The potential of *Moringa oleifera* for agricultural and industrial uses

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Introduction

Moringa Oleifera Lam (synonym: *Moringa pterygosperma* Gaertner) belongs to a monogeneric family of shrubs and tree, Moringaceae and is considered to have its origin in Agra and Oudh, in the northwest region of India, south of the Himalayan Mountains. Although the name "Shigon" for *M. oleifera* is mentioned in the "Shushruta Sanhita" which was written in the beginning of the first century A.D., there is evidence that the cultivation of this tree in India dates back many thousands of years. The Indians knew that the seeds contain edible oil and they used them for medicinal purposes. It is probable that the common people also knew of its value as a fodder or vegetable. This tree can be found growing naturally at elevations of up to 1,000 m above sea level. It can grow well on hillsides but is more frequently found growing on pastureland or in river basins. It is a fast growing tree and has been found to grow to 6 – 7 m in one year in areas receiving less than 400 mm mean annual rainfall (Odee, 1998).

In the Dravidian language, there are many local names for this tree but all are derived from the generic root "Morunga". In English it is commonly known as Horseradish tree, Drumstick tree, Never Die tree, West Indian Ben tree, and Radish tree (Ramachandran *et al*., 1980).

It is now cultivated throughout the Middle East, and in almost the whole tropical belt. It was introduced in Eastern Africa from India at the beginning of 20th century. In Nicaragua the Marango (local name for *Moringa oleifera*) was introduced in the 1920s as an ornamental plant and for use as a live fence. The tree grows best and is most commonly found in the Pacific part of Nicaragua but can be found in forest inventories in every part of the country. As a non-cultivated plant it is known for its resistance to drought and diseases. Because this tree has so many potential uses, we have been conducting an extensive research program on it over the last 10 years with the financial assistance of the Austrian government and University of Hohenheim, Stuttgart. The plant possesses many valuable properties which make it of great scientific interest. These include the high protein content of the leaves twigs and stems, the high protein and oil contents of the seeds, the large number of unique polypeptides in seeds that can bind to many moieties, the presence of growth factors in the leaves, and the high sugar and starch content of the entire plant. Equally important is the fact that few parts of the tree contain any toxins that might decrease its potential as a source of food for animals or humans. For the sake of simplicity and clarity we will refer to the plant, *Moringa oleifera* as Moringa throughout this article.

Socio-economic importance

Moringa is one of the most useful tropical trees. The relative ease with which it propagates through both sexual and asexual means and its low demand for soil nutrients and water after

being planted make its production and management easy. Introduction of this plant into a farm which has a biodiverse environment can be beneficial for both the owner of the farm and the surrounding eco-system.

Morphology and physical characteristics

Moringa is a fast growing, perennial tree which can reach a maximum height of 7-12 m and a diameter of 20-40 cm at chest height.

Stem

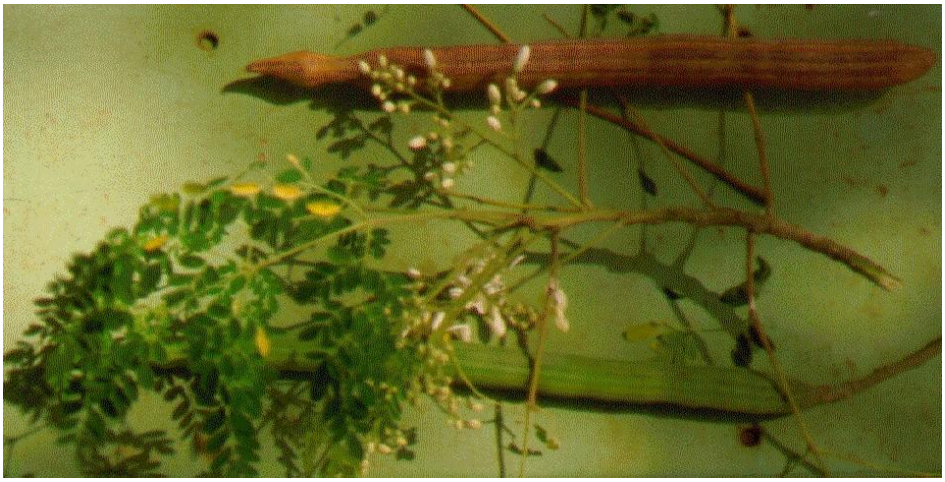
The stem is normally straight but occasionally is poorly formed. The tree grows with a short, straight stem that reaches a height of 1.5-2 m before it begins branching but can reach up to 3,0 m.

Branch

The extended branches grow in a disorganized manner and the canopy is umbrella shaped.

Leaves

The alternate, twice or thrice pinnate leaves grow mostly at the branch tips. They are 20-70 cm long, grayish-downy when young, long petioled with 8-10 pairs of pinnae each bearing two pairs of opposite, elliptic or obovate leaflets and one at the apex, all 1-2 cm long; with glands at the bases of the petioles and pinnae (Morton, 1991).



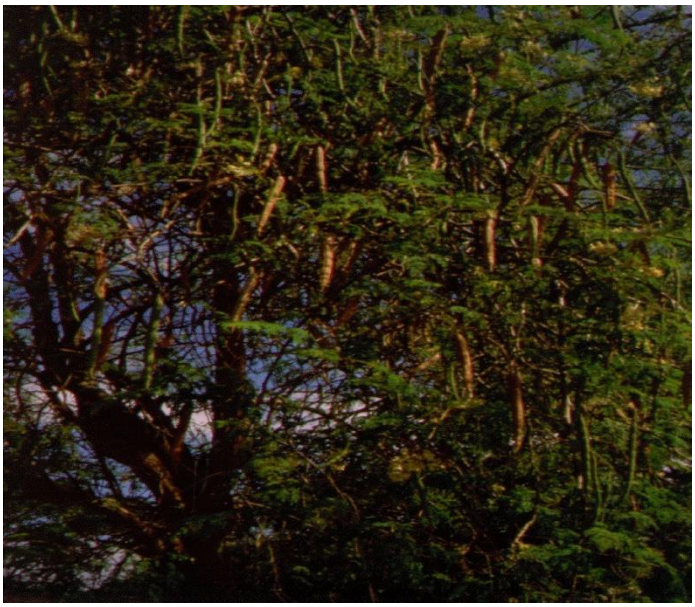
Moringa leaves with flowers and green and ripe pod Photo: Becker

Flowers

The flowers, which are pleasantly fragrant, and 2.5 cm wide are produced profusely in axillary, drooping panicles 10 to 25 cm long. They are white or cream colored and yellow-dotted at the base. The five reflexed sepals are linear-lanceolate. The five petals are slender-spatulate. They surround the five stamens and five staminodes and are reflexed except for the lowest (Morton, 1991).

Fruits

The fruits are three lobed pods which hang down from the branches and are 20-60 cm in length. When they are dry they open into 3 parts. Each pod contains between 12 and 35 seeds.

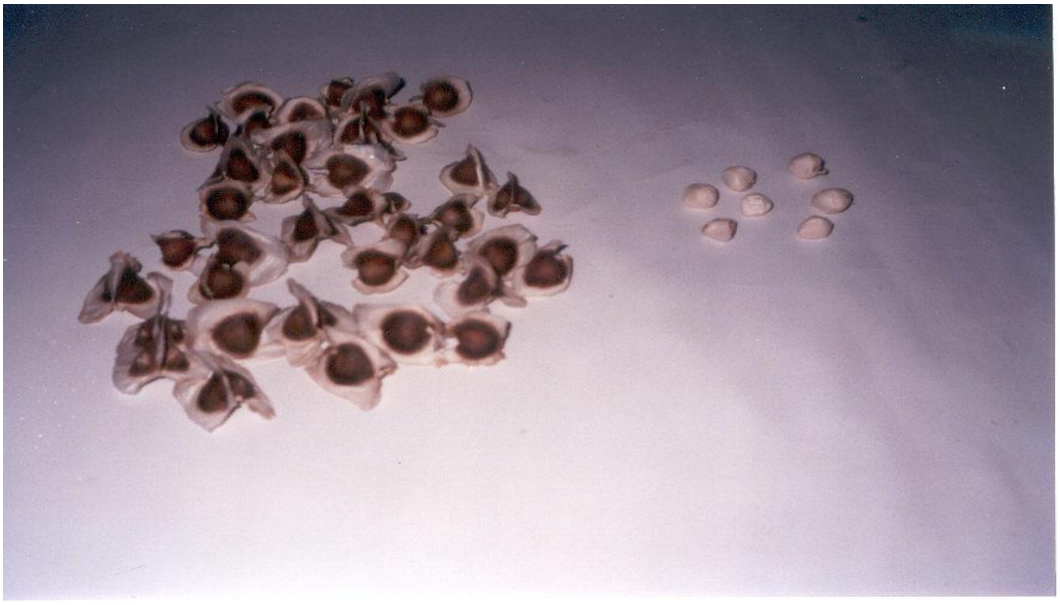


A wild tree bearing ripe and green pods and flowers Photo: Becker

Seeds

The seeds are round with a brownish semi-permeable seed hull. The hull itself has three white wings that run from top to bottom at 120-degree intervals. Each tree can produce between 15,000 and 25,000 seeds/year. The average weight per seed is 0.3 g and the kernel to hull ratio is 75 : 25 (Makkar and Becker, 1997). Physical characterization of pods and seeds are given in Table 1.

Split open ripe pods Photo: Becker



"Winged" *Moringa oleifera* seeds and seed kernels. Photo: Foidl

Table 1. Physical properties of pods and seeds of Moringa

Determination	1	2	3
Average weight of pod (g)	7.60	-	7.95
Average weight of seeds (g) / pod	3.59	5.03	4.83
Average number of seeds / pod	12	17	16
Average weight (g) / 100 seeds	29.9	29.6	30.2
Average weight of kernels (g) / 100 seeds	21.2	-	22.5
Percent weight of kernel in relation to entire seed	72.5	-	74.5
Percent weight of hull in relation to entire seed	27.5	-	25.5
Moisture in kernel (%)	4.5	-	6.5
Moisture in hull (%)	9.2	-	12.9
Moisture in whole seed (%)	5.8	-	7.5

1. Ferrao and Ferrao (1970)
2. Carlos Foletti (1996; Personal communication)
3. Proyecto Biomasa (1996)

Utilization of Moringa

Figure 1 outlines important uses of various parts of the plant. The details are presented in subsequent sections.

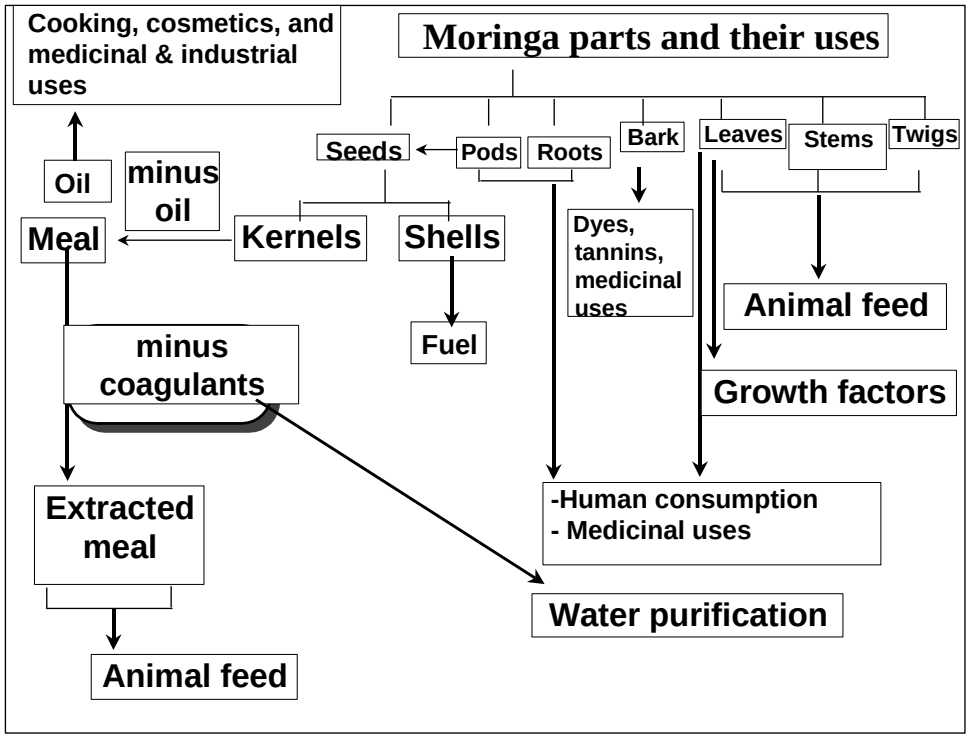


Figure 1. Uses of different parts of Moringa

Human consumption of Moringa

The young leaves are edible and are commonly cooked and eaten like spinach or used to make soups and salads. They are an exceptionally good source of provitamin A, vitamins B, and C, minerals (in particular iron), and the sulphur-containing amino acids methionine and cystine. The composition of the amino acids in the leaf protein is well balanced (see below).

Table 2. Mineral contents of Moringa leaves from different agroclimatic origins (Becker and Makkar, unpublished)

Mineral	Nicaragua	India	Niger
Macro elements (g kg^{-1} DM)			
Calcium	17.5	26.4	13.9
Phosphorus	1.16	1.36	1.22
Magnesium	0.11	0.11	0.11
Sodium	1.16	2.73	2.61
Potassium	19.1	21.7	18.4
Micro-elements (mg kg^{-1} DM)			
Iron	582	175	347
Magense	47.1	51.8	113.9
Zinc	13.5	13.7	24.2
Copper	11.2	7.1	10.6

The young green pods are very tasty and can be boiled and eaten like green beans. The pods are best for human consumption at the stage when they can be broken easily without leaving any visible strings of fibre. These are rich in free leucine. The seeds must first be boiled for a few minutes to remove the fine transparent hull and the water drained before they are eaten. Seeds should be eaten green before they change color to yellow. The hull is not desirable as food because it tastes bitter.

The dry seeds can be ground to a powder and used for seasoning sauces. The roots from young plants can also be dried and ground for use as a hot seasoning base with a flavor similar to that of horseradish. This is why the Moringa tree has been given the name "Horseradish Tree" (Delaveau and Boiteau, 1980). A tasty hot sauce from the roots can also be prepared by cooking them in vinegar. The flowers can be eaten after being lightly blanched or raw as a tasty addition to salads. The resin from the trunk of the tree is also useful for thickening sauces.

Table 3. Carotenoids in different morphological fractions of Moringa (Becker and Makkar, unpublished)

Carotenoid	Morphological Fraction		
	Leaves	Stem	Seed
	mg kg^{-1} DM		
alpha-Carotene	6.5	n.d.	n.d.
Beta-Carotene	401	n.d.	3.8
Echinenon	n.d.	n.d.	n.d.
Fucxanthin	n.d.	n.d.	n.d.
Lutein	702	21.8	4.0
Myxoxanthophyll	n.d.	n.d.	n.d.
Neoxanthin	219	5.9	n.d.
Violaxanthin	76.5	1.3	n.d.
Zeaxanthin	19.4	n.d.	n.d.
Xanthophyll	83.1	1.6	n.d.
Carotenoids	1508	34.4	4.0
Chlorophyll	6890	271.1	n.d.

n.d. not detected

Table 4. Vitamin C content of Moringa leaves from three locations and from plants raised in Hohenheim from Nicarguan seeds (Becker and Siddhuraju, unpublished)

Location	Vitamin C content ($g\ kg^{-1}$ Dry matter)
1) Nicaragua *	9.18
2) India *	8.36
3) Niger *	6.78
4) Nicaragua * (grown in Hohenheim)	7.09
5) Nicaragua ** (grown in Hohenheim)	9.67

* analysed in freeze dried material
** analysed in fresh leaves

Industrial uses of Moringa oil

The oil content of de-hulled seed (kernel) is approximately 42 %. The oil is brilliant yellow. It is used as a lubricant for fine machinery such as timepieces because it has little tendency to deteriorate and become rancid and sticky (Ferrao and Ferrao, 1970; Ramachandran *et al.*, 1980). It is also useful as a vegetable cooking oil. The oil is known for its capacity to absorb and retain volatile substances and is therefore valuable in the perfume industry for stabilising scents. The free fatty acid content varies from 0.5 to 3 %.

The seed oil of Moringa contains approximately 13 % saturated fatty acids and 82 % unsaturated fatty acids. It has a particularly high level of oleic acid (70 %) (Table 5). Other vegetable oils normally contain only about 40 % oleic acid.

Table 5. Physico-chemical properties and fatty acid composition of Moringa seed oil

Property	**Value**	
Saponification value	182.9	
Iodine value	66.4	
Density at 20 ºC (g/ml)	0.89737	
Refractive Index at 20 ºC	1.4670	
Solidification Point (Pour point ºC) (Method D-97)	6	
Free fatty acids (%)	Up to 2.98	
Fatty acid composition (%)		
Lauric	Trace	(ND)
Myristic	0.08	(0.05)
Pentadecanoic	Trace	(ND)
Palmitic	5.45	(4.75)
Palmitoleic	1.48	(1.22)
Margaric	0.08	-
Margaroleic	0.05	-
Stearic	5.42	(5.66)
Oleic (C18-1)	72.9	(71.0)
Linoleic	0.76	(0.46)
Linolenic	0.14	(0.09)
Arachidic	3.39	(4.01)
Gadoleic	2.2	(2.24)
Eicosadieroic	-	(ND)
Behenic	6.88	(9.03)
Erucic	0.14	(0.13)
Lignoceric	0.92	(1.12)
Nurvonic	Trace	-
Cerotic	-	(ND)
Other Fatty Acids	0.10	(0.2)

Analysis: Thionville Laboratories, Inc. New Orleans, USA (March 1994)
Values in parantheses (Becker and Siddhuraju, unpublished)

Water purification

Moringa seeds contain between 30-42 % oil and the press cake obtained as a by-product of the oil extraction process contains a very high level of protein. Some of these proteins (approximately 1 %) are active cationic polyelectrolytes having molecular weights between 7-17 K Dalton. The cationic polyelectrolytes neutralize the colloids in muddy or dirty water since the majority of these colloids have a negative electrical charge. This protein can therefore be used as a non-toxic natural polypeptide for sedimenting mineral particles and organics in the purification of drinking water, for cleaning vegetable oil, or for sedimenting fibers in the juice and beer industries. It thus works as a primary coagulant as natural bridges are continuously formed between the colloid particles. In contrast, industrial coagulants such as alumina can be toxic. Their proper use requires qualified personnel and the majority of underdeveloped countries don't have the means of producing them. In addition, these industrial coagulants are expensive and represent a considerable drain on the hard currency reserves of developing countries.

The properties of the natural polypeptides produced from the seeds of Moringa have been known for many centuries in China. With the colonization of India by the British, this knowledge was effectively dispersed to the rest of the world. It has been employed with particular effectiveness in both Egypt and Sudan for cleaning water from the Nile specifically for human consumption. The wings are removed from the dry seeds and then the seeds are ground to powder. The powder is mixed with water, agitated for approximately five minutes and after about an hour it is filtered through a piece of woven fabric to obtain pure water. Alternatively, a cloth containing the seed powder is suspended in water, generally overnight, to coagulate impurities. The cloth containing the seeds is then removed, and the purified water is decanted leaving behind the coagulated particles on the bottom. Up to 99 % of colloids can be removed. Only one seed is required per litre for slightly contaminated water and two seeds for very dirty water.

At Biomasa at the technical university, investigations have been conducted using the seeds from Moringa for the final treatment in wastewater treatment units. In oxidation lagoons, 80 % of the oxygen demand of water is caused by unicellular algae. These algae also contain between 40-60 % of the nitrogen and phosphorous found in the pre-treated wastewater. To avoid eutrophication of rivers or lakes by the release of high loads of both phosphorous and nitrogen, the seeds can be used to coagulate algae and remove them by sedimentation. Up to 98 % of the algae can be removed by this treatment. After sedimentation the residual wastewater is both clear and transparent. The treatment also reduces the oxygen demand of the water by approximately 70 % and its content of both phosphorous and nitrogen by 60 %. The algae recovered by sedimentation after drying and pulverization have a protein content of about 46 % and can be used as a protein supplement for cows, pigs, chickens and even shrimps thereby reducing the cost of feeding substantially. One hectare of wastewater in an oxidation lagoon in the tropics can produce up to 80 metric tons of dry algae in a year.

For the final treatment of wastewater in a town of 10,000 inhabitants, approximately 960 kg of Moringa flour is required per day. This means that a plantation of about 105 hectares with 1,100 trees/ha would be needed to produce sufficient seed to treat the wastewater for this community. Due to the large volume and weight of the Moringa flour, which makes it difficult to store and manage, the Biomasa department developed a process by which the polypeptides were concentrated using ultrafiltration after they had been extracted in water and alcohol. This post-concentrate form allows users to get rid of 80 % of the overall weight while retaining the useful physical and chemical characteristics. This pre-concentrate form also has a bitter taste which is important to eliminate if one wants to use it as food for human consumption. This can be done by continuous extraction and re-crystallization of polypeptides. It has been suggested (Odee, 1998) that flocculation qualities of *M. stenepetala* is higher than *M. oleifera* seeds. Our experience suggests that the clarification/flocculation quality of *M. oleifera* seeds change with season, and therefore the comparative results reported for *M. stenepetala* and *M. oleifera* should be interpreted with caution.

Moringa plantation for seed production Photo: Foidl

Plant growth enhancers

The extract obtained from the leaves of Moringa in 80 % ethanol contains growth enhancing principles (i.e. hormones of the cytokinine type). The extract can be used in the form of a foliar spray to accelerate the growth of young plants. Use of the growth hormone spray will also cause the plants to be firmer and more resistant to pests and disease. Plants that are treated with this growth hormone spray will also produce more and larger fruit and will consequently have a higher yield at harvest time. The extract can be obtained either through press extraction or by using an ultra-turrax and filtering 20 g of tender leaves in a total volume of 675 ml of 80 % aq. ethanol (Makkar and Becker, 1996).
Spraying the leaves of plants with the Moringa extract prepared in 80 % ethanol and then diluted with water produced some notable effects such as a longer, more vigorous life-span, heavier roots stems and leaves, bigger fruits and higher sugar levels etc. The extract produces an overall increase in yield of between 20-35 % based on data such as the stem diameter, number of nodules, number of axels, number of flower buds, and number of fruits per flower bud (Tables 6 and 7).

Table 6. Effects of the application of an ethanol extract from the leaves of Moringa on the nodules, buds and roots of black-gram (*Vigna munga* L.)

Concentration of the ethanolic extract (%)	Average fresh weights of various parts of the plant (mg/plant)		
	Nodules	Buds	Roots
0	16.4	600	350
0.08	54.0	1100	403
0.16	49.6	990	550
0.24	35.0	890	660
0.32	30.0	800	800
0.40	25.4	700	700

Source: Bendona Bose, Department of Botany, University of Gorekhpur

In an experiment to test the retention of chlorophyll, it was discovered that the highest retention exists with a concentration of between 0.08 and 0.16 %.

Table 7. Some results of using Moringa as natural phytohormone as a foliar spray.

Crop	Effects of the use of the Moringa hormone	Crop yield with hormone (kg/manzana)	Crop yield without hormone (kg/manzana)
Peanut (floor runner)	Larger flowers Increased dry matter Greater yield Higher quality nuts	3,750	2,954
Soya bean CEA-CH 86	Larger flowers Greater biomass Greater yield	2,182	1,591
Corn NB-6	Greater yield	6,045	4,454
Sorghum H887-V2	Greater yield	3,234	2,787
Onion (sondeo) Granex	Increased weight of average bulb	2,954	2,591
Tomato (sondeo) Santa Clara	Increased flowering	-	-
Cantalope	Fewer losses of flowers after polinisation Higher percentage of sugars and minerals	11592 (melons)**	8820 (melons)**
Bell Pepper Yolo Wonder	Increased dry matter Increased fruit weight	17,380	11,752
Coffee	Larger grain size Higher quality bean formation	1,682 (semi-cleaned)	1,409 (semi-cleaned)
Sugar Cane	Greater number of shoots per planting Higher percentage of sugars and minerals	82,400	77,320
Black bean Dor-364	Greater yield	1,125	945
Black bean Esteli 150	Greater yield	841	886

* 1 manzana = 0.705 hectares or 7,050 square meters
** i.e. individual fruit
Data from Project Biomasa (1999)

Moringa as a source of biogas

Moringa plants (approximately 30 days old) were milled together with water. The fibre was separated by filtration through a mesh with 5 mm pores and the liquid fraction produced was then added to a biogas reactor. With an average feed of 5.7 g of volatile solids the gas production was 580 liters of gas per 1 kg of volatile solids. The average methane content of the gas was 81 %.

Moringa as a forage plant

The nutritional characteristics of the Moringa tree are excellent so it can easily be used as a fresh forage material for cattle. The leaves are rich in protein, carotene, iron and ascorbic acid and the pod is rich in the amino acid lysine (CSIR, 1992; Chawla *et al*., 1998; Dogra *et al.*, 1975). Another important advantageous characteristic of Moringa is its high productivity of fresh material per unit area compared with other forage crops (see below; Productivity of Moringa plantations). Moringa is especially useful as a forage for cattle both economically and productively given the problems facing typical cattle breeders (70 % of the national herd in Nicaragua is in the hands of these small cattle producers). Major among these problems are:
a) Low availability of feed during the dry season, which extends from December through May.
b) Lack of capacity for pasturing animals as farmers generally own small areas and these are typically not well worked or managed.
c) Nutritional imbalances caused by a lack of access to proteins, carbohydrates and minerals.
d) Farmers have little control over the reproductive activities of their animals either as regards timing of mating or quality of sire.

Chemical constituents. The protein content of fresh leaves does not vary substantially from place to place (Table 8).

Table 8. Chemical composition (% in DM) of fresh leaves and fruits of Moringa

Fraction	DM (%)	CP	CF	EE	Ca	P
Fresh Leaves[1]	18.7	29.0	19.1	5.2	2.06	0.24
Fresh Leaves[2]	-	25.1	-	5.4	-	-
Fresh Leaves[3]	-	26.4	-	6.5	-	-
Fruit[4]	10.7	20.7	27.0	1.0	-	-

DM = Dry matter; CP = Crude Protein (N x 6.25), CF = Crude fibre; Ca = Calcium; P = Phosphorus
1. Bangladesh
2. Nicaragua
3. India
4. Sri Lanka

It has been shown above that the application of 80 % ethanol extract of Moringa increases nodulation and production of various crops. Since large scale cultivation of Moringa has been initiated at Malawi, Kenya, India, Tanzania and Nicaragua, there is a need to make proper use of the large amount of the residual leaves left after extraction of growth promoting component. With the aim of using the extracted and unextracted leaves as a component of animal feed, we analysed these samples for nutrients and antinutrients (Makkar and Becker, 1996). Table 8 presents the chemical composition of both extracted and unextracted leaves. The crude protein content of extracted and unextracted Moringa leaves was 43.5 and 25.1 % respectively, suggesting that both the extracted and unextracted leaves are good sources of protein for livestock. As expected, the crude protein and fiber contents of the extracted leaves were higher than those of the unextracted leaves due to the loss of some cell solubles and

lipids during the treatment with 80% ethanol. The crude protein, crude lipid and ash values of 26.4 %, 6.5 %, and 12 % respectively reported for the unextracted leaves by Gupta *et al*. (1989) are in good agreement with the present values. On the other hand, higher levels of NDF (28.8 vs 21.9%) and ADF (13.9 vs 11.4 %) have been reported by Gupta *et al.* (1989). These variations may be due to differences in agro-climatic conditions or to different age of trees, and possibly not due to different stages of maturity, since tender green leaves have been used in both these studies..

Table 9. Chemical composition of unextracted and extracted Moringa leaves

Type of leaf	Crude protein	Lipid	Ash	NDF	ADF	ADL	Gross energy (MJ/Kg DM)
Extracted leaves	43.5	1.4	10.0	47.4	16.3	2.2	17.7
Unextracted leaves	25.1	5.4	11.5	21.9	11.4	1.8	18.7

All values except gross energy are expressed as % dry matter. NDF = neutral detergent fiber, ADF = acid detergent fiber, ADL = acid detergent lignin.

Amino acid composition of Moringa leaves.. Amino acid profiles are presented in Table 10. The amino acid content (g/16g N) of unextracted leaves was lower than that of extracted leaves which is due to the presence of a higher amount of non protein nitrogen in the unextracted leaves (4.7 vs 2.7 %). The potential food value of the protein (as a source of amino acids) can be evaluated by comparison with the FAO reference pattern (Zarkadas *et al.,* 1995). All essential amino acids are at higher than adequate concentrations when compared with the recommended amino acid pattern of the FAO/WHO/UNO reference protein for 2 to 5 year old children. A comparison between the amino acid composition of extracted and unextracted leaves and that of soybeans (Bau *et al.,* 1994; Sarkar and Peace, 1994) revealed an almost identical pattern of all essential amino acids.

Table 10. Amino acid composition of extracted and unextracted Moringa leaves.

Amino acid	Amino acid composition of extracted leaves		Amino acid composition of unextracted leaves.		Amino acid composition of FAO reference protein *
	(g/16g N)	(g/kg DM)	(g/16g N)	(g/kg DM)	(g/16g N)
Lysine	6.61	26.77	5.6	14.06	5.80
Leucine	9.86	42.89	8.70	21.84	6.60
Isoleucine	5.18	22.53	4.50	11.30	2.80
Methionine	2.06	8.96	1.98	4. 97	2.50
Cystine	1.19	5.18	1.35	3.39	2.50
Phenylalanine	6.24	27.14	6.18	15.51	6.3
Tyrosine	4.34	18.88	3.87	9.71	6.3
Valine	6.34	27.58	5.68	14.26	3.5
Histidine	3.12	13.57	2.99	7.50	1.9
Threonine	5.05	21.97	4.66	11.70	3.4
Serine	4.78	20.79	4.12	10.34	-
Glutamic Acid	11.69	50.85	10.22	25.65	-
Aspartic Acid	10.60	46.11	8.83	22.16	-
Proline	5.92	25.75	5.43	13.63	-
Glycine	6.12	26.62	5.47	13.73	-
Alanine	6.59	28.67	7.32	18.37	-
Arginine	6.96	30.28	6.23	15.64	1.10
Tryptophan	2.13	9.26	2.10	5.27	-

*Data from Zarkadas *et al*.(*1*995).

Metabolizable energy (ME) and organic matter digestibility (OMD). The *in vitro* method of Menke *et al*. (1979) was used to predict the metabolizable energy (ME) and organic matter digestibility (OMD) of the materials (the higher the numerical values the higher the nutritional values of the material). The ME and OMD were calculated from the chemical constituents (crude protein, lipid and ash) presented in Table 8 and the gas production observed after 24 h when the materials were fermented in closed tubes as described in Menke *et al.* (1979). The ME and OMD of unextracted leaves were 9.5 MJ/Kg and 74% respectively, and the corresponding values for the extracted leaves were 9.2 MJ/Kg and 75.7% respectively. These values are slightly lower compared with commonly used meals in animal diets. The ME of both types of leaves are of similar order of magnitude as for fresh forages, whereas OMD contents are approximately 5 % units higher (Table 11).

Table 11. Crude protein (CP) and fiber contents (CF), metabolizable energy (ME) and organic matter digestibility (OMD) of some commonly used oil meals (data are on dry matter basis).

Oil cakes/meals	CP (%)	CF (%)	ME (MJ/Kg)	OMD (%)
Castor seed, Ricinus, Commercially extracted meal	38.5	32.3	6.9	47.0
Coconut, *Cocos nucifera* extracted meal	23.7	16.2	11.9	81.0
Cottonseed, *Gossypium* spp., Decorted extracted meal	51.5	8.8	10.6	73.0
Cottonseed, *Gossypium* spp., Partly decorted extracted meal	41.7	19.2	10.5	74.0
Groundnut, *Arachis hypogaea*, Dehulled, extracted meal	56.3	6.4	12.5	86.0
Groundnut, *Arachis hypogaea* Partly dehulled, extracted meal	51.3	10.7	12.0	83.0
Linseed, Linum usitatissim, extracted meal	38.7	10.3	12.2	79.0
Mustard, *Sinapis alba*, extracted meal	42.2	10.8	11.9	83.0
Rape seed, *Papaver somm*. extracted meal	39.4	14.0	10.9	77.0
Soya bean, *Glycine max*, extracted meal	51.4	6.7	13.0	92.0
Sunflower, *Helianth annuus*, extracted meal	42.9	15.1	10.6	75.0
Fresh forages				
Alfalfa, pre-bloom	22.1	23.7	10.0	70.0
Berseem, bloom	20.3	23.1	9.2	68.0
Clover red, bloom	17.5	24.3	9.6	70.0
Clover white, bloom	21.5	20.3	9.7	70.0
Lupin white	22.0	23.9	10.9	79.0
Mulberry*	Up to 27.6	48.0	11.3	64.0
***Moringa oleifera* leaves**				
Extracted	43.5	47.4*	9.2	75.7
Unextracted	25.1	21.9*	9.5	74.1

Source: Close, W and Menke, K.H. (1986), except for Mulberry (Singh and Makkar 2000)
*neutral detergent fiber and not CF

Protein degradability. In vitro rumen crude protein degradability (RDCP) at 24 h of incubation was 44.8 and 48.6 % for the extracted and unextracted Moringa leaves respectively. Much higher values for protein degradability have been reported for seed cakes (Krishnamoorthy *et al.*, 1995). Negi *et al*. (1989) have reported that the rumen protein degradability of some tannin-containing tree forages was low (16-40 %). The acid detergent fiber (ADF) content of the extracted and unextracted Moringa leaves was 16.3 and 11.4 %

respectively, and the protein contents of the ADF (known as the ADIP) were 13.2 and 9.8 % respectively. ADIP represents 4.4 % and 5.0 % of the total crude protein of unextracted and extracted leaves respectively. This protein is unavailable to the animal. Higher protein contents of ADF obtained from extracted as compared to unextracted Moringa leaves could be due to precipitation of soluble proteins by 80 % ethanol (ethanol is used to precipitate out proteins from the solutions). These precipitated proteins remain in the residue (called "extracted leaves") following the ethanol treatment. Generally these proteins are soluble in acid detergent solution but the heat treatment (80 ^{o}C) used to dry the residue following the ethanol treatment could have rendered them insoluble in acid detergent solution (Van Soest, 1965). About 95 % of the total nitrogen in Moringa leaves was found to be available either in the rumen or in the post rumen (Table 12). This value closely resembles the pepsin digestibility of the leaves which was 92 % (Makkar and Becker, 1997). Fifty and 47 % of the total protein of extracted and unextracted Moringa leaves respectively was potentially digestible in the intestine (PDI = total crude protein – {RDCP + ADIP}). In protein supplements (coconut meal, cottonseed meal, groundnut meal, sesame meal, sunflower meal, and wheat bran) these values varied from 0 to 26 % with the exception of rice bran (45 %). Among fodders, Leucaena had the maximum amount of PDI (41-58 %) followed by Gliricidia (34 %) and Centrosema pubescens (32 %). In cereal straws, PDI varied from 0 – 35 % (Krishnamoorthy *et al.,* 1995). Negi *et al.* (1988) reported PDI of 11 % for wheat straw and 46 % for rice straw. The PDI is available to the animal for production purposes. The high values of protein and PDI observed in both extracted (50 %) and unextracted (47 %) leaves of Moringa suggest that these leaves are a good source of protein supplement for ruminants.

Table 12. Levels of crude protein (CP), rumen degradable crude protein (RDCP), acid detergent insoluble protein (ADIP) and protein potentially digestible at the intestine (PDI) in extracted and unextracted Moringa leaves.

Sample	g CP/100 g a	g RDCP/100 g b	g ADIP/100 g c	g PDI/100 g a - (b + c)
Unextracted	25.1	12.2 (48.6)	1.1 (4.4)	11.8 (47.0)
Extracted	43.5	19.5 (44.8)	2.2 (5.1)	21.8 (49.9)

Values in parentheses represent the percentage of total protein

Non-protein nitrogen and total buffer soluble nitrogen. The levels of non-protein nitrogen (NPN) in non-extracted and extracted leaves of Moringa were found to be 4.7 and 2.7 % respectively. The NPN is considered to be completely degraded in the rumen. The NPN contents of defatted seed meals of Jojoba, Soybean, Sunflower and Rapeseed were 21-30 %, 2.9-7.8 %, 5.0 % and 6.9 % respectively (Wolf *et al.* 1994). The true protein in the non-extracted and extracted leaves of Moringa was 20.4 and 40.8 % in dry matter respectively. The buffer (pH 7) soluble nitrogen for the extracted and non-extracted leaves was 3.1 and 5.9 % respectively (7.1 and 23.5 % of the total CP), suggesting that the solubility of the proteins in Moringa leaves is very low. Al-Kathani and Abou-Arab (1993) have reported similar results for *M. peregrina*. One of the factors responsible for the low rumen protein degradability observed in the *M. oleifera* leaves (see above), could be the low solubility of the proteins.

*Digestion kinetics***.** Table 13 presents the rate (c) and potential (b) extent of gas production using the method of Menke *et al*. (1979) for the extracted and unextracted Moringa leaves, their neutral detergent fibre (NDF) fractions, and other feed stuffs. The rate is the index of the

rapidity with which organic matter is fermented in the rumen. High rate of digestion of Moringa leaves and the NDF suggest higher intake by animals. The fibre degradation rate of the extracted Moringa leaves was lower than the unextracted leaves, which could be attributed to the high temperature (80 ^{o}C) of drying the leaves following 80 % aq. ethanol treatment. The drying temperature could have a significant effect on lowering degradability of the fibre and rendering the protein unavailable to the animal. In order to make the best use of the extracted leaves, the leaves following ethanol treatment may be dried at low temperatures. The digestion kinetic parameters (Table 13) suggest the nutritive value of Moringa leaves to be as high as other well known feed resources such as *Leucaena* and Mulberry.

Table 13. The rate (c) and potential (b) extent of gas production using exponential model

Sample / **Leaves/straw**	**c (per h)**	**b (ml / g sample)**
Moringa leaves		
- unextracted	0.0852	247.5
- extracted	0.0489	268.3
Mulberry leaves		
- young*	0.0703	303
- mature	0.0624	177
Leucaena*	0.0578	186
Sorghum straw	0.0648	252.1
Barley straw	0.0417	286.7
NDF		
Moringa leaves		
- unextracted	0.0753	267.8
- extracted	0.0648	260.3
Sorghum straw	0.0299	272.5
Barley straw	0.034	302.1

***** Data from Singh and Makkar (2000)

Tannins and other anti-nutritional factors. Polyphenols, commonly known as tannins, occur widely in many different plants, especially those from tropical regions. Their consumption by animals has adverse effects on productivity and health. They are present in various agro-industrial by-products such *as Acacia nilotica* pods, *Madhuca indica* seed cake, *Mangifera indica* seed kernel, *Panicum miliaceum* polish, *Garcinia indica* cake and *Theobroma cacao* pods (Makkar *et al.*, 1990; Makkar and Becker, 1998). The unextracted leaves had negligible amounts of tannins (1.4 %) and condensed tannins were not detectable. The content of total phenols was 3.4 % (Table 14). A total phenol content of 2.7 % has been reported by Gupta *et al.* (1989) for the unextracted leaves. At this concentration, these simple phenols do not produce any adverse effects when eaten by animals. In the extracted leaves, no tannins were detected and the content of phenols was very low (1.6 %). The tannins are soluble in aqueous organic solvents such as ethanol, methanol, acetone etc. (Makkar and Singh, 1992) and

therefore, tannins would also be present in the isolated hormonal preparation obtained through the process in which the leaves are treated with 80 % ethanol. The absence of an increase in gas production on addition of polyethylene glycol (a tannin bioassay based on incubation of a feed in a buffered medium containing rumen microbes; Makkar *et al.*, 1995) also indicated absence of tannins in the extracted and unextracted leaves.

Another group of anti-nutritional factors reported to occur in the unextracted Moringa leaves are the saccharides raffinose and stachyose which produce flatulence in monogastrics. According to Gupta et al., (1989) these compounds comprise 5.6 % of the dry matter in the unextracted leaves but occur in higher concentrations in legumes. They can however be removed to a large extent by soaking and cooking in water (Bianchi *et al*., 1983). These flatulence factors are determined after extraction in 80 % aqueous ethanol (Williams, 1984; Gupta *et al*., 1989), and would therefore be absent in extracted Moringa leaves. Other antinutritional factors present in unextracted Moringa leaves are nitrate (0.5 mmol/100 g), oxalate (4.1 %), saponin (1.2 %) and phytate (3.1 %). Trypsin inhibitor activity was not detected (Gupta *et al*., 1989). Phytates are present to the extent of 1 to 5 % in legumes and are known to decrease the bioavailability of minerals in monogastrics (Reddy *et al.*, 1982). The leaves of Moringa are quite rich in minerals and the presence of oxalates and phytates at concentrations of 4.1 % and 3.1 % respectively is likely to decrease the minerals' bioavailability. Saponins from some plants have an adverse effect on the growth of animals but those present in Moringa leaves appear to be innocuous (did not show haemolytic activity), and humans consume them without apparent harm. Cyanogenic glucoside and glucosinolates were not detected in leaves (Makkar and Becker, 1997). Most of the antinutritional factors mentioned above are soluble in aqueous ethanol and would most probably be absent in the extracted leaves.

Table 14. Contents of total phenols, tannins, condensed tannins, saponins, phytate, lectin and trypsin inhibitor in unextracted and extracted Moringa leaves.

Sample	Total phenols (%)	Tannins[a] (%)	Condensed tannins (%)	Saponins[b] (%)	Phytate[c] (%)
Extracted	1.6	0.0	0.0	0.2	2.5
Unextracted	3.4	1.4	0.0	5.0	3.1

Condensed tannins, lectin and trypsin inhibitors were not detected in either extracted or unextracted leaves.

a: as tannic acid equivalent

b: as diosgenin equivalent

c: as phytic acid

Trials using Moringa as feed to fatten cattle. Feeding Tests were conducted with a herd of 24 animals. During the day animals grazed on gamba (a pasture containing some leguminous plants). During the night, 12 of the animals (divided into 3 groups of 4) were fed *ad libidum* with freshly cut pasture and 12 were fed *ad libidum* with chopped 35 day old Moringa.

Table 15 Weight gain of cattle fed *ad libitum* with freshly cut pasture or 35 day old Moringa during the night

Animal group	Range of weight gains (g/day)	Average weight gain (g/day)
Pasture fed group (3 x 4 animals)	750 – 980	950
Experimental group (3 x 4 animals)	1150 – 1450	1250

The Moringa group gained considerably more weight than the group fed on pasture (Table 15). Mineral salt, water, and all other conditions did not differ between the groups.

Production level of fresh green matter in Moringa plantations. A study consisting of many trials was completed to discover the optimum density at which Moringa should be planted to produce a maximum amount of fresh green matter. Spacing in the trials ranged from 1 meter x 1 meter or 10,000 plants per ha to 2.5 cm x 2.5 cm or 16,000,000 plants per ha. After taking into account a number of factors that affected the overall efficiency including the cost of seeds, losses of plants in the first cuttings, and the cost of soil preparation the optimum density in sandy, well drained and fertile soils was found to be 10 cm x 10 cm or 1 million plants per ha (Table 16).

The final density and hence the number of plants eliminated depends on the specific production goals. If for example the goal is to produce green fodder with a maximum of protein and a minimum of lignin then cutting should be done every 33 to 40 days. If instead the goal is to produce a maximum of lignocellulose fibers for paper production, the ideal cutting time would be after 6 to 8 months of growth. This amount of time would enable the trunk of the plant to reach the necessary diameter and for the percentage of leaves, small branches and bark to be reduced thereby optimising the percentage of lignified wood.

As Moringa continues to grow between cuttings the number of plants per hectare is dramatically reduced owing to the different growth rates among the plants. As they compete for sunlight the larger plants shade out the slower growing or smaller plants. At 35 days, the average height of the plants is still between 1.6 and 2.0 meters and so the competition for light is not yet very great. Differences in height between plants at this stage range between 10 and 40 cm.

Intensive production of Moringa forage Photo: Foidl

Table 16 Production parameters of Moringa at first cutting

Plant density (Plants / ha)	Fresh Matter (Metric tons/ha/ cutting)	Dry Matter (Metric tons/ha)	Protein (kg/ha)	Loss of plants after first cutting
95,000	19.6	3.33	566	n.d
350,000	29.7	5.05	859	n.d.
900,000	52.6	8.94	1,520	n.d.
1,000,000	78.0	13.26	2,254	Approx. 2%

n.d. = not determined

After completing the initial trials, only the one with 1,000,000 plants per hectare (optimal spacing) was continued. This trial was observed over a four-year period during which time a total of 9 cuttings per year were harvested. It should be noted that this large number of cuttings per year was only possible because a strict regime of adequate fertilization and irrigation was followed. Although irrigation was given regularly and consistently throughout the year, the yield per cutting varied significantly between the dry and rainy seasons. During the dry season the yield per cutting was as low as 45 metric tons / ha while during the rainy season the yield per cutting was at times as high as 115 metric tons/ha.

In smaller trial areas (10 m^2) densities of 4 million plants per ha and 16 million plants per ha were tried. The results from these trials are given in Table 17.

Table 17 Production parameters of Moringa at first cutting on test plots with high density plants.

Density (Plants / ha)	Fresh Matter (metric tons / ha)	Dry Matter (metric tons / ha)	Protein (kg / ha)	Losses of plants per cutting (%)
4 million	97.4	16.56	2,815	Approx. 25
16 million	259.0	44.03	7,485	Approx. 40

In the next cutting the losses were still very high. Interpolation showed that after 4-6 cuttings we would be back down to about 1 million plants per ha. Taking into account the high cost of seeds and the difficulties associated with maintaining a regular spacing of 2.5 cm x 2.5 cm in larger areas, this density was discontinued. We do however believe that if the goal of the producer is soley to maximize the output of biomass production including roots, this high density seeding using hydroponic technologies could lead to enormous amounts of biomass production per ha (up to 1,000 metric tons/ha each year).

In the trials with 1 million plant/ha and 9 cuttings/year over 4 years, the average fresh matter production was 580 metric tons of fresh material per ha/year equivalent to about 99 tons of dry matter. This amount of dry matter contains an average of 16.8 tons of protein, 9.9 tons of sugar, 7.9 tons of starch and 4.9 tons of lipids.

Because the content of lignin is very low (about 5 %), the hemi-cellulose + cellulose fraction is very high. By using a co-fermentation process to transform starch, hemi-cellulose and cellulose into sugars and afterwards into alcohol, there is the potential for the production of over 20,000 liters of alcohol per ha per year.

After a number of years, the root mass of Moringa contains a considerable percentage of the overall mass of the plant. More research is required to discover the full potential usefulness of this root mass. As far as we know, the productivity of Moringa in industrial plantations is higher than that of any other plant. There is still a need to continue these trials to find out whether, in the long term, this kind of productivity is truly sustainable and at what costs. Large amounts of minerals will be needed per hectare per year to maintain productivity at the suggested plantation density of 1 million/ha. A systematic evaluation of the fertilizer requirement is needed.

Conclusions on Moringa as a forage plant. The crude protein contents of extracted and unextracted Moringa leaves is high (43.5 and 25.1 % respectively) with the true protein content of above 95 %. About 95% of the total crude protein was found to be available either in the rumen or in the post rumen, with a high proportion resistant to rumen degradation but available in the post rumen for production purposes. These data suggest that both extracted and unextracted Moringa leaves are good sources of protein supplement for high production cows. Higher rates of digestion of NDF (index of the rapidity with which a feed/fiber is fermented in the rumen) were observed for both the extracted and unextracted M. oleifera leaves. This suggests that the fiber quality of these leaves is also good. It is worth noting that the fiber degradation rate of the extracted leaves was significantly lower than that of the unextracted leaves, which could be attributed to the high temperature (80 ^{o}C) the leaves were subjected to in order to dry them following treatment with 80% aqueous ethanol. The drying temperature could significantly lower the degradability of the fiber and render the protein unavailable to the animal by increasing the ADIP. Given that our objective is to make the best use of the extracted Moringa leaves, it becomes imperative to conduct further studies to find a temperature at which leaves can be dried following ethanol treatment which does not produce

these adverse effects. Moringa leaves had negligible levels of tannins and saponins, which were similar to those present in soybean meal. Trypsin inhibitors and lectins were not detected. The phytate content of 3.1 % might decrease availability of minerals in monogastrics. The leaves extracted with 80 % aqueous ethanol would still be a better source of feed (protein supplement) since these, besides being free of tannins, lectins, trypsin inhibitors, cyanogenic glucosides, glucosinolates, and flatus factors, have low levels of saponins and phytates.

Twigs and stems have a low crude protein content (7 and 6 % respectively; 40 and 48 % of this was non-protein nitrogen). About 78 and 68 % of the total crude protein in the twigs and stems respectively was degradable after 24 h in the rumen and the acid detergent insoluble protein (protein unavailable to the animal) accounted for 15 and 17 % respectively, suggesting a low availability of proteins from twigs and stems in the post rumen (Makkar and Becker, 1997).

All essential amino acids including sulfur-containing amino acids in leaves were in higher than adequate concentration when compared with the recommended amino acid patterns of the FAO/WHO/UNO reference protein for 2 to 5 year old children. The essential amino acid composition of these leaves was also comparable to that of soybean. It is worth noting that the data reported above also suggest that Moringa is a good source of protein for monogastric animals as well.

Moringa kernel and meal as animal feed

The kernels of Moringa can be crushed and its water extract used for purification of water, and the water extract is a viable replacement coagulant 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 (obtained after extraction of oil) has been used to purify water. This residue is still active as a coagulant. We determined chemical constituents, organic matter digestibility, gross and metabolizable energies, rumen degradable and undegradable nitrogen, non-protein nitrogen, pepsin degradability of proteins and presence of antinutritional factors in kernels, seed meal (fat-free kernel) and in the residues obtained after removal of water soluble coagulants from kernels and seed meal obtained from the Moringa plant. Amino acid composition of these four fractions of kernels has also been analysed (Makkar and Becker, 1997). This information together with reported above for the Moringa forage will pave the way for better utilization of different fractions/residues of Moringa, which are generated as by-products in the process of extraction of oil, growth hormones and coagulants, as animal feed.

***Solubility of kernel and meal in water*.** Loss in DM from kernels and meal following extraction in water was 20.5 and 41.8 % respectively. By taking into account these solubility values and CP of kernels, extracted-kernel, meal and extracted-meal, it was found that 23.7 and 33.4 % of the CP present in the kernel and meal was lost in water.

Chemical constituents. The kernels had 36.8 % CP and 41.7 % lipids. The residues left after water extraction of kernels or meal had CP contents of 35.3 and 70.3 % respectively. Non protein nitrogen (NPN) in kernels and meal was only approximately 9 % of the total CP, and was not detected in the extracted samples, suggesting presence of high amounts of true protein in these samples.

Protein degradability. The RDCP of kernel and meal was 64 and 61 % respectively. Similar values for rumen protein degradability have been reported for seed cakes (Krishnamoorthy *et*

al. 1995). The RDCP of the extracted-kernel and extracted-meal was much lower (36 and 28 %). The pepsin soluble protein varied from 82 - 91 % and the ADIP was only approximately 1 to 2 % (Makkar and Becker, 1997).

The low RDCP, high pepsin soluble nitrogen, and low ADIP values suggest that most of the protein in the extracted-kernel or extracted-meal samples would be available to the animal postrumen (PDI of approximately 62 - 69 % of the total CP). The PDI is available to the animal for production purposes. In protein supplements such as coconut meal, cottonseed meal, groundnut meal, sesame meal, sunflower meal and wheat bran, PDI values varying from 0 to 26 %, with the exception of rice bran (45 %), have been observed (Krishnamoorthy *et al.*, 1995).

Amino acid composition. Amongst essential amino acids, lysine, leucine, phenylalanine + tyrosine and threonine were deficient in kernels, in meal and in their water-extracted residues when compared to the standard FAO protein, whereas sulphur-containing amino acids were higher (Table 16). The amino acid composition of moringa kernels and of the meal were similar which is expected. The values for the extracted-kernels were higher compared to those for the kernel and also for extracted-meal compared to meal. One of the factors contributing to higher amino acid values in residues obtained following water treatment could be the loss of NPN from the samples. The amino acid composition of the water- soluble and insoluble proteins appears to be similar (Table 18).

Antinutritional factors in kernel, meal and their water-extracted residues. Tannins, trypsin and amylase inhibitors were not detected in untreated or treated kernel samples. The saponin content was also not high; 1.1, 1.4, 0.5 and 0.6 % in kernels, meal, extracted-kernel and extracted-meal, respectively. The water treatment of kernels and meal, used for extraction of active moieties to purify water, removed approximately 50 % of the saponins. Only the kernel and extracted-kernel samples showed haemolytic activity; meal and extracted meal were free of haemolytic activity.

Phytate contents of the kernel samples were higher than those in the vegetative parts (Table 19). The levels of phytate were higher in extracted samples of kernels as compared to corresponding untreated samples, suggesting phytate was not removed by the water treatment. Phytate levels of about 3.0 and 6.7 % observed for extracted-kernel and extracted-meal respectively are likely to decrease bioavailability of minerals, particularly Zn and Ca. This phytate level is of the similar order of magnitude as observed for many other conventional protein supplements (soyabean meal 3.2 – 3.8 %, rapeseed meal 6.0 – 7.3 %, sunflower 6.2 – 9.2 %, peanut meal 3.2 – 4.3 %; 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 review: Thompson 1993).

The contents of cyanogen glucosides in kernel, meal, extracted-kernel and extracted-meal were 5.2, 13.1, 15.3 and 31.2 mg HCN equivalent/kg respectively using the exogenous ß-glucosidase for hydrolysis of glucosides (Table 19). Using autohydrolysis, a level of 5.0 mg HCN equivalent/kg was observed for the kernel. The cyanogenic glucosides levels observed for kernel samples are much lower than those considered safe per EC regulations, < 100 mg HCN equivalent/kg for cassava and almond cakes and < 250 mg HCN equivalent/kg for linseed meal. Furthermore, according to EC regulations for livestock, the cyanogen levels in a complete feed should not exceed 50 mg HCN equivalent/kg except for the chickens 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).

Table 18. Amino acid composition (g/16 g N) of Moringa unextracted and extracted meal

Amino acid	Unextracted meal	Extracted meal
Lysine	1.47	1.48
Leucine	5.27	5.84
Isoleucine	3.05	3.49
Methionine	1.90	2.13
Cystine	4.22	4.72
Phenylalanine	3.97	4.29
Tyrosine	1.50	1.41
Valine	3.47	3.63
Histidine	2.27	2.28
Threonine	2.25	2.28
Serine	2.75	2.85
Glutamic Acid	19.35	19.63
Aspartic Acid	3.97	3.76
Proline	5.52	6.04
Glycine	4.90	4.40
Alanine	3.77	4.05
Arginine	11.63	16.68
Tryptophan	Not determined	Not determined

Levels of glucosinolates (sulphur-containing glycosides) in kernel, meal and extracted-kernel were 46.4, 65.5 and 4.4 µmol/g respectively. Glucosinolates were not detected in the extracted meal (Table 19). The levels of glucosinolates observed for kernel and meal samples are of the same order as for rapeseed meal (Saini & Wratten 1987; Smith & Dacombe 1987) and *Camelina sativa* seeds (Lange *et al.,*. 1995). While some of these 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 *et al.,* 1981). 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. 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 glucosinolates 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).

Table 19. Contents of total phenols, tannins, condensed tannins, saponins, phytate, and glucosides in Moringa samples.

Sample	Total phenols (%)[a]	Saponins[b] (%)	Phytate[c] (%)	Cyanogenic glucoside (mg/kg)	Glucosinolate (μmol/g)
Kernel	0.02	1.1	2.6	5.2	46.4
Meal	0.04	1.4	4.1	13.1	65.5
Extracted-kernel	0.07	0.5	3.0	15.3	4.4
Extracted-meal	0.07	0.6	6.7	31.2	Not detected

Tannins were not detectable

a: as tannic acid equivalent; b: as diosgenin equivalent; c: as phytic acid

Alkaloid positive spots were not observed in kernel or extracted-kernel samples, but were present in defatted kernels which could be due to incomplete extraction of alkaloids in presence of lipids. In defatted kernels (meal), three alkaloid positive spots with Rf values (mean $\pm$ S.D., *n*) of 0.227 $\pm$ 0.011 (4), 0.69 $\pm$ 0.008 (4) and 0.798 $\pm$ 0.021 (5) were observed. The colour intensity of the spot with 0.69 Rf value was the highest, followed by 0.227 and 0.798. In the extracted-meal sample, only one spot with Rf value of 0.78 $\pm$ 0.01 was present and its colour intestity on the TLC plates was almost similar to that obtained for the meal. A substantial amount of alkaloids was removed from the meal following the water-treatment.

Conclusions on kernel and meal as animal feed. The higher CP content of the meal as compared to kernels together with the higher solubility of proteins from meal suggested that the coagulants used for the purification of water which are proteinous in nature can be recovered efficiently from meal. Higher recovery of the active proteinous coagulants from 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 (approximately 70 %), all of which is in the form of true protein, ii) high availability of protein postruminal (69 % of the total protein) and high pepsin digestibility, iii) virtual absence or presence of negligible levels of antinutrional 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 2 to 5 years old child. Presence of phytate at about 6.7 % might decrease bioavailability of minerals. The residue obtained after extraction of coagulants from the defatted moringa kernels (meal) could replace some of these conventional seed meals. This may be a good source of sulphur amino acids for fibre-producing animals (i.e. Angora rabbits, sheep and goats) in a mixed diet containing sufficient levels of other essential amino acids. However, before recommendations are made to farmers, *in vivo* experiments are required to study various performance parameters and possible toxicity arising due to factors not studied in the present investigation. It may be noted that the presence of high levels of sulphur-containing amino acids would offer the animal some protection against toxic factors since these acids are

known to enhance the detoxification process of the animal by acting as methyl donors in various organs.

The kernels of the *M. oleifera* variety used by us are bitter but the bitter taste was almost absent in the residue left after extraction of coagulants from the defatted kernels. The bitter taste is generally attributed to alkaloids, saponins, cyanogenic glucosides, glucosinolates which were removed by the treatment (see Table 19), suggesting that the bitter taste would not limit the use of this material in animal diets. Considerable genetic diversity exist within and between *M. Oleifera* and *M. stenopetala* (Odee, 1998; Muluvi *et al.*, 1999). Perusal of the literature reveals that many different varieties exist whose kernels taste from sweet to very bitter (CSIR 1962; Dogra *et al*., 1975). Seeds of some varieties are consumed by humans after roasting and taste like peanuts (Ramachandran et al. 1980). Our study has shown that the kernel's antinutrional components or their degraded products, say for example of glucosinolates which are known to cause various adverse effects (Mawson *et al*. 1994, 1995), would be consumed by humans through drinking water, which might produce clinical or sub-clinical changes in internal organs. Workers in this area are aware of this problem and studies are available where kernel have been fed to rats and mice without any apparent toxic symptoms (Barth *et al.*, 1982; Berger *et al*., 1984). However, in depth studies are required in this direction especially in light of the fact that various *M. oleifera* varieties are presently in use.

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