

Chemical composition and effect of heat on organic matter- and nitrogen-degradability and some antinutritional components of *Jatropha* meal

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Abstract

Jatropha curcas, a member of the Euphorbiaceae is a multipurpose tree of significant economic importance because of its several industrial and medicinal uses. The kernel to shell ratio of *J. curcas* seeds was 63:37 and the kernels contained about 580 g kg⁻¹ oil. The oil-free kernels of *J. curcas* had crude protein content of about 580 g kg⁻¹, however 24 h in vitro rumen nitrogen degradability (IVDN) was very low (29 to 43%). In addition, the meal had high activity of trypsin inhibitor (TIA, 19 to 21 mg trypsin inhibited g⁻¹ sample) and phytate (ca 10%). Lectins (a minimum of 66.7 mg ml⁻¹ assay produced agglutination) and saponins (2.6% as diosgenin equivalent) were also present. Tannins were not detected and the phenolic content was negligible (0.2 to 0.4% as tannic acid equivalent). Effect of several heat treatments (moist: 100°C, 67% moisture; 130 and 160°C, initial moisture 80%, dry: 130 and 160°C, combination of moist and dry heating: 100°C, 67% moisture, 60 min followed by dry heating at 160°C) on nutritive value and deleterious components of partially defatted (PD, about 23% residual oil) and defatted (D, about 1.5% residual oil) *Jatropha* meals were studied. Some treatments which could be promising for monogastrics were: (i) moist heating (67% moisture) at 100°C for 60 min which increased IVDN of PD and D meals to 66.5 and 67.4% respectively and decreased TIA to about 5 mg trypsin inhibited g⁻¹ sample; and (ii) moist heating (80% initial moisture) at 130°C for 30 min which increased IVDN of PD and D meals to 55.2 and 73.3% respectively and decreased TIA to about 4 mg trypsin inhibited g⁻¹ sample. For ruminants, dry heating at 160°C for 120 min might be

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advantageous as IVDN decreased to 23.7% for PD meal and to 38.6% for D meal. The TIA of these treated meals was about 4 mg trypsin inhibited g^{-1} sample. Presence of oil was found to decrease the effect of heat in increasing IVDN and inactivating trypsin inhibitors. The levels of other antinutritional factors did not decrease by the treatments studied. The pepsin insoluble nitrogen in the moist heated samples were only 4 to 6% of the total nitrogen and those in the dry heated samples were from 8 to 15%. The calculated organic matter digestibility and metabolizable energy and IVDN for D *Jatropha* meal following heat treatment (80% initial moisture, 130°C, 30 min) were: 82.9%, 11.8 MJ kg^{-1} and 73.3% respectively which were lower by 5% units, 2.5 MJ kg^{-1} and 7.6% units respectively compared with soyabean meal. © 1997 Elsevier Science B.V.

Keywords: *Jatropha curcas*; Meal; Heat treatment; Composition; In vitro rumen nitrogen degradability; Antinutritional factors; Lectin; Trypsin inhibitor; Phytate

1. Introduction

Jatropha curcas is a member of the Euphorbiaceae family which grows in most of the tropics. The plant (a shrub or small tree) grows readily in swamp or shade and is quick growing (Ishii et al., 1987), survives in poor stony soils and is resistant to drought (Munch and Kiefer, 1989), reaches a height of 3 m (Scultz, 1968), and has an annual seed yield of 5 t per hectare (Raina and Gaikwad, 1987). The seed which weighs about 0.75 g contains 30–32% protein and 60–66% lipid (Liberalino et al., 1988), indicating good nutritional value. The oil from the nut of *J. curcas* can serve as fuel for diesel engines (Ishii et al., 1987; Ishii and Takeuchi, 1987; Munch and Kiefer, 1989; Ouedraogo et al., 1991), indicating its potential as a renewable energy source. The plant can be used for land reclamation, produces seeds which can be transported without deterioration and at a low cost due to its high specific mass. These multipurpose uses have lately generated interest in the plant which is now becoming a cash crop in South and Central American countries.

The seed and/or oil have been found to be toxic to mice (Adam, 1974), rats (Liberalino et al., 1988), calves, sheep and goats (Ahmed and Adam, 1979a,b); humans (Mampane et al., 1987), chickens (Samia et al., 1992) and fish (unpublished observations; K. Becker and coworkers, 1996). Hence, its use as a food or feed source is limited. Some toxic and/or irritant compounds isolated from the plant include β -D-glycosides of sitosterol (Bose et al., 1961), curcin (Mourgue et al., 1961; and Stirpe et al., 1976); flavonoids vitexine and isovitexine (Sankara et al., 1971) and 12-deoxy-16-hydroxyphorbol (Adolf et al., 1984). However, the lectin (curcin) is considered to be responsible for the toxicity (Cano Asseleih et al., 1989).

Increased production of *J. curcas* as a fuel source will increase production of the toxic by-product (meal) which if not utilized as feed, can at best be used as a fertilizer. We report here, for the first time, the presence of high levels of trypsin inhibitor activity and phytate in the meal. Furthermore, no information is available on the presence of other antinutritional factors such as saponins, tannins and cyanogenic glucoside in the seed or seed meal. As most of these antinutritional factors are heat labile, the objective of this investigation was to study effects of heat treatment (moist and/or dry) on various

antinutritional components, and to enhance the nutritive value of *Jatropha* meal in an effort to produce high quality livestock feed from toxic, non-edible waste.

2. Experimental

2.1. *Physical characteristics of seeds*

Two varieties of fresh *J. curcas* seeds (Capoverde and Nicaragua) supplied by Sucher and Holzer, Project Biomasse, Managua, Nicaragua were used for the study. Ten handfuls of seeds were randomly taken from each variety. Average weight of seeds was calculated by dividing the total weight by the total number of seeds.

Two kg of randomly collected seeds from each variety were cracked, the shells carefully removed and the weight of kernels and shells recorded.

2.2. *Jatropha meal samples*

For extraction of the oil, two methods are generally used: (i) use of screw press and (ii) use of solvents like hexane or petroleum ether. In our laboratory, the kernels were milled using an ordinary coffee grinder and the ground kernel from each variety were divided into two portions. These were either partially defatted (which correspond to press seed cake) or completely defatted (which correspond to solvent extraction) in a Soxhlet-type extractor using petroleum ether (boiling point, 40°C). The partially defatted samples (PD) were extracted once (4 h) while the completely defatted samples (D) were extracted several times until the evaporation of residual ether revealed less than 1.5% lipid. These produced the following samples which are described as: (a) PD Capoverde meal; (b) PD Nicaragua meal; (c) D Capoverde meal; and (d) D Nicaragua meal.

Heat treated soyabean meal was obtained from Soya Mainz GmbH and Co KG, Dammweg 2, Mainz, Germany.

2.3. *Composition*

All *Jatropha* samples and the Soyabean meal were analyzed for dry matter (DM), organic matter (OM), crude protein (CP), lipid and ash using the Association of Official Analytical Chemists (1980) procedure. Neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) were determined as described by Van Soest et al. (1991), omitting sodium sulfite and decahydronaphthalene from the neutral-detergent analysis. Gross energy (GE) was determined using a bomb calorimeter.

2.4. *Heat treatments*

Samples in duplicate were subjected to different heat treatments. Most studies were conducted on the variety Capoverde due to its higher economic importance (production

per unit area is higher compared with the variety Nicaragua; N. Foidl, unpublished observations, 1996).

2.4.1. Moist heat treatment (MH) at 100°C, 67% moisture

PD samples of both varieties of *Jatropha* meal (2 g) were weighed (in duplicate) into 25 ml conical flasks, 4 ml distilled water was added, contents were made into paste using glass rods, flasks were stoppered tightly and placed in an oven at 100°C for 0, 10, 20, 30, 40, 60, 75 or 90 min. The samples were allowed to cool in a dessicator, placed in a freezer (6 h) and freeze-dried. Selected D samples were similarly treated for selected time (0, 20, 40, 60 or 90 min).

2.4.2. Moist heat treatment (MH) at 130°C and 160°C, 80% initial moisture

Procedure similar to mentioned above was used to prepare MH samples containing 80% initial moisture (2 g sample plus 8 ml distilled water) which were heated at 130 or 160°C for 0, 20, 40, 60, 90 or 120 min. The flasks were not stoppered during heating. Residual moisture from weights of the flask containing sample before and after the treatment was determined following these treatments. The remaining moisture was removed using a lyophilizer.

2.4.3. Dry heat (DH) treatment at 160°C

PD and D meals were similarly subjected to DH treatment at 160°C for 0, 20, 40, 60, 90 or 120 min.

2.4.4. Moist heat treatment followed by dry heat treatment

PD and D meals MH at 100°C for 60 min using 67% moisture (see Section 2.4.1) were dry heated (DH) for 0, 30, 60, 90 or 120 min resulting in a combination of moist and dry heat treatments (MH + DH). These conditions simulate the industrial conditions as the material after the treatment needs to be dried before its transport and industry would prefer heat drying compared with lyophilization.

PD Nicaragua meals DH at 160°C for 20, 40, and 60 min were also analyzed for lipids, besides other parameters, to observe the effect of dry heating on lipid content.

2.5. In vitro rumen protein degradability

In vitro rumen crude protein degradability was determined according to the method of Raab et al. (1983). In brief, the samples (in triplicate; 90 mg each) which contained at least 3.2 mg N in order to conform with the requirement of Raab et al. (1983) were incubated with (160 mg) and without starch. Rumen liquor and particulate matter (approximately 60:40) were collected from a cannulated dairy cow (kept exclusively on a medium quality diet) before the morning feeding into prewarmed CO₂ filled thermos flasks and then strained through a cheese cloth. In vitro incubation was conducted according to the method of Menke et al. (1979) using 30 ml buffered rumen inoculum. Three syringes containing 30 ml inoculum only served as blanks. Syringes were placed in a rotating holder positioned in a ventilated oven set at 39° ± 1°C during the 24 h incubation period. The 24 h gas production in syringes were recorded.

After incubation, syringes were put into ice bath to prevent further microbial activity and the contents were transferred into Kjeldahl flasks placed on ice for determination of $\text{NH}_3\text{-N}$ content by distillation. Immediately before placing each flask in the distillation unit, 2 ml of 1 M NaOH (found to be sufficient for evolution of all the ammonia present; ammonia was not evolved from amino acids under these conditions) and 50 ml distilled water were added. Liberated NH_3 was trapped in 40 ml of 3% (w/v) boric acid and titrated with 0.2 M H_2SO_4 . In vitro rumen degradable nitrogen (RDN) as a % of total nitrogen was calculated from appropriate linear regression of gas production (X , ml) vs. $\text{NH}_3\text{-N}$ concentration (y , mg) as described by Raab et al. (1983). The RDN was multiplied by 6.25 to get rumen degradable crude protein (RDCP).

The protein bound to ADF (i.e. acid-detergent insoluble protein; ADIP) is considered to be unavailable to animals, therefore total nitrogen minus ADIP is the nitrogen available in the rumen and intestine. The protein potentially digestible in the intestine is: total nitrogen – (ADIP + RDCP)]. The RDCP in excess of microbial requirements results in nitrogen loss as ammonia (Mathison and Milligan, 1971) and inefficient nitrogen utilization by ruminants (Storm et al., 1983). Higher PDI allows more amino acids to reach the small intestine which are used then directly for production purposes (Chalupa, 1975).

2.6. Pepsin insoluble nitrogen

It was determined by incubating 0.5 g of the sample with 0.5 g pepsin (Sigma, P-7125) and 50 ml of 0.1 M HCl. After 20 h of the incubation the mixture was filtered on nitrogen-free filter paper and the residue on the filter paper was made HCl-free by several washings with distilled water till the filtrate is of neutral pH. Nitrogen in the filter paper and the residue was determined using Kjeldahl method. Pepsin insoluble nitrogen was calculated by dividing nitrogen of this residue from the nitrogen in 0.5 g sample. The results were expressed on per cent basis.

2.7. Organic matter digestibility and metabolizable energy

The digestibility of organic matter (DOM, %) and the contents of metabolizable energy (ME, MJ kg^{-1} DM) were calculated from the gas values and chemical constituents according to Menke et al. (1979).

2.8. Determination of toxic / antinutritional components

Trypsin inhibitor activity was determined essentially according to Smith et al. (1980) except that the enzyme was added in the last, after inhibitor is mixed with substrate, as suggested by Liu and Markakis (1989). Ground samples (0.25 g each) were extracted in 12.5 ml of 0.01 M NaOH at pH 9.4 to 9.6 using an ultra-turrax at 20 000 rpm for 5 min (2×2.5 min) with intermittent cooling by keeping the tubes containing the samples in an ice bath. The contents were centrifuged at 3500 g for 15 min and the supernatants were collected and this supernatant was centrifuged a second time at 9500 g, following which the supernatants were collected by slowly pipetting between the residue at the

bottom and the fatty layer on top, if any. These solutions were used for the assay after appropriate dilution (with distilled water) based on pre-assay trial results. The results are expressed as mg trypsin inhibited per g of sample.

Analysis for lectin content was conducted by haemagglutination assay described by Gordon and Marquardt (1974) in round bottomed wells of Microtiter plates with 1% (v/v) trypsinized erythrocyte (from cattle blood) suspension in phosphate buffered saline (PBS). Ground samples (2 g each) were extracted in 10 ml of the PBS using an ultra-turrax at 20 000 rpm for 5 min (2×2.5 min) with intermittent 5 min cooling by keeping the tube containing the sample in an ice bath. The contents were filtered through No. 540 filter paper and the filtrate was collected. The solution was mixed with an equal volume of 1% erythrocytes (0.05 ml each) in Microtiter plates. The sedimentation pattern of the erythrocyte suspensions were read after 2 h at room temperature. A positive pattern which indicated agglutination was a uniform effacement of the bottom of the well by erythrocytes while a negative pattern (indicating no agglutination) was a circular clump of erythrocytes surrounded by a concentric, clear zone of equal size to the blank (which contained PBS instead of sample). The contents of the wells were also examined microscopically for agglutination. The formation of erythrocyte aggregates of at least four or five cells that were not disrupted by gentle movement was considered as evidence of agglutination. The haemagglutination activity was defined as the minimum amount of meal in mg per ml of assay medium which produced agglutination.

Total saponin (triterpenoid and steroidal) content was determined using a spectrophotometric method described by Hiai et al. (1976). To 0.5 g ground meal samples in a screw-capped centrifuge tubes was added 10 ml of 80% aqueous methanol. The tubes were tightly capped and the contents were stirred overnight using a magnetic stirrer. The tubes were centrifuged at 3000 g for 10 min and the supernatants were collected in 25 ml volumetric flasks. The residues were washed three times with 5 ml of 80% aqueous methanol followed by centrifugation and the supernatants were collected in volumetric flasks. The final volume was made to 25 ml with 80% aqueous methanol. Aliquot samples from the flasks were used for saponin determination. The results are expressed as diosgenin equivalent from a standard curve of different concentrations of diosgenin in 80% aqueous methanol. Saponins were also determined by haemolytic assay as described in Thilborg et al. (1994).

Phytate content was determined by a colorimetric procedure described by Vaintraub and Lapteva (1988). Ground samples (0.5 g each) were stirred in 10 ml 3.5% HCl for 1 h. The contents were centrifuged at 3500 rpm for 10 min to obtain supernatants. Suitable aliquot of the supernatants were diluted with distilled water to make 3 ml and then used for the assay. Results are expressed as percentage phytic acid.

Total phenols, tannins and condensed tannins were determined by colorimetric methods as described in Makkar et al. (1993). Total phenols were quantified by Folin-Ciocalteu reagent, and tannins as the difference of phenolics before and after tannin removal from the extract using insoluble polyvinylpyrrolidone. Condensed tannins were measured by butanol-HCl- Fe^{3+} reagent. Total phenols and tannins are expressed as tannic acid equivalent and condensed tannins as leucocyanidin equivalent.

Total cyanogenic glucosides were assayed according to the procedure of Essers et al. (1993).

Amylase inhibitor activity was determined against porcine pancreatic alpha-amylase (Boehringer GmbH, Mannheim, Germany, Catalogue Number 102806). The activity of amylase was determined by the method of Bernfeld (1955) at 30°C. To 0.1 ml of Tris-HCl buffer (20 mM containing 1 mM CaCl₂, pH 6.9) was added 0.1 ml of the enzyme preparation (0.89 µg protein ml⁻¹ Tris-HCl buffer; alpha-amylase from porcine pancreas, type 1, 10 mg ml⁻¹ suspension). After 10 min, 0.3 ml of the above Tris-HCl buffer was added and then after keeping these tubes at 30°C for next 5 min the reaction was started by the addition of 0.5 ml of prewarmed (30°C) starch solution (1% in the Tris-HCl buffer). After 30 min the reaction (preliminary studies showed that the reaction is linear up to 60 min duration under these conditions) was stopped by the addition of 1 ml of dinitrosalicylic acid (DNS) reagent. Amylase inhibitor activity was determined as mentioned above for the amylase activity except that 0.1 ml of the sample extract (for preparation: see below) was mixed with 0.1 ml of the amylase, kept for 10 min at 30°C, followed by 0.3 ml of the Tris-HCl buffer and then after 5 min addition of 0.5 ml of the starch solution. The absorbance was recorded against proper blank, containing the extract but without the enzyme.

For isolation of amylase inhibitor, 0.5 g of the sample was extracted with 10 ml of the above Tris-HCl buffer using an ultra-turrax at 20 000 rpm for 4 min (2 × 2 min with intermittent coolings) at about 4°C. It was centrifuged at 3500 g followed by filtration if the supernatant is not clear. The clear supernatant was used for determination of amylase inhibitor activity.

Analyses for tannins, trypsin inhibitor activity, lectin, saponin, phytate, cyanogenic glucoside and amylase inhibitor activity were conducted at least in duplicate. All data are expressed on dry matter basis.

3. Results and discussion

3.1. Physical characteristics

The average mass of *J. curcas* seeds were 0.69 and 0.86 g for varieties Capoverde and Nicaragua respectively, indicating varietal difference. Liberalino et al. (1988) reported that *J. curcas* seed (variety was not mentioned) weighed about 0.75 g. The kernel to shell ratio was 62.7:37.3 for both varieties, indicating that it was not affected by seed size or weight.

3.2. Chemical composition

The chemical composition of kernels and shells of the two varieties (Capoverde and Nicaragua) of *Jatropha* samples are shown in Table 1. *J. curcas* kernel is composed of mainly lipid and protein (lipids + proteins: 805 and 824 g kg⁻¹ respectively for Capoverde and Nicaragua), with very little moisture (< 5%) and ash (< 4%). The gross energy was high (30.7 and 30.5 MJ kg⁻¹ respectively for Capoverde and Nicaragua). The higher crude protein (CP) content observed for Nicaragua kernel (256 g kg⁻¹) than for Capoverde kernel (227 g kg⁻¹) reflected varietal difference. The low moisture

Table 1.
Chemical composition of kernels and shells of two varieties of *Jatropha* samples *

Item	Variety			
	Capoverde		Nicaragua	
	Kernel	Shell	Kernel	Shell
Dry matter (DM, %)	96.6	90.3	96.9	90.4
<i>Analysis, g kg⁻¹ DM:</i>				
Crude protein (CP)	227	43	256	45
Lipid	578	7	568	14
Ash	36	60	36	61
Neutral detergent fiber (NDF)	38 **	839	35 **	858
Acid detergent fiber (ADF)	30 **	746	30 **	756
Acid detergent lignin (ADL)	2 **	451	1 **	475
Gross energy (MJ kg ⁻¹)	30.7	19.3	30.5	19.5

* Kernel to shell ratio (w:w) was 62.7:37.3 for both varieties. ** Calculated from values obtained for lipid-free samples since high lipid content interfered with fiber analyses.

content of the shell (< 10%) and kernel (< 5%) coupled with the fact that the seed has toxic factors appear to be partly responsible for the non deterioration over a long period. A 7-year-old seed sample (Capoverde) contained similar kernel: shell ratio (63:37), and almost similar chemical constituents in the kernel (CP 256 g kg⁻¹, lipid 570 g kg⁻¹ and ash 34 g kg⁻¹) as those observed for fresh kernels. Each kg of Capoverde seed provided 373 g of shell and 605.7 g of dry kernel (62.7% kernel; 96.6% dry matter) which contained about 138 g CP and 350 g lipid. Corresponding values for each kg of Nicaragua seed were 373 g of shell and 607.6 g of dry kernel containing about 156 g CP and 345 g lipid. The shell of *Jatropha* seed is composed of mainly fiber (NDF, 830 g kg⁻¹) with very little protein (< 50 g kg⁻¹), indicating poor nutritional value. But its high gross energy (about 19.5 MJ kg⁻¹) suggests that it could be a good source of fuel.

The chemical composition of *Jatropha* meals and Soyabean meal are shown in Table 2. The CP contents of PD meals were 458 and 466 g kg⁻¹ for Capoverde and Nicaragua, respectively, and these values for defatted samples were 564 and 612 g kg⁻¹. These were higher than the values obtained by Panigrahi et al. (1984) who reported 480 g kg⁻¹ CP for oil free *Jatropha* meal. Commercial Soyabean meal contained lower CP (457 g kg⁻¹) than defatted *Jatropha* meals. The CP content of D Nicaragua meal (612 g kg⁻¹) was also higher than that of D Capoverde meal (564 g kg⁻¹). In most tropical countries where the expeller method is used for oil extraction, residual oil in meals is often up to 150 g kg⁻¹. The PD samples were designed to contain residual lipid (232 and 249 g kg⁻¹ in PD Capoverde and PD Nicaragua meals, respectively) in order to study the effect of heat treatment, on the nutritive and toxic components, in presence of oil. The D *Jatropha* meals contained 90 to 118 g kg⁻¹ ash which were higher than that in Soyabean meal (64 g kg⁻¹). The gross energy content of defatted *Jatropha* meals was similar to that in Soyabean meal (Table 2). The above results show that *Jatropha* meal has a good nutrient profile, comparable with Soyabean meal, with a higher CP than soyabean.

Table 2
Chemical composition of *Jatropha* samples used for various studies

Item	Sample				
	Partially defatted Capoverde meal	Defatted Capoverde meal	Partially defatted Nicaragua meal	Defatted Nicaragua meal	Commercial Soya bean meal
<i>Analysis, g kg⁻¹ DM:</i>					
Crude protein	458	564	466	612	457
Lipid	232	15	249	12	18
Ash	92	96	90	104	64
Neutral detergent fiber (NDF)	70 *	90	62 *	81	172
Acid detergent fiber (ADF)	55 *	70	52 *	68	122
Acid detergent lignin (ADL)	0.3 *	0.4	0.2 *	0.3	0.0
Gross energy (MJ kg ⁻¹)	22.4	18.2	23.1	18.3	19.4

* Calculated from values obtained for lipid-free samples since high lipid content interfered with the analysis.

3.3. Rumen protein degradability

The 24 h in vitro rumen degradable nitrogen (IVDN₂₄) for the PD and D *Jatropha* meals moist heated (67% moisture; 100°C) for 0 to 90 min are shown in Table 3. IVDN₂₄ was higher for PD Capoverde meal (37.7%) than for PD Nicaragua meal (29.5%), reflecting varietal difference. There was an increase in IVDN₂₄, to almost the same level, for PD samples of both varieties at 60 min. For PD Capoverde meal, no further increase in IVDN₂₄ was observed between 60 and 90 min. IVDN₂₄ of D Capoverde meal increased with increasing treatment time to 67.4% in 60 min with no further change at 90 min (Table 3). These showed that 60 min was optimum for this treatment (67% moisture; 100°C). IVDN₂₄ were higher for D Capoverde meal than for PD Capoverde meal at all treatment times, suggesting that the presence of lipid reduced the effect of heat treatment in inducing higher in vitro nitrogen degradability. Similar

Table 3
Effect of moist heating (67% moisture; 100°C) of partially defatted and defatted *Jatropha* meals for various time on 24 h in vitro rumen degradable nitrogen (IVDN₂₄) as a percentage of total nitrogen

Time (min)	Variety		
	Capoverde	Nicaragua	Capoverde
	Partially defatted meal	Partially defatted meal	Defatted meal
0	37.7	29.5	43.3
20	39.1	31.6	40.9
40	44.7	30.9	54.6
60	63.3	64.6	67.4
75	64.8	na	na
90	63.9	na	67.1

na: not analyzed.

Table 4

Effect of moist heating (80% initial moisture) at 130 or 160°C of partially defatted and defatted *Jatropha* meals (Capoverde) for various time on 24 h in vitro degradable nitrogen (IVDN₂₄) as a percentage of total nitrogen

Time (min)	Temperature (°C)			
	130		160	
	Partially defatted meal	Partially defatted meal	Defatted meal	Defatted meal
0	35.8	36.4	43.3	43.3
30	55.2	60.3	73.3	71.9
60	57.8	57.0	73.4	72.1
90	56.3	54.2	74.3	69.1
120	55.1	42.3	73.3	52.8

trends were observed for IVDN₂₄ of other heat treated samples (Table 4, Table 5 and Fig. 1). Table 4 shows the IVDN₂₄ for PD and D Capoverde moist heated (80% initial moisture) at 130 or 160°C for 0 to 120 min. In the 130°C treatment, IVDN₂₄ of PD samples increased with time from 35.8 to 57.8% in 60 min and then decreased slightly with time to 55.1% in 120 min, indicating that 60 min was optimum for this treatment. IVDN₂₄ for the 160°C treated PD samples increased from 36.4 to 60.3% in 30 min and then decreased with time to 42.3% in 120 min, suggesting that 30 min was optimum for this treatment. IVDN₂₄ for the 130°C treated D samples increased from 43.3 to 73.3% in 30 min and remained unchanged thereafter, while those for the 160°C treated D samples increased to 72% at 30 and 60 min, and then decreased with further treatment time to 52.8% in 120 min. The drastic reduction in IVDN₂₄ between 90 min and 120 min observed for the 160°C samples could be attributed to the fact that some dry heating (roasting) occurred in the 120 min treatment which contained 0 and 12.8% moisture respectively for PD and D samples after the treatment as opposed to the 40.0 and 51.5% residual moisture in these samples at 90 min of the treatment. Thus, accumulation of Maillard products was probably higher between 90 and 120 min.

The IVDN₂₄ for the PD and D *Jatropha* meals dry heated at 160°C for 0 to 120 min

Table 5

Effect of dry heating (160°C) of partially defatted and defatted *Jatropha* meals for various time on 24 h in vitro degradable nitrogen (IVDN₂₄) as a percentage of total nitrogen

Time (min)	Variety		
	Capoverde	Nicaragua	Capoverde
	Partially defatted	Partially defatted	Defatted
0	36.5	28.9	43.3
20	36.0	30.7	46.0
40	29.8	29.5	41.4
60	25.8	20.3	37.3
90	21.9	17.1	na
120	23.7	14.7	38.6

na: not analyzed.

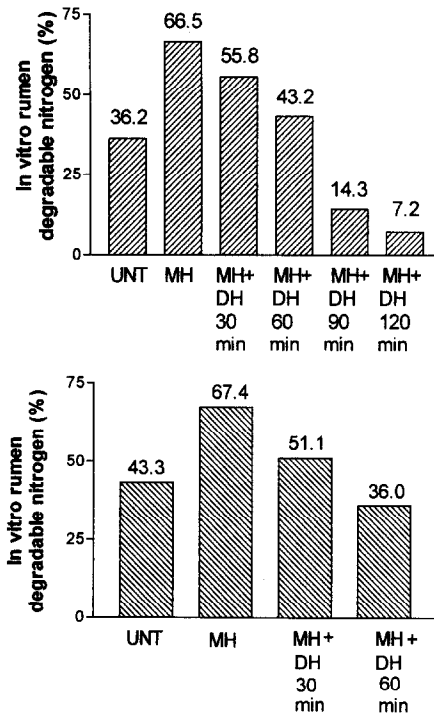


Fig. 1. Effect of moist heating (MH; 67% moisture; 100°C for 60 min) or moist heating followed by dry heating (MH+DH; 160°C for various time) of (a) partially defatted; and (b) defatted Jatropha meal (Capoverde; UNT) on 24 h in vitro rumen degradable nitrogen.

are shown in Table 5. $IVDN_{24}$ decreased with increasing time for PD samples of both varieties from 20 min (36.0 and 30.7% for PD Capoverde and PD Nicaragua meals, respectively) to values of 23.7 and 14.7 for PD Capoverde and PD Nicaragua meals, respectively in 120 min. These probably reflected increased Maillard products with increased dry heating time. $IVDN_{24}$ for D samples also decreased with increasing time up to 60 min. It should be noted that $IVDN_{24}$ values for PD Capoverde meals were higher than those for PD Nicaragua in all treatments, indicating varietal difference. Fig. 1a shows the effect of moist heating or moist heating followed by dry heating for 30 to 120 min on $IVDN_{24}$ of PD Capoverde meal. $IVDN_{24}$ increased sharply from 36.2% in untreated sample to 66.5% in the moist heated sample and then decreased with increased dry heating of the moist heated samples to a value of 7.2% in the moist heated plus 120 min dry heated sample, indicating increased Maillard products with further dry heating of the moist heated samples. A more intense trend of similar nature was observed for the D samples (Fig. 1b).

Knowledge of protein degradability in the rumen is an important tool for predicting the amount of protein passing through the rumen undegraded to the abomasum and small intestine, and for calculating protein utilization and requirements of ruminants. Heat treatment is used to protect proteins from digestion in the rumen. However,

excessive heat treatment may over-protect proteins, making them unavailable for digestion in the abomasum and small intestine (Broderick and Craig, 1980). Our results show that *Jatropha* meals with IVDN₂₄ ranging from 72% (PD Capoverde meal, MH + DH, 120 min, Fig. 1a) to 74.3% (D Capoverde meal, MH, 80% initial moisture, 130°C, 90 min, Table 4) can be produced using various heat treatments. IVDN₂₄ for heat treated Soyabean meal was 80.9% (value not presented in tables/figures). For quinoa seeds (*Chenopodium quinoa* Willd), in vitro rumen protein degradability has been shown to increase initially followed by a decrease with increase in time of heat treatment (Ruales and Nair, 1994). Similar to the present study, roasting of soyabean has also been shown to decrease in vitro rumen protein degradability (Hsu and Satter, 1995). These authors have also shown that roasting increased availability of the proteins at the intestine. Liener (1979) observed that raw Soyabean protein which was resistant to digestion and was available to the animal only after it had been denatured by heat. Van Soest and Mason (1991) reported that heating forages and feeds generated Maillard products of low digestibility which are signalled by a rise in the nitrogen content of acid detergent fiber (ADIN). Recently, Nakamura et al. (1994) have shown that 58% of the ADIN was digestible in non forage plant protein sources, indicating that in these feeds ADIN value predicted more protein damage than that estimated by in vivo nitrogen digestibility values. Similar results have also been obtained by Hussein et al. (1995). In the present study ADIN values varied from 0.6 to 1.0% in the moist heat treated samples and from 2 to 6% in dry heated samples. In light of the observations of Nakamura et al. (1994) and the low values obtained for ADIN suggest that only a very small portion of the protein present in the *Jatropha* samples would not be available to the animals after heat treatments. In accordance with this conclusion is the low pepsin insoluble nitrogen (5 to 6% of the total nitrogen) observed in the moist heated samples, and a slightly higher pepsin insoluble nitrogen in the dry heated samples (8 and 15% respectively for both PD and D Capoverde meals dry heated at 160°C for 60 and 120 min respectively).

3.4. Toxic / antinutritional components

3.4.1. Trypsin inhibitors

Trypsin inhibitor activity (TIA, mg trypsin inhibited per g sample) for the PD and D *Jatropha* meals moist heated (67% moisture; 100°C) for 0 to 40 or 90 min are shown on Fig. 2. PD Capoverde and PD Nicaragua meals contained the same TIA (18.9) which was unaffected by this treatment up to 40 min, indicating the need for further treatment. When PD Capoverde meal was moist heated further, TIA decreased sharply from 19.2 in 40 min to 4.5 in 60 min and then decreased gradually to 2.5 in 90 min. These indicated that 60 min was adequate for lowering TIA of PD samples using this treatment. TIA of D Capoverde meal (21.3) which was higher than that of PD Capoverde meal (18.9) decreased steadily with time from 21.3 in untreated sample to 0.4 in 90 min. Comparison of the data up to 40 min of heating time for PD and D *Jatropha* meals (Fig. 2) revealed that the presence of lipids protect trypsin inhibitors from heat inactivation. Table 6 shows the TIA for PD and D Capoverde meals moist heated (80% initial moisture) at 130 or 160°C for 0 to 120 min. After only 30 min of this treatment, TIA decreased drastically to 4.5 and 3.8 respectively for PD and D samples at 130°C and to

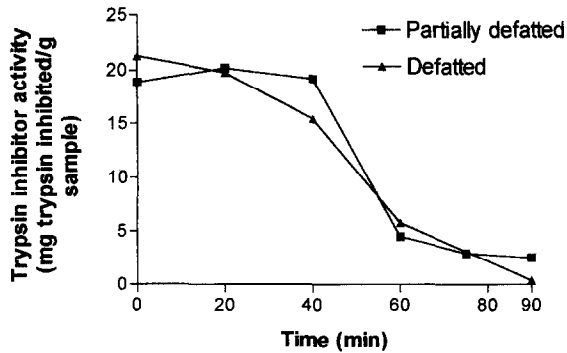


Fig. 2. Effect of moist heating (67% moisture; 100°C) of partially defatted and defatted Jatropha meal (Capoverde) for various time on trypsin inhibitor activity.

1.1 and 0.8 respectively at 160°C, followed by a gradual decrease with time at both temperatures. Thus, trypsin inhibitors in Jatropha meals are quickly inactivated using moist heat at 160°C.

The TIA for the PD and D Capoverde meals dry heated at 160°C for 0 to 120 min are shown on Table 7. TIA for PD samples of both varieties were unaffected by treatment for 20 min. A slight decrease was observed at 40 min (17.2 and 16.7 for PD Capoverde and PD Nicaragua meals, respectively), and it decreased sharply (9.3 and 4.6 for PD Capoverde and PD Nicaragua meals, respectively) at 60 min of the treatment. Further reduction in TIA was observed at 120°C. TIA for D Capoverde decreased steadily with time from 21.3 in the untreated sample to 4.7 in 120 min using dry heating at 160°C (Table 7). TIA values for PD and D samples using dry heat treatment at 160°C were higher than those for moist heated PD and D sample at 160°C (Tables 6 and 7), indicating that trypsin inhibitors in Jatropha meals were more easily inactivated with moist heat than with dry heat. Fig. 3 shows the effect of moist heating or moist heating followed by dry heating for 30, 60 or 120 min on TIA of PD and D Capoverde meals.

Table 6

Effect of moist heating (80% initial moisture) at 130 or 160°C of partially defatted and defatted Jatropha meals (Capoverde) for various time on trypsin inhibitor (TIA) content

Time (min)	Temperature (°C)			
	130		160	
	Partially defatted	Partially defatted	Defatted	Defatted
0	18.9	18.9	21.3	21.3
30	4.5	1.1	3.8	0.8
60	2.9	0.4 *	1.2	0.3 *
90	2.8	0.2 *	1.1	0.2 *
120	2.2	0.1 *	1.1	0.1 *

TIA: Trypsin inhibitor activity expressed as mg trypsin inhibited per g sample. * Percentage inhibition was less than 40% using undiluted extract; see Smith et al. (1980).

Table 7

Effect of dry heating (160°C) of partially defatted and defatted *Jatropha* meals for various periods on trypsin inhibitor (TIA) content

Time (min)	Variety		
	Capoverde	Nicaragua	Capoverde
	Partially defatted	Partially defatted	Defatted
0	18.9	18.9	21.3
20	19.5	19.0	19.0
40	17.2	16.7	17.7
60	9.3	4.6	6.7
120	3.6	1.7	4.7

TIA: Trypsin inhibitor activity expressed as mg trypsin inhibited per g sample.

TIA decreased from 18.9 and 21.3 respectively in the untreated samples to 4.5 and 5.8, respectively in the moist heated samples and to less than 1.5 in samples dry heated for 60 min following the moist heating, indicating that a combination of moist heating (67% moist, 100°C, 60 min) and dry heating (160°C, 60 min) would also inactivate all trypsin inhibitor in *Jatropha* meals beside removing moisture from the meal.

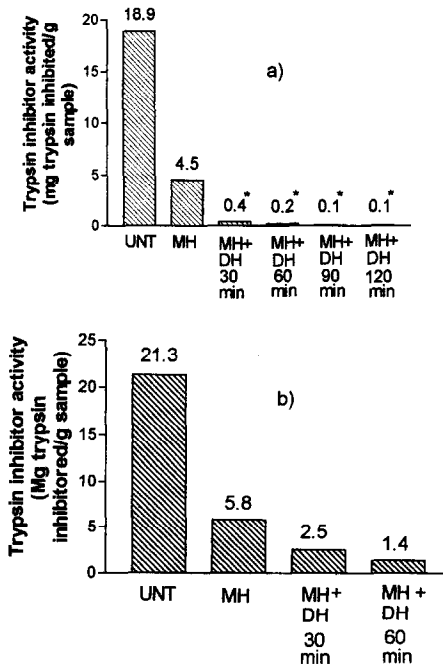


Fig. 3. Effect of moist heating (MH; 67% moisture; 100°C for 60 min) or moist heating followed by dry heating (MH+DH; 160°C for various time) of (a) partially defatted; and (b) defatted *Jatropha* meal (Capoverde; UNT) on trypsin inhibitor activity. (*, Percentage inhibition was less than 40% using undiluted extract; see Smith et al., 1980).

Trypsin inhibitors are antinutritional factors which interfere with the physiological process of digestion through interference with the normal functioning of pancreatic proteolytic enzymes in non ruminants (White et al., 1989), leading to severe growth depression. It is possible that the antinutrient effect of trypsin inhibitors is due to their direct interaction with pancreatic proteolytic enzymes and a corresponding reduction in the digestibility of the proteins of the diet (Hajos et al., 1995). Feed ingredients containing high levels of trypsin inhibitors (such as raw soyabean) are considered to be of little nutritional value to non ruminants. Protease inhibitors did not affect rumen microbial fermentation adversely, however a considerable fraction of ingested protease inhibitor could pass through the rumen to exert its detrimental effects on the host animal (Susmel et al., 1995). Trypsin inhibitors are heat-labile and can be partially or completely denatured when exposed to elevated temperature. Smith et al. (1980) reported TIA values (using the same method as used in the present investigation) of 18.6 to 18.9 for fresh Soyabean meal, 29.1 to 30.2 for Soyabean flour, 23 and 30, respectively for two varieties of defatted Soyabean meal, 2.4 to 2.6 for heat processed Soyabean flour and 2.4 for toasted soybean protein concentrate. We have successfully used heat treatment to inactivate the trypsin inhibitors in *Jatropha* meals. TIA was reduced from 18.9 and 21.3, respectively in the untreated PD and D samples (a) to 4.5 in both the PD Capoverde meal moist heated (67% moisture) at 100°C for 60 min (Fig. 2a) and the PD Capoverde meal moist heated (80% moisture) at 130°C for 30 min (Table 6); (b) to 0.8 in D Capoverde meal moist heated (80% moisture) at 160°C for 30 min (Table 6); (c) to 0.4 in both the D Capoverde samples moist heated (67% moisture) at 100°C for 90 min (Fig. 2b) and in the D Capoverde samples moist heated (67% moisture) at 100°C for 60 min followed by dry heating at 160°C for 30 min (Fig. 3b); and (d) to 3.6 and 4.7 respectively in PD Capoverde and D Capoverde dry heated at 160°C for 120 min. The $IVDN_{24}$ (Tables 3–5, Fig. 1) generally increased with decreasing TIA values (Tables 6 and 7, Fig. 2 and Fig. 3), indicating that the increase in the nitrogen degradability observed on heating could be due to higher proteolytic activity. This increase in the nitrogen degradability could also be due to unfolding of the *Jatropha* proteins due to heat treatment, similar to soya protein (Liener, 1979) making them more susceptible to degradation by proteolytic enzymes. Research is warranted on these lines.

3.4.2. Lectins

Table 8 shows the effect of various heat treatments on lectin content of D Capoverde meal. Lectin content tended to increase with increasing heat treatment. Lectins are known to be heat labile. Higher agglutination observed on heating may be due to: (i) presence of certain factors in *Jatropha* meal which mimic the action of lectin (agglutination of erythrocytes) and that such factors increase with heat treatment; (ii) presence of some moieties (similar to sugars which are known to inhibit action of lectins) in the extract prepared from the unheated *Jatropha* samples which inhibit the action of lectins, and in the heated samples these moieties either become inactivated or bind to some macromolecules, and are not extracted with lectins, thereby showing higher lectin activity in the heat treated samples; (iii) presence of lectins in the bound form (Komarova et al., 1995) in the untreated sample and possible liberation of these lectins by heat treatment. In the present study the lectin activity observed for Soyabean meal

Table 8

Effect of heat treatment (moist heat, MH; dry heat, DH; or moist heat plus dry heat, MH + DH) for various time on lectin content (mg ml⁻¹ of assay mixture which produced agglutination) of defatted *Jatropha* Capoverde meals

Time (min)	Treatment				
	MH, moisture, 100°C	MH, 80% moisture, 130°C	MH, 80% moisture 160°C	DH, 160°C	MH + DH *
0	66.7	66.7	66.7	66.7	66.7
20	50	na	na	50	na
30	na	12.5	12.5	na	12.5
90	6.3	12.5	12.5	na	na
120	na	na	na	6.3	na

* Samples were moist heated (67% moisture, 100°C, 60 min) and then dry heated at 160°C. na: not analyzed.

(12.5 mg ml⁻¹ of assay mixture) was higher than for *Jatropha* samples. However, if the second or third possibility mentioned above are true and the lectins are also being inactivated with heat treatments, the true lectin activity in the unheated *Jatropha* samples would be very high, and this could contribute to the *Jatropha* toxicity. Further studies are warranted to know the true level of lectins and their possible role in *Jatropha* toxicity.

3.4.3. Saponins

D Capoverde meal contained 2.6% total saponins which was slightly higher than that in D Nicaragua meal (2.0%). These were lower than the value of 4.7% in Soyabean meal. Saponins of soyabean are relatively innocuous, and have also been shown not to be haemolytic (Liener, 1979). We also did not detect saponins in the commercially obtained soyabean meal and in any of the *Jatropha* meals by haemolytic assay up to a level of 1.25 mg ml⁻¹ of the assay medium (this level is about 23 to 30 times higher at which diosgenin and quillaja saponins produce 50% haemolysis). None of the heat treatments had any effect on saponin content of *Jatropha* meal (results not shown). These results agree with those of Reddy and Pierson (1994) who have reported that saponins are not destroyed by cooking.

3.4.4. Phytate

The phytate content of D Capoverde meal was 9.4 and those of D Nicaragua meal and Soyabean meal were 10.0 and 1.5% respectively (results not shown). The value obtained for phytate content in the present study for Soyabean agrees well with those compiled in Reddy and Pierson (1994). The phytate content of *Jatropha* meals was much higher than that of peanut presscake (1.36%; Fardiaz and Markakis, 1981). These values suggest presence of high levels of phytate in *Jatropha* samples. These high levels of phytate might decrease bioavailability of minerals. Phytates have also been implicated in decreasing protein digestibility by forming complexes and also by interacting with enzymes such as trypsin and pepsin (Reddy and Pierson, 1994). None of the heat treatments studied decreased phytate level (results not shown).

3.4.5. Tannins, cyanogenic glucosides and amylase inhibitors

Negligible amounts of phenols (0.22 to 0.37%; results not shown in tables/figures) were found in *Jatropha* meals. Tannins, condensed tannins, cyanogenic glucosides and amylase inhibitor activity were not present. Therefore, these were not studied in the heat treated samples.

3.5. Digestible organic matter and metabolizable energy

Table 9 shows the effect of moist heat treatments up to a period of 60 min on the calculated digestible organic matter (DOM, %) and metabolizable energy (ME, MJ kg⁻¹ DM) contents of PD and D *Jatropha* meals. Moist heating increased slightly the DOM and ME of both PD and D samples. ME values were lower for D than for PD samples due to high lipid content of PD samples. PD Nicaragua samples dry heated at 160°C for 20, 40 and 60 min contained 23.5, 24.6 and 23.9% lipid respectively showing no effect of treatment on lipid content. The PD and D Capoverde samples were moist heated (initial moisture 80%) at 130 and 160°C up to 120 min (results not shown). At 130°C, DOM and ME for both PD and D samples did not change from 60 min to 120 min of treatment. However, at 160°C, DOM and ME values for the PD samples decreased by

Table 9

Comparison of digestible organic matter (DOM, %), metabolizable energy (ME, MJ kg⁻¹ DM), 24 h in vitro degradable nitrogen (IVDN₂₄; % total nitrogen), trypsin inhibitor activity (TIA, mg g⁻¹), saponin (% as diosgenin equivalent), lectin * and phytate (%) contents of *Jatropha* meals and soyabean meal

Sample	DOM	ME	IVDN ₂₄	TIA	Saponin	Lectin	Phytate
Partially defatted Capoverde	72.7	14.8	37.7	18.9	na	na	na
Partially defatted Nicaragua	71.0	14.9	29.5	18.9	na	na	na
Defatted Capoverde	78.0	10.9	43.3	21.3	2.6	66.7	9.4
Defatted Nicaragua	78.0	10.7	37.7	21.1	2.0	66.7	10.1
MH Partially defatted Capoverde ^a	74.3	15.1	66.5	4.5	na	50	na
MH Partially defatted Capoverde ^b	72.4	14.7	55.2	4.5	na	na	na
MH Partially defatted Capoverde ^{b'}	73.0	14.8	57.8	2.9	na	50	na
MH Partially defatted Capoverde ^c	75.4	15.3	60.3	1.1	na	na	na
MH Partially defatted Capoverde ^{c'}	73.7	15.0	57.0	0.4	na	50	na
MH Defatted Capoverde ^a	81.0	11.4	67.4	5.8	2.5	12.5	8.7
MH Defatted Capoverde ^b	82.9	11.8	73.3	3.8	2.6	12.5	9.8
MH Defatted Capoverde ^{b'}	81.2	11.5	73.4	1.2	2.6	12.5	9.2
MH Defatted Capoverde ^c	80.3	11.3	71.9	0.8	2.6	12.5	na
MH Defatted Capoverde ^{c'}	80.3	11.3	72.1	0.3 ^e	2.6	12.5	9.4
MH + DH Partially defatted Capoverde ^d	75.5	15.3	55.8	0.4 ^e	na	na	na
MH + DH Defatted Capoverde ^d	76.6	10.7	51.1	2.5	2.5	12.5	9.8
Soyabean meal	87.9	13.3	80.9	3.9	4.7	12.5	1.5

^a Sample was moist heated with 67% moisture at 100°C for 60 min. ^b Samples were moist heated with 80% moisture at 130°C for 30 min. ^{b'} Samples were moist heated with 80% moisture at 130°C for 60 min. ^c Samples were moist heated with 80% moisture at 160°C for 30 min. ^{c'} Samples were moist heated with 80% moisture at 160°C for 60 min. ^d Sample was moist heated (67% moisture; 100°C; 60 min) and then dry heated (160°C; 30 min). ^e Percentage inhibition was less than 40% using undiluted extract. * Minimum amount in mg per ml of the assay which produced agglutination. na: not analyzed.

5.6% units and 1 MJ kg^{-1} respectively from 60 min to 120 min. Similarly for the D sample, heating at 160°C decreased DOM by 6% units and ME by 1 MJ kg^{-1} on increasing treatment time from 60 min to 120 min. These suggest that moist (initial moisture 80%) heat treatment at 130 or 160°C for 30 min was sufficient in enhancing DOM of *Jatropha* meal. The decrease in DOM with time after 60 min observed for the 160°C treatment was probably due to increased Maillard products with increased time. It may be pointed out that residual moisture in PD samples at 130°C treatment was: 77.3, 72.5, 65.4 and 48.2% respectively for 30, 60, 90 and 120 min, while these values at 160°C were: 73.1, 59.1, 40.0 and 0%. Residual moisture in defatted samples at 130°C was: 78.0, 74.5, 69.3 and 58.4% respectively at 30, 60, 90 and 120 min. At 160°C , residual moisture was 51.5 and 12.8% at 90 and 120 min respectively. Residual moisture was higher in defatted samples than in PD samples, suggesting that water evaporated faster in the presence of lipid which might partly account for the reduced effect of moist heat treatment in presence of lipid.

The DOM and ME contents of PD and D *Jatropha* meals dry heated at 160°C for 0 to 120 min were also studied. No change in DOM and ME was observed up to 40 min of heating. At 60 min of heating, a decrease of about 5% and 8% in DOM was observed for D and PD *Jatropha* meals respectively, and at 120 min the decrease was 12% and 15% respectively. The decrease in ME for both D and PD *Jatropha* meals at 60 min and 120 min of heating was 6% and 13% respectively. This decrease in DOM and ME was probably due to increased Maillard products with increased dry heating which also decreased rumen degradability. The increased brownish coloration of the whitish samples with increased time of dry heating was evident. Heat treatment may improve energy release from feed sources, however, excessive heat treatment may lead to over-protection resulting in decreased utilization of nutrients (Ruales and Nair, 1994). Dry heating of the moist heated samples decreased DOM and ME marginally: a decrease of about 6% and 7% in DOM and ME respectively at 60 min of dry heating at 160°C was observed for D *Jatropha* meal; no change was observed for PD *Jatropha* meal. These changes are consistent with a reduction in substrate fermentability imposed by dry heat treatment (Demjanec et al., 1995). DOM and ME for Soyabean meal were: 87.9% and 13.3 MJ kg^{-1} respectively. The highest DOM and ME observed for D *Jatropha* meals were: 82.9% and 11.8 MJ kg^{-1} (D Capoverde, MH, 80% initial moisture, 130°C , 30 min, Table 9); and the highest DOM and ME for PD *Jatropha* meal were: 74.3% and 15.1 MJ kg^{-1} (PD Capoverde, MH, 67% moisture, 100°C , 60 min, Table 9).

4. Conclusions

The results are summarized in Table 9 which shows the comparison of DOM, ME, IVDN₂₄, TIA, sponin, lectin and phytate contents of *Jatropha* meals and soyabean meal.

Unheated *Jatropha* meals are rich in protein but are low in in vitro rumen degradable proteins. There were varietal differences in the rumen degradability of proteins (Capoverde had a higher value compared with the Nicaragua variety). Trypsin inhibitors and phytate contents in *Jatropha* meals were very high. This is the first report showing presence of these two antinutritional components in *Jatropha* meals/seeds. Heat treat-

ment can be used to inactivate trypsin inhibitors and to increase in vitro rumen protein degradability of both defatted and partially defatted *Jatropha curcas* meals. Presence of oil decreased the effect of heat in inactivating trypsin inhibitors and increasing rumen protein degradability. The levels of other antinutritional components (saponins, lectins, phytate) could not be decreased using heat treatments. Based on the results, the treatments suggested for both partially and defatted Capoverde meals when these are to be incorporated in the diets of non ruminants are: (i) moist heating (67% moisture) at 100°C for 60 min; and (ii) moist heating (80% initial moisture) at 130°C for 30 min. For defatted Capoverde meal, the treatment (ii) was slightly better as increase in the in vitro rumen protein degradability was higher and trypsin inhibitor lower. These treatments decrease trypsin inhibitor activity to a level similar to that present in heat treated Soyabean meal used in animal feeds without any harmful effect, and also increase the rumen protein degradability of *Jatropha* meals over two-fold. For ruminants, dry heating alone (160°C for 60 to 120 min) may be advantageous (Demjanec et al., 1995) as besides inactivating trypsin inhibitors it would increase availability of *Jatropha* proteins at the intestine by protecting the proteins from digestion in the rumen. The treatments standardized here have applications both for the industrially defatted *Jatropha* meal which is obtained after extraction of oil using hexane and has a very low residual oil content, and also for the meal obtained using expeller and screw-press which has residual oil level up to 15%. It is interesting to note that shells, a by-product in the process of obtaining *Jatropha* meal, has a high gross energy and therefore is a good source of fuel, which can be used for the heat treatments thereby reducing their cost. There is a need for feeding trials to evaluate the toxicity and nutritive value of heat treated *Jatropha* meals.

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