins from other sources, as the biological effects of both tannins and saponins are dependent on their structure and chemical properties. Very little is known about 'antinutrient-antinutrient' interactions. Results from such studies, besides providing a sound basis for development of detoxification processes, may also extend the understanding of the nutritional role of complex mixtures of antinutrients in feeds, as generally, antinutrients do not exist in isolation.

CONCLUSIONS AND FUTURE LINES OF ACTION

Mankind depends on a diverse range of cultivated species. At least 6000 of such species are used for a wide range of purposes. It is true that only a few staple crops produce the majority of our food supply, but the important contribution of lesser known seed crops should not be underestimated since some of these seeds are native to and grow well in poor, marginal and degraded lands where food and water shortage or even famine are endemic and deforestation is widespread. The tropics happen to be the location of our planets greatest collection of biodiversity. There is a convergence between problems and plants; the greatest global hazards originating in the region where the greatest array of botanical wealth is found.

Tropical seeds often contain antinutritional and toxic factors (table 6) which impart the crop with some positive agronomic characteristics allowing the production of reasonable yields in adverse, harsh conditions, but these same factors are deleterious to animals. Systematic studies are imperative to identify and remove or inactivate such factors for better utilization of seeds and seed byproducts.

J. curcas does not compete with conventional food crops for land and/or water and is therefore the ideal choice to make use of vast land resources that are presently under-utilized. Phorbol esters are the main toxic agent in jatropha toxicity. The high levels of trypsin inhibitor, lectin and phytate might aggravate adverse effects but do not seem to be responsible for the short-term toxicity.

The protein and amino acid composition of *J. curcas* meal from the non-toxic Mexican provenance is similar to that from the toxic variety. The levels of essential amino acids except lysine are comparable with those for the FAO reference protein. The seed/meal from the non-toxic provenance is of as good a quality as that from the toxic variety. Both meals contained significant levels of trypsin inhibitor and lectin which can be destroyed by heat. The presence of a high level of phytate which is heat-stable can decrease the bioavailability of minerals. However, the high protein efficiency ratio (86% of that for casein) observed in rats and good growth of fish on a diet containing 32% jatropha meal suggest that phytate does not affect animal performance adversely to any appreciable extent. The non-toxic provenance of jatropha from Mexico could be

Table 6. Antinutritional and toxic factors in some tropical seeds

Seeds	Antinutritional and toxic factors	Reference(s)
Acacia nilotica	Tannins	Negi (1985), Makkar & Becker (1996b)
Albizia adinocephala	Lectins, unidentified toxic factor(s)	Grant et al. (1995)
Albizia lebbeck	Lectins, unidentified toxic factor(s)	Grant et al. (1995)
Artocarpus altilis	Lectins	Grant et al. (1995)
Bauhinia violacea	Lectins, unidentified toxic factor(s)	Grant et al. (1995)
Canavalia ensiformis	Lectin (Cocanavalin A), canavanine, antigenic proteins	Melcion et al. (1994), Grant et al. (1995), D'Mello (1995a,b)
Canavalia maritima	Lectins	Grant et al. (1995)
Cassia nodosa	Lectins, unidentified toxic factor(s)	Grant et al. (1995)
Cassia tora	Crysophanic acid, lectins, unidentified toxic factor(s)	Punj (1988), Grant et al. (1995)
Ceiba pentandra	Cyclopropionic fatty acid	Sebedio & Grandgirard (1989)
Crotalaria spp	Pyrollizidine alkaloids	Mkiwa et al. (1994)
Cyamopsis tetragonoloba	Galactomannan gum (guaran), proteinase inhibitors, saponins	D'Mello (1995b)
Dioclea grandiflora	Lectins	Grant et al. (1995)
Dioclea sclerocarpa	Lectins, unidentified toxic factor(s)	Grant et al. (1995)
Entada phaseoloides	Lectins, unidentified toxic factor(s)	Grant et al. (1995)
Enterolobium cyclocarpum	Lectins, unidentified toxic factor(s)	Grant et al. (1995)
Garcinia indica	Tannins	Makkar et al. (1990)
Hevea brasiliensis	Cyanogens (HCN)	Punj (1988), Selmar et al. (1991)
Indigofera spicata	Canavanine, indospicine	D'Mello (1995a)
Jatropha curcas	Phorbol esters, lectins, trypsin inhibitor, phytate	Makkar and Becker (1997b), Makkar et al. (1997, 1998a)
Leucaena leucocephala	Lectins, unidentified toxic factor(s), mimosine	Grant et al. (1995), Soedarjo & Borthakur (1996)
Madhuca indica	Tannins, saponin (mowrin)	Punj (1988), Makkar et al. (1990)
Mangifera indica	Tannins, cyanogens (HCN)	Makkar et al. (1990), Ravindran & Sivakanesan (1996)
Moringa oleifera	Glucosinolates, alkaloids, cyanogens, Haemagglutinating factor(s)	Makkar & Becker (1997c)
Phaseolus acutifolius	Lectins	Grant et al. (1995)
Prunus armaniaca	Cyanogen (amygdalin), HCN	Tuncel et al. (1995)
Phaseolus coccineus	Lectins	Grant et al. (1995)
Phaseolus vulgaris	Lectins	Grant et al. (1995)
Pongamia glabra	Karanjine, Protease inhibitors	Punj (1988), Rattansi & Dikshit (1997)
Prunus persica	Cyanogen (amygdalin), HCN	El-Adawy & El-Kadousy (1995)
Quercus spp	Tannins	Negi (1985)
Ricinus communis	Lectin (ricin), allergen	Rhee et al. (1987)
Robinia pseudoacacia	Canavanine	D'Mello (1995a)
Schleichera oleosa,	Cyanogens (HCN)	Punj (1988)
Shorea robusta	Tannins	Negi (1985), Makkar & Becker (1996b)
Simmondsia chinensis	5-demethyl-simmondsin, 4,5-didemethyl-simmondsin, simmondsin, 2-ferulate, trypsin inhibitors, tannins	Abbott et al. (1991), Cokelaere et al.(1993)
Tamarindus indica	Lectins, tannins	Grant et al. (1995), Makkar & Becker (1996b)
Theobroma cacao	Tannins	Makkar et al. (1990)

a suitable alternative to toxic jatropha varieties, and it is suggested to propagate its cultivation. This non-toxic variety of jatropha is a potential source of edible oil. As with soyabean and peanut, the processed seed meal from the non-toxic variety can be a good protein component for humans, and the seed meal after heat treatment (to destroy trypsin inhibitor and lectin) can also be a valuable protein supplement for livestock. Treatments such as extraction with 92% aqueous methanol or 80% ethanol hold promise for detoxification of meal obtained after extraction of oil from the already existing toxic varieties. Phorbol esters obtained as byproducts of this detoxification process have potential as insecticidal and molluscicidal agents. Studies on comparative evaluation of seed yield and resistance to diseases for the non-toxic and toxic varieties grown by conventional (plantation by seeding or cutting) and tissue culture (Sujatha and Mukta, 1996) should be conducted. Studies have been initiated in this direction in India, Zimbabwe, Nicaragua and Mexico. Presence of high levels of antinutritional factors such as trypsin inhibitor, lectin, and phytate in the non-toxic provenance is likely to provide resistance to this *in vitro* rumen protein degradability of unheated jatropha meal is about 43% whereas it increased on heat treatment to 73% (Aderibigbe et al., 1997). On the other hand, there is no difference between the pepsin digestibility of unheated and heat treated jatropha meal (95%). These observations suggest that unheated jatropha meal from the non-toxic provenance could be a good source of rumen undegradable protein, provided that the lectin and trypsin inhibitors which are present in high amounts in the unheated meal do not exert any adverse effects on ruminants. Degradation of lectin and trypsin inhibitors by rumen microbes is possible. The effects of incorporating unheated and heat treated jatropha meal from the non-toxic provenance providing different level of rumen degradable and undegradable protein into diets should be investigated using lactating or wool-producing animals.

The coagulants can be recovered efficiently both from *M. oleifera* seed kernel as well as meal by their extraction with water. The use of coagulants from the meal would benefit the overall economy of the system. The oil recovered can be used for human consumption and other purposes such as illumination and lubrication. The residues left after extraction of coagulants from the meal can form a good source of protein supplement because of: i) high crude protein content (*c.* 70%), all in the form of true protein, ii) high availability of protein post-ruminal (69% of the total protein) and high pepsin digestibility, iii) virtual absence of antinutritional factors such as tannins, saponins, alkaloids, inhibitors of trypsin and amylase, lectin, cyanogenic glucosides and glucosinolates, and iv) higher concentration of sulphur-containing amino acids than that of the recommended amino acid pattern of FAO/WHO/UNO reference protein for a 2 to 5 year old child. Presence of phytate at about 6.7% might decrease bioavailability of minerals. The residue obtained after extraction of coagulants from the meal could replace some conventional seed meals. This may be a good source of sulphur amino acids for fibre-producing animals (such as Angora rabbits, sheep and goats) in a mixed diet containing sufficient levels of other essential amino acids. However, before recommendations can be made to farmers, *in vivo* experiments are required to study various performance parameters and possible toxicity arising due to factors not yet studied. It may be noted that the presence of high levels of sulphur-containing amino acids would offer the animal some protection against toxic factors, if any, since these acids are known to enhance the detoxification process of the animal by acting as methyl donors in various organs. It may be noted that young seeds are eaten as peas in India and mature seeds are fried or roasted like groundnuts (Ramachandran et el., 1980; FAO, 1988). Some studies on mice, rats and fish (Bart et al., 1982; Berger et al., 1984; Grabow et al., 1985) showing no toxicity of seeds also give rise to optimism for their possible use as animal feed, although Grant et al. (1995) have shown adverse effects on rats fed seed meal. Studies are also warranted on exploitation of seed and seed meal of another species, *M. stenopetala* (Bak.) Cif. (synonym: *Donaldsonia stenopetala, M. streptocarpa, M. peregrina*), which is also a fast-growing deciduous species and is cultivated in semi-arid and sub-humid Ethiopia (Southern Rift Valley), Somalia and Kenya. Many different varieties exist whose pods and kernels vary in taste from sweet to bitter, suggesting different levels of antinutritional factors and, possibly, of glucosinolates (see Makkar and Becker, 1997c). Systematic studies are required to screen and propagate cultivation of different moringa species of required traits.

For many other tropical seeds, antinutritional factors and toxins have been identified, their effects studied and detoxification approaches suggested. However, none of these detoxification procedures seems to have been adopted commercially. In most cases, the cost involved is the main constraint. Seed byproducts containing heat-labile antinutritional factors are easier to detoxify using heat treatments but this requires energy which is expensive and rare in many tropical countries. Development and utilization of value-added products other than seed meal can make a process economically viable, which will in turn determine the economic viability of cultivating such a seed crop. The available detoxification methods can be grouped into: physical (heat treatment; direct or through extrusion), chemical (extraction with solvents, water with or without alkalies or with oxidising agents), a combination of physical and chemical (heat treatment followed or preceeded by chemical treatments) and microbiological treatments. In most cases systematic animal studies on evaluation of nutritional value of detoxified seed meal are lacking. Plant breeding strategies to reduce antinutritional and toxic factors from seeds might result in agronomical disadvantages leading to extinction or excessive use of fungicides, pesticides and other crop-protecting chemicals

which harm the environment. Detoxification by dietary supplements (enzymes, anti-antinutritional factors) needs the attention of research workers. Safeguards are required against: erroneous conclusions in experiments designed to determine safe levels of inclusion of byproducts containing incriminating factors, and improper exploitation of these safe levels by the feed industry (Negi, 1985). Novel ways of using seed-byproducts can convert disposal problems into opportunities for development. Domestication and development of conventional oilseeds such as soyabean or rapeseed took place over thousands of years before the properties of these crops were generally understood leading to their use extensively as animal feeds. Furthermore, there has always been an incubation period, a time lag between development of a process and its adoption by industry. This presumably is due to mobilization of opinion of a large number of scientists, end-users and industry towards applicability, economic viability and usefulness of a techology, which is a slow process. It is hoped that this paper will help meet this goal, and play a vital role in converting 'an unconventional feed/food of today to a conventional feed/food of the future' as well as in bridging the wide gap that exists between supply and demand for nutrients and energy.

REFERENCES

Abdu-Aguye, I., A. Sannusi, R. A. Alafiya-Tayo, and S. R. Bhusnurmath. 1986. Acute toxicity studies with *Jatropha curcas*. Human Toxicol., 5, 269-274.

Abbott, T. P., L. K. Nakamura, G. Buchholz, W. J. Wolf, D. M. Palmer, H. J. Gasdorf, T. C. Nelsen and Kleiman, R. 1991. Processes for making animal feed and protein isolates from jojoba meal. J. Agric. Food Chem., 39, 1488-1493.

Adam, S. E. I. 1974. Toxic effects of *Jatropha curcas* in mice. Toxicol., 2, 67-76.

Adam, S. E. I. and M. Magzoub. 1975. Toxicity of *Jatropha curcas* for goats. Toxicol., 4, 347-354.

Aderibigbe, A. O., C. O. L. E. Johnson, H. P. S. Makkar, K. Becker and N. Foidl. 1997. Chemical composition and effect of heat on organic matter- and nitrogen-degradability and some antinutritional components of Jatropha meal. Anim Feed Sci. Technol., 67, 223-243.

Adolf, W., H. J. Opferkuch and Hecker, E. 1984. Irritant phorbol derivatives from four *Jatropha* species. Phytochemistry, 23, 129-132.

Ahmed, O. M. M. and S. E. I. Adam. 1979a. Effects of *Jatropha curcas* on calves. Vet. Pathol., 16, 476-482.

Ahmed, O. M. M. and S. E. I. Adam. 1979b. Toxicity of *Jatropha curcas* in sheep and goats. Res. Vet. Sci., 27, 89-96.

Aregheore, E. M., H. P. S. Makkar and K. Becker. 1998. Assessment of lectin activity in a toxic and non-toxic variety of *Jatropha curcas* using latex agglutination and haemagglutination methods and inactivation of lectin by heat treatment. J. Sci. Food Agric. 77:349-352.

Bart, V. H., M. Habs, R. Klute, S. Müller and B. Tauscher. 1982. Trinkwasseraufbereitung mit Samen von *Moringa oleifera* Lam. Chemik. Zeit., 106, 75-78.

Bau, H. M., C. Villaume, C. F. Lin, J. Evrard, B. Quemener, J. P. Nicolas and Méjean. 1994. Effect of a solid-state fermentation using *Rhizopus oligosporus* sp. T-3 on elimination of antinutritional substances and modification of biochemical constituents of defatted rapeseed meal. J. Sci. Food Agric., 65, 315-322.

Becker, K. and H. P. S. Makkar. 1998. Toxic effects of phorbol esters in carp (*Cyprinus carpio* L.). Vet. Human Toxicol. 40:82-86.

Berger, M. R., M. Habs, S. A. A. Jahn and D. Schmahl. 1984. Toxicological assessment of seeds from *Moringa oleifera* and *Moringa stenopetala*, two highly efficient primary coagulants for domestic water treatment of tropical raw waters. E. Afr. Med. J., 61, 712-716.

Cano Asseleih, L. M., Plumbly, R. A. and Hylands, P. J. 1989. Purification and partial characterization of the hemagglutinin from seeds of *Jatropha curcas*. J. Food Biochem., 13, 1-20.

Carratù, G., A. M. Carafa, M. M. Corsaro and M. Giannattasio, 1995. Pollen hemagglutinating activity is not related to lectin. Sex Plant Reprod., 8, 91-94.

Cokelaere, M. M., J. Buyse, P. Daenens, E. Decuypere, E. Kühn and M. V. Boven. 1993.Influence of jojoba meal supplementation on growth and organ function in rats. J. Agric. Food Chem., 41, 1444-1448.

D'Mello, J. P. F. 1995a. Ant-nutritional substances in legume seeds. In: Tropical legumes in animal nutrition (Eds. D'Mello, J. P. F. and C. Devendra), pp 135-172, CAB Int., UK.

D'Mello, J. P. F. 1995b. Under-utilized legume grains in non-ruminant nutrition. In: Tropical legumes in animal nutrition (Eds. D'Mello, J. P. F. and C. Devendra), pp 283-329, CAB Int., UK.

Eilert, U., B. Wolters and A. Nahrstedt. 1981. The antibiotic principle of seeds of *Moringa oleifera* and *Moringa stenopetala*. Planta Medica, 42, 55-61.

El-Adawy, T. A., E. H. Rahma, A. A. El-badawey, M. A. Gomaa, R. Lasztity and L. Sarkadi. 1994. Biochemical studies of some non-conventional sources of proteins. 7. Effect of detoxification treatments on the nutritional quality of apricot kernels. Nahrung, 38, 12-20.

El-Adawy, T. A and S. A. El-Kadousy. 1995. Changes in chemical composition, nutritional quality, physico-chemical and functional properties of peach kernel meal during detoxification. Food Chem., 52, 143-148.

El Badwi, S M. A., H. M. Mousa, S. E. I. Adam and H. J. Hapke. 1992. Response of brown hisex chicks to low levels of *Jatropha curcas*, *Ricinus communis* or their mixture. Vet. Hum. Toxicol., 34, 304-306.

FAO 1988. Traditional food plants. In: Food and nutrition, Paper 42, p. 369-373, FAO, Rome.

FAO/WHO 1991. Joint FAO/WHO Food Standard Programme, Codex Alimentarius Commission, XII, supplement 4, FAO/WHO, Rome.

Fish, B. C and L. U. Thomson. 1991. Lectin-tannin interactions and their influence on pancreatic amylase activity and starch digestibility. J. Agric. Food Chem., 39, 727-731.

Fitzhugh, H. A., S. K. Ehui and A. Lahlou-Kassi. 1992. Research strategies for development of animal agriculture. World Anim. Rev., 72, 9-19.

Freeland, W. J., P. H. Calcott and L. R. Anderson. 1985. Tannins and saponins: interaction in herbivore diets. Biochemical System Ecol., 13, 189-193.

Gandhi, V. M., K. M. Cherian and M. J. Mulky. 1994. Detoxification of castor seed meal by interaction with sal sed meal. JAOCS, 71, 827-831.

Goldstein, W. S. and K. C. Spencer. 1985. Inhibition of

cyanogenesis by tannins. J. Chem. Ecol., 11, 847-857.
Grabow, W., J. L. Slabbert, W. S. G. Morgan and S. A. A. Jahn. 1985. Toxicity and mutagenicity evaluation of water coagulated with *Moringa oleifera* seed preparation using fish, protozoan, bacterial, coliphage, enzyme and Ames *Salmonella assays*. Water S.A., 11, 9-14.
Grant, G., L. J. More, N. H. McKenzie, P. M. Dorward, W. C. Buchan, I. Telek and A. Pusztai. 1995. Nutritional and haemagglutination properties of several tropical seeds. J. Agric. Sci. (Camb.), 124, 437-445.
Heaney, R. K. and G. R. Fenwick 1980. Glucosinolates in *Brassica* vegetables. Analysis of 22 varieties of Brussels sprout (*Brassica oleracea* var. gemmifera). J. Sci. Food Agric., 31, 785-793.
Heller, J. 1996. Physic nut *Jatropha Curcas* L. Promoting the conservation and use of underutilized and neglected crops. 1. Institute of Plant Genetics and Crop Plant Research, Gartersleben, International Plant Genetic Resources Institute, Rome, 1996.
Hirota, M., M. Suttajit, H. Suguri, Y. Endo, K. Shudo, V. Wonchai, E. Hecker and H. Fujiki. 1988. A new tumor promoter from the seed oil of *Jatropha curcas* L., an intramolecular diester of 12-desoxy-16-hydroxyphorbol. Cancer Res., 48, 5800-5804.
Huisman, J., A. F. B. van der Poel and I. E. Liener. 1989. Recent advances of Research in Antinutritional factors in legume seeds. PUDOC, Wageningen.
Joubert, P. H., J. M. M. Brown, I. T. Hay and P. D. B. Sebata. 1984. Acute poisoning with *Jatropha curcas* purging nut tree in children. S. Afric. Med. J., 65, 729-730.
Kingsbury, J. M. 1964. In Poisonous plants of the United States and Canada, Prentice-Hall Inc., Englewood Cliffs, N.J., 1964.
Lange, R., W. Schumann, M. Petrzila, H. Busch and R> Marquard. 1995. Glucosinolate in Leindottersamen. Fat Sci. Tech., 4, 146-152.
Liberalino, A. A. A., E. A. Bambirra, T. Moraes-Santos and E. C. Viera. 1988. *Jatropha curcas* L. seeds: Chemical analysis and toxicity. Arq. Biol. Technol., 31, 539-550.
Liener. I. E. 1994. Implications of antinutritional components in soyabean foods. CRC Crit. Rev. Food Sci. Nutr., 34, 31-67.
Lippmann, A. 1913. Zwei Fälle von schwerer Vergiftung durch Curcasnüsse. Medizinische Klinik No. 13, 500-501.
Liu, Y. G., B. Steg, V. A. Hindle and S. Tamminga. 1994a. Cramble meal: removal of glucosinolates by heating with additives and water extraction. Anim. Feed Sci. Technol., 48, 273-287.
Liu, Y. G., M. Q. Zhou and M. L. Liu. 1994b. A survey of nutrients and toxic factors in commercial rapeseed meal in China and evaluation of detoxification by water extraction. Anim. Feed Sci. Technol., 45, 257-270.
Makkar, H. P. S., B. Singh and S. S. Negi. 1990. Tannin levels and their degree of polymerisation and specific activity in some agro-industrial by-products. Biological Wastes, 31, 137-144.
Makkar, H. P. S., M. Blümmel and K. Becker. 1995. *In vitro* effects of and interactions between tannins and saponins and fate of tannins in the rumen. J. Sci. Food Agric., 69, 481-493.
Makkar, H. P. S. and K. Becker. 1996a. Nutritional value and antinutritional components of whole and ethanol extracted *Moringa oleifera* leaves. Anim. Feed Sci. Technol., 63, 211-228.
Makkar, H. P. S. and K. Becker. 1996b. Effect of pH, temperature, and time on inactivation of tannins and possible implications in detannification studies. J. Agric. Food Chem., 44, 1291-1295.
Makkar, H. P. S. and K. Becker. 1997a. Potential of jatropha seed meal as a protein supplement to livestock feed and constraints to ist utilization. Proceedings of *Jatropha* 97: International Symposium on Biofuel and Industrial Products from *Jatropha curcas* and other Tropical Oil Seed Plants, 23-27 Feb. 1997, Managua, Nicaragua, Mexico.
Makkar, H. P. S. and Becker, K. 1997b. *Jatropha curcas* toxicity: identification of toxic principle(s). Proceedings 5th International Symposium on Poisonous Plants, San Angelo, Texas, USA, May 19-23, 1997.
Makkar, H. P. S. and K. Becker. 1997c. Nutrients and antiquality factors in different morphological parts of *Moringa oleifera* tree. J. Agric. Sci. (Camb.), 128, 311-322.
Makkar, H. P. S., K. Becker, F. Sporer and M. Wink. 1997. Studies on nutritive potential and toxic constituents of different provenances of *Jatropha curcas*. J. Agric. Food Chem., 45, 3152-3157.
Makkar, H. P. S., A. O. Aderibigbe and K. Becker. 1998a. Comparative evaluation of a non-toxic and toxic varieties of *Jatropha curcas* for chemical composition, digestibility, protein degradability and toxic factors. Food Chem. 62: 207-215.
Makkar, H. P. S., K. Becker and B. Schmook. 1998b. Edible provenances of *Jatropha curcas* from Quintna Roo state of Mexico and effects of roasting on antinutrients and toxic factors in seeds. Plant Foods Hum. Nutr. 52:31-36.
Mampane, K. J., P. H. Joubert and I. T. Hay, 1987. *Jatropha curcas*: use as a traditional Tswana medicine and its role as a cause of acute poisoning. Phytotherapy Res., 1, 50-51.
Mawson, R., R. K. Heaney, Z. Zdunczyk and H. Kozlowska. 1994. Rapeseed meal-glucosinolates and their antinutritional effects Part 5. Animal reproduction. Nahrung, 38, 588-598.
Melcion, J. P., C. Michelangeli and M. Picard. 1994. Evaluation of the effect of extrusion cooking of jackbean (*Canavalia ensiformis* L.) seed on short-term feed intake in chicks. Anim. Feed Sci. Technol., 46, 197-213.
Mkiwa, F. E. J., A. B. Lwoga, R. D. Mosha and J. A. Matovelo. 1994. Antinutritional effects of *Crotalaria ochroleuca* (Marejea) in animal feed supplements. Vet. Human Toxicol., 36, 96-100.
Morton, J. F. 1991. The horseradish tree, *Moringa pterygosperma* (Moringaceae)-a boon to arid lands? Econ. Bot., 45, 318-333.
Mourgue, M., J. Delphant, R. Beret and R. Kassab. 1961. Etude de la toxicite et localisation de la toxalbumine (curcine) des graines de *Jatropha curcas* Linn. Bull. Soc. Chim. Biol., 41, 517-531.
Negi, S. S. 1985. A review on the utilization of agricultural wastes as feeds for livestock and experimental safeguards against erroneous conclusions. Agric. Wastes, 13, 93-103.
Nout, M. J. R., G. Tuncel and L. Brimer. 1995. Microbial degradation of amygdalin of bitter apricot seeds (*Prunus armfniaca*). Int. J. Food Microbiol., 24, 407-412.
Pointillart, A. 1993. Importance of phytates and cerealsphytases in the feeding of pigs. In: Enzymes in Animal Nutrition (Eds. Wenk, C. and Boessinger, M.), pp. 192-198. Proceedings of the 1st symposium, Kartause Ittingen, Switzerland, 13-16 Oct. 1993, ETH-Zürich.
Punj, M. L. 1988. Agricultural byproducts and industrial wastes for livestock and poultry feeding. All India Co-ordinated Research Project, Indian Council of Agricultural Research, New Deldi, India.
Raina, A. K. and B. R. Gaikwad. 1987. Chemobotony of

Jatropha species in India and further characterization of Curcas oil. J. Oil Tech. India, 19, 81-85.

Ramachandran, C., K. V. Peter and P. K. Gopalakrishnan. 1980. Drumstick (*Moringa oleifera*): a multipurpose Indian vegetable. Econom. Bot., 34, 276-283.

Rattansi, R. and M. Dikshit. 1997. Protease inhibitors and *in vitro* digestibility of karanja (*Pongamia glabra*) oil seed residue-a comparative study of various treatments. JAOCS, 74, 1161-1164.

Ravindran, V. and R. Sivakanesan. 1996. The nutritive value of mango seed kernels for starting chicks. J. Sci. Food Agric., 71, 245-250.

Reddy, N. R., S. K. Sathe and D. K. Salunkhe. 1982. Phytates in legumes and cereals. Adv. Food Res., 28, 1-92.

Rehm, S. and G. Espig. 1991. Oil Plants. In: The cultivated plants of the tropics and subtropics: cultivation, economic value, utilization, p.76-119, Verlag Josef Margraf, Weikersheim, Germany.

Rhee, K. C. 1987. The production of non toxic castor bean meal free of allergen. Food Protein Research and Development Center, UNDP, USA, 1987.

Saini, H. S. and N. Wratten. 1987. Quantitative determination of total glucosinolates in rapeseed and meal digests. JAOAC, 70, 141-145.

Sebedio, J. L. and A. Grandgirard. 1989. Cyclic fatty acids:natural resources, formation during heat treatment, synthesis and biological properties. Prog. Lipid Res., 28, 303-336.

Selmar, D., R. Lieberei, N. Junqueira and B. Biehl. 1991. Changes in cyanogenic glucoside content in seeds and seedlings of *Hevea* species. Phytochemistry 30, 2135-2140.

Smith, C. A. and C. Dacombe. 1987. Rapid method for determining total glucosinolates in rapeseed by measurement of enzymatically released glucose. J. Sci. Food Agric., 38, 141-150.

Smith, C., W. Van Megen, L. Twaalfhoven and C. Hitchcock. 1980. The determination of trypsin inhibitor levels in foodstuffs. J. Sci. Food Agric., 31, 341-350.

Soedarjo, M. and D. Borthakur. 1996. Simple procedure to remove mimosine from young leaves, pods and seeds of *Leucaena leucocephala* used as food. Int. J. Food Sci. Technol., 31, 97-103.

Stirpe, F., A. Pession-Brizzi, E. Lorenzoni, P. Strochi, L. Montanaro and S. Sperti. 1976. Studies on the proteins from the seeds of *Croton tiglium* and *Jatropha curcas*. Biochem. J., 156, 1-6.

Sujatha, M. and N. Mukta. 1996. Morphogenesis and plant regeneration from tissue cultures of *Jatropha curcas*. Plant Cell Tiss. Org. Cult., 44, 135-141.

Tepal, J. A., R. Castellanos and A. Larios. 1994. Detoxification of jack beans (*Canavalia ensiformis*): I.-extrusion and canavanine elimination. J. Sci. Food Agric., 66, 373-379.

Thompson, L. U. 1993. Potential health benefits and problems associated with antinutritients with foods. Food Res. Int., 26, 131-149.

Tuncel, G., M. J. R. Nout and L. Brimer. 1995. The effects of grinding, soaking and cooking on the degradation of amygdalin of bitter apricot seeds. Food Chem., 53, 447-451.

Verbiscar, A. J., T. F. Banigan, C. W. Weber, B. L. Reid, J. E. Trei, E. A. Nelson, R. F. Raffauf and D. Kosersky. 1980. Detoxification of jojoba meal. J. Agric. Food Chem., 28, 571-578.

Verbiscar, A. J., T. F. Banigan, C. W. Weber, B. L. Reid, R. S. Swingle, J. E. Trei and E. A. Nelson. 1981. Detoxification of jojoba meal by *Lactobacilli*. J. Agric. Food Chem., 29, 296-302.

Verma, A. K., V. R. B. Sastry and D. K. Agrawal. 1995. Feeding of water washed *neem* (*Azadirachta indica*) seed kernel cake to growing goats. Small Rumin. Res., 15, 105-111.

Villasenor, I. M., P. Finch, C. Y. Lim-Sylianco and F. Dayrit. 1989. Structure of a mutagen from roasted seeds of *Moringa oleifera*. Carcinogenesis, 10, 1085-1087.

Winkler, E., N. Foidl, G. M. Gübitz, R. Staubmann and W. Steiner. 1997. Enzyme-supported oil extraction from *Jatropha curcas* seeds. Appl. Biochem. Biotechnol., 63-65, 449-45.