# Studies on Nutritive Potential and Toxic Constituents of Different Provenances of *Jatropha curcas*

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Eighteen different provenances of *Jatropha curcas* from countries in West and East Africa, North and Central America, and Asia were characterized for nutrient and antinutritional factors. The mean weight of the 18 seed provenances was 0.64 ± 0.10 g (mean ± sd). The kernel forms a large proportion of the seed and accounts for 61.3% ± 3.1%. There were large variations in the contents of CP (19−31%; 26.0% ± 3.2%), lipid (43−59%; 53.0% ± 4.8%), neutral detergent fiber (3.5−6.1%; 5.0% ± 0.87%), and ash (3.4−5.0%; 4.2% ± 0.52%) in kernels. The gross energy of kernels was relatively similar (28.5−31.2 MJ/kg; 30.1 ± 0.80 MJ/kg). Trypsin inhibitor activity in the defatted kernels (meal) varied from 18.4−27.5 mg of trypsin inhibited/g. Similarly a wide variation was observed for saponins (1.8%−3.4% as diosgenin equivalent), phytate (6.2%−10.1% as phytic acid equivalent), and lectin activity, inverse of minimum amount of the sample in milligrams per milliliter of the assay which produced agglutination (0.85−6.85 using a latex agglutination test and 51.3−204 using a hemagglutination assay) in the meals. Tannins, amylase inhibitor, glucosinolates, and cyanogens were not detected in any of the meals. Phorbol esters were not detected in the seeds collected in Papantla, Mexico, whereas the level of phorbol esters in the remaining 17 provenances ranged from 0.87 to 3.32 mg/g of kernel.

**Keywords:** *Jatropha curcas; physic nut; nutrients; trypsin inhibitor; lectins; phorbol esters; phytate*

## INTRODUCTION

*Jatropha curcas*, commonly known as physic nut, purging nut, pinoncillo, Habb-El-Mueluk, black vomit nut, Barbados purging nut, big purge nut, bagbherebdra, ratanjyoti, etc., belongs to the Euphorbiaceae family. It grows quickly, survives in poor stony soils, and is resistant to drought and diseases, reaches a height of 3−8 m, and can be grown on wastelands or barren and marginal agricultural lands where no irrigation facility is available. It does not compete with conventional food or feed crops for land and water, and thus it could be an ideal choice to make use of vast land resources that are presently underutilized. In tropical countries it is well-known for its medicinal properties and as an oilseed. It is also used as a live hedge (not browsed by livestock) and is propagated using branch cuttings or by direct seeding (Heller, 1996).

The seed resembles the castor seed in shape, but is smaller in size and of dark brown color. The seed yield is up to 5 tons/hectare (Heller, 1996). The kernel contains up to 60% oil. The oil is used for illumination (it burns without emitting smoke) and as a lubricant and for making soaps, candles, and varnish. It can also serve as fuel for diesel engines. The oilseed cake (left after extraction of oil) is presently used as a fertilizer, but it has potential to be used as livestock feed as it is rich in crude protein (50−58% depending on the residual oil). The levels of essential amino acids except lysine in *J. curcas* meal protein is higher than those of the FAO reference protein for a growing child of 2−5 years (Makkar and Becker, 1997a). However, both seed and oil have been found to be toxic (Heller, 1996; Aderibigbe et al., 1997). There could be an enormous amount of variation in secondary plant metabolites or toxic components (Kakes, 1991) and also in nutrients which may be caused by genetic differences or by the environment. The objective of this study was to investigate the nutritive potential and toxic constituents of different provenances of *J. curcas*, originating from different parts of the world. It is hoped that the information generated will be useful for breeding programs aimed at yielding varieties of nontoxic or lesser toxic in nature, and also will give insight into the toxic principle of *J. curcas* seeds.

## MATERIALS AND METHODS

Table 1 shows the origin of the seed provenances used and the corresponding climatic data. The provenances originated from different countries in West and East Africa, North and Central America, and Asia. Among the 18 different samples investigated, 16 were wild varieties collected from different places and the other two were the Cape Verde and Nicaragua varieties cultivated in Nicaragua. Presently, about 1000 ha of plantation of these two varieties (mainly the Cape Verde because of its higher yield) exists in Managua, Nicaragua. The oil after transesterification is being used for running diesel engines.

**Physical Characteristics of Seeds.** Ten handfuls of seeds were randomly taken from each provenance. The average weight of the seeds was calculated by dividing the total weight by the total number of seeds. These seeds were cracked, the shells carefully removed, and the weight of the kernels and shells recorded.

**Chemical Analyses.** *Nutrients.* The kernels were ground and then analyzed for dry matter (DM), crude protein (CP), lipid, and ash using the AOAC (1980) procedure. Neutral

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**Table 1. Origin of Seed Provenances and Climatic Data of Collecting Sites**

| serial no. | origin | altitude (m) | av temperature (°C) | av annual rainfall (mm) |
|---|---|---|---|---|
| 1 | Cape Verde, Fogo | 150−1600 | 21 | 600 |
| 2 | Senegal, Santhie Ram | 15 | 28 | 700 |
| 3 | Senegal, Nioro du Rip | 15 | 28 | 700 |
| 4 | Ghana, Nyankpala | 183 | 278 | 1080 |
| 5 | Benin, Cotonou | 7 | 253 | 1330 |
| 6 | Burkina Faso, Kongoussi | 300 | ? | 520 |
| 7 | Kenya, Kitui | 1020 | 28 | 790 |
| 8 | Tanzania, Mombo | 430 | >20 | 670 |
| 9 | Burma, Sink Gaing, Mandalay | 80 | 27 | 825 |
| 10 | India, Kangra | 580 | 181 | 2500 |
| 11 | India, Kangra | 434 | 245 | 2200 |
| 12 | Costa Rica, Rio Grande | 10 | 275 | 2000 |
| 13 | Mexico, Veracruz | 16 | 248 | 1623 |
| 14 | India, Nasik | 700 | 24 | 450 |
| 15 | Nicaragua (Cape Verde variety cultivated in Managua) | 30 | 31 | 1200 |
| 16 | Nicaragua (Nicaragua variety cultivated in Managua) | 30 | 31 | 1200 |
| 17 | Nigeria, Ife | 400 | 265 | 1600 |
| 18 | Mexico, Papantla | 298 | 24 | 1170 |

[a] Data for provenances in serial nos. 1−13 taken from Heller (1996).

detergent fiber (NDF) was determined as described by Van Soest et al. (1991). Gross energy was determined using a bomb calorimeter.

*Antinutrients.* The kernels were ground and defatted using a Soxhlet-type extractor. The defatted kernel (meal) samples were analyzed for tannins (Makkar et al., 1993), trypsin inhibitor (Smith et al., 1980), amylase inhibitor (Bernfeld, 1955), saponins (Hiai et al., 1976), phytate (Vaintraub and Lapteva, 1988), and cyanogens (Essers et al., 1993). Lectin was quantified using a haemagglutination test using cattle erythrocytes after trypsinization (Gordon and Marquardt, 1974) and also by the latex (ovalbumin adsorbed) agglutination method (Kaul et al., 1991). Both these lectin assays were conducted in the presence of 10 mM $Mn^{2+}$. Lectin activity has been expressed as inverse of minimum amount of the sample in milligrams per milliliter of the assay which produced agglutination. Glucosinate content was determined by the method of Heaney et al. (1988) as described in Makkar and Becker (1997b). The details of other methods are available in Aderibigbe et al. (1997).

*Quantification of Phorbol Esters.* Five seeds of each variety were weighed and ground with a small amount of sand using a pestle and mortar, and then 20 mL of dichloromethane was added. The mixture was ground again for about 5 min with the mortar. The material was allowed to settle, and the liquid phase was filtered. The residue on the filter paper and in the pestle were pooled using about 20 mL of dichloromethane and then ground for about 5 min using the mortar. The liquid phase was again collected. This extraction procedure was repeated three more times and the filtrate from all five extractions were pooled. The residue (sand plus kernels) was subjected to ultrasonic waves (105 W) for 3 min in the presence of about 50 mL of dicholoromethane. It was then filtered, and this filtrate was pooled with the pooled filtrates from the previous five extractions. The filtrate was dried under vacuum at 40 °C. The dried residue was dissolved in 5 mL of tetrahydrofuran, passed through a 0.2 $\mu$m glass filter, and injected (20 $\mu$L) into the HPLC.

*HPLC Conditions for Quantification of Phorbol Esters.* The HPLC equipment used consisted of a Hewlett Packard 1050 HPLC pump, a Hewlett Packard 1040A photo diode array detector, and a Spark Holland-Basic Marathon autosampler. The analytical column was reverse phase C18 (LiChrospher 100, endcapped 5 $\mu$m; Merck) 250 × 4 mm i.d. (Lichrocart; Merck) protected by a guard column containing the same material as in the main column. Three solvents were used: (A) 1.75 mL of *o*-phosphoric acid (85%) in 1 L of distilled water, (B) acetonitrile, and (C) tetrahydrofuran. Solvent A was filtered before use, and solvents B and C were of HPLC and analytical grade and used without filteration. All solvents were degassed by ultrasonication and by application of vacuum. The gradient used was as follows: 60% A and 40% B at start, decrease A to 50% and increase B to 50% in the next 10 min, decrease A to 25% and increase B to 75% in the next 30 min, increase B to 100% in the next 15 min. Then the column is washed with C by increasing C to 100% in the next 15 min, and then the column is adjusted to the starting conditions (60% A and 40% B). Separation was performed at room temperature (ca. 22 °C), and the flow rate was 1.3 mL/min. Phorbol esters (four in number) appeared between 41 and 48 min (Adolf et al., 1984; Hirota et al., 1988). The peaks were integrated at 280 nm, and the results are expressed as equivalent to phorbol-12-myristate 13-acetate (obtained from Sigma), which appeared between 52 and 53 min.

Each analysis was conducted at least in duplicate. The results are presented as mean ± SD.

## RESULTS

**Physical Characteristics.** The physical characteristics of different provenances are presented in Table 2. There was wide variation in the mean seed weight viz. 0.49 g for the provenance from Fogo, Cape Verde, to 0.86 g for Nicaraguan variety cultivated in Managua, Nicaragua. The mean seed weight of the 18 different seed provenances was 0.64 ± 0.10 g. The variation in the weight of kernel as percent of the seed weight (53.9−64%; 61.3% ± 3.1%) was not as large as for the seed weight. The kernel forms a large proportion of the seed.

**Chemical Composition.** The chemical composition of kernels from different provenances is presented in Table 3. There was a large variation in the contents of CP (19−31%; 26.0% ± 3.2%), lipid (43−59%; 53.0% ± 4.8%), neutral detergent fiber (3.5−6.1%; 5.0% ± 0.87%), and ash (3.4−5.0%; 4.2% ± 0.52%). The gross energy of kernels was relatively similar (28.5−31.2 MJ/kg; 30.1 ± 0.80 MJ/kg). Digestible organic matter (DOM) and metabolizable energy (ME) were estimated (results not shown in the table) for the two cultivated varieties (Cape Verde and Nicaragua) and for the nontoxic provenance from the 24 h of gas production and chemical composition studies according to the method of Menke et al. (1979). The DOM percentages of the meal (oil-free) of Cape Verde and Nicaragua varieties and for nontoxic provenances were 78.0%, 78.0%, and 78.4% and the ME values were 10.9, 10.7, and 10.8 MJ/kg, respectively.

**Toxic/Antinutritional Components.** The results for these components are presented in Table 4. Trypsin inhibitor activity in the defatted kernels (meal) varied from 18.4 to 27.5 mg of trypsin inhibited/g of DM. Similarly wide variations were observed for saponins

**Table 2. Physical Characteristics of 18 Different Seed Provenances**

| serial no. | origin | av seed wt (g) | kernel wt (% of seed) | shell wt (% of seed) |
|---|---|---|---|---|
| 1 | Cape Verde, Fogo | 0.490 | 62.2 | 37.8 |
| 2 | Senegal, Santhie Ram | 0.625 | 58.0 | 42.0 |
| 3 | Senegal, Nioro du Rip | 0.658 | 61.8 | 38.2 |
| 4 | Ghana, Nyankpala | 0.571 | 55.1 | 44.9 |
| 5 | Benin, Cotonou | 0.725 | 64.0 | 36.0 |
| 6 | Burkina Faso, Kongoussi | 0.658 | 58.9 | 41.1 |
| 7 | Kenya, Kitui | 0.543 | 62.2 | 37.8 |
| 8 | Tanzania, Mombo | 0.500 | 64.2 | 35.8 |
| 9 | Burma, Sink Gaing, Mandalay | 0.649 | 65.7 | 34.3 |
| 10 | India, Kangra | 0.545 | 53.9 | 46.1 |
| 11 | India, Kangra | 0.658 | 62.0 | 38.0 |
| 12 | Costa Rica, Rio Grande | 0.592 | 60.9 | 39.1 |
| 13 | Mexico, Veracruz | 0.833 | 61.8 | 38.2 |
| 14 | India, Nasik | 0.699 | 62.9 | 37.1 |
| 15 | Nicaragua (Cape Verde variety cultivated in Managua) | 0.690 | 62.7 | 37.3 |
| 16 | Nicaragua (Nicaragua variety cultivated in Managua) | 0.860 | 62.7 | 37.3 |
| 17 | Nigeria, Ife | 0.530 | 60.0 | 40.0 |
| 18 | Mexico, Papantla | 0.650 | 63.5 | 36.5 |

**Table 3. Chemical Composition of Kernels from Different Seed Provenances (Data Are on DM Basis)**

| serial no. | origin | crude protein (%) | lipid (%) | neutral detergent fiber (%)[a] | ash (%) | gross energy (MJ/kg) |
|---|---|---|---|---|---|---|
| 1 | Cape Verde, Fogo | 25.6 | 55.5 | 4.7 | 3.4 | 30.7 |
| 2 | Senegal, Santhie Ram | 25.1 | 50.7 | 5.62 | 4.5 | 29.5 |
| 3 | Senegal, Nioro du Rip | 28.9 | 46.7 | 5.4 | 4.4 | 29.5 |
| 4 | Ghana, Nyankpala | 31.1 | 42.9 | 6.1 | 4.7 | 28.5 |
| 5 | Benin, Cotonou | 30.1 | 48.2 | 6.1 | 4.8 | 29.4 |
| 6 | Burkina Faso, Kongoussi | 28.1 | 51.0 | 5.3 | 4.2 | 29.6 |
| 7 | Kenya, Kitui | 25.0 | 52.6 | 5.8 | 3.4 | 29.8 |
| 8 | Tanzania, Mombo | 29.3 | 47.2 | 4.4 | 4.9 | 28.9 |
| 9 | Burma, Sink Gaing, Mandalay | 29.6 | 50.0 | 5.7 | 3.9 | 29.9 |
| 10 | India, Kangra | 24.1 | 58.4 | – | 4.1 | 30.7 |
| 11 | India, Kangra | 23.2 | 55.0 | 4.5 | 4.4 | 30.4 |
| 12 | Costa Rica, Rio Grande | 19.0 | 59.1 | – | 4.5 | 31.2 |
| 13 | Mexico, Veracruz | 23.7 | 56.6 | 5.5 | 3.6 | 30.7 |
| 14 | India, Nasik | 23.0 | 54.8 | 5.4 | 3.8 | 31.2 |
| 15 | Nicaragua, (Cape Verde variety cultivated in Managua) | 22.2 | 57.8 | 3.8 | 3.6 | 30.7 |
| 16 | Nicaragua, (Nicaragua variety cultivated in Managua) | 25.6 | 56.8 | 3.5 | 3.6 | 30.5 |
| 17 | Nigeria, Ife | 27.7 | 53.9 | 4.1 | 5.0 | 29.7 |
| 18 | Mexico, Papantla | 27.2 | 58.5 | 3.8 | 4.3 | 31.1 |

[a] Calculated from values obtained for fat free samples since high lipid content interferred with fiber determination; α-amylase treatment was also used.

**Table 4. Levels of Trypsin Inhibitor, Lectin, Saponin, and Phytate in Defatted Kernels of Different Seed Provenances[a]**

| serial no. | origin | trypsin inhibitor activity[b] | lectin activity[c] | saponins (%)[d] | phytate (%)[e] |
|---|---|---|---|---|---|
| 1 | Cape Verde, Fogo | 27.3 | 0.85 (102) | 1.82 | 7.2 |
| 2 | Senegal, Santhie Ram | 23.6 | 0.85 (102) | 2.21 | 8.2 |
| 3 | Senegal, Nioro du Rip | 21.6 | 0.85 (102) | 1.98 | 8.1 |
| 4 | Ghana, Nyankpala | 22.2 | 6.85 (102) | 2.25 | 7.8 |
| 5 | Benin, Cotonou | 21.8 | 0.85 (204) | 2.04 | 8.4 |
| 6 | Burkina Faso, Kongoussi | 22.8 | 0.85 (102) | 1.91 | 8.2 |
| 7 | Kenya, Kitui | 24.9 | 0.85 (204) | 2.67 | 6.2 |
| 8 | Tanzania, Mombo | 24.4 | 0.85 (102) | 2.58 | 8.6 |
| 9 | Burma, Sink Gaing, Mandalay | 25.3 | 0.85 (102) | 2.04 | 7.5 |
| 10 | India, Kangra | 27.5 | 6.85 (51.3) | 2.02 | 8.2 |
| 11 | India, Kangra | 24.7 | 6.85 (51.3) | 2.39 | 8.2 |
| 12 | Costa Rica, Rio Grande | 26.3 | 6.85 (102) | 2.72 | 9.6 |
| 13 | Mexico, Veracruz | 24.5 | 6.85 (102) | 2.06 | 8.6 |
| 14 | India, Nasik | 24.7 | 0.85 (102) | 2.01 | 8.6 |
| 15 | Nicaragua (Cape Verde variety cultivated in Managua) | 21.3 | 2.88 (102) | 2.6 | 9.4 |
| 16 | Nicaragua, (Nicaragua variety cultivated in Managua) | 21.1 | 2.88 (102) | 2.0 | 10.1 |
| 17 | Nigeria, Ife | 18.4 | | 2.0 | 7.2 |
| 18 | Mexico, Papantla | 26.5 | 1.70 (51.3) | 3.4 | 8.9 |

[a] Tannins, amylase inhibitor, glucosinolates, and cyanogens were not detected. [b] mg of trypsin inhibited/g of DM. [c] Inverse of minimum amount of the sample in mg per mL of the assay which produced agglutination; values in parentheses have been observed using erythrocytes, and those outside parentheses are using the latex. [d] As diosgenin equivalent. [e] As phytic acid equivalent.

(1.8%−3.4% as diosgenin equivalent), phytate (6.2%−10.1% as phytic acid equivalent), and lectin activity (0.85−6.85 using haemagglutination assay and 51.3−204 using latex agglutination test) in the meal. There was a weak correlation ($r = 0.41$, $n = 18$) between lectin values obtained by the latex and the haemagglutination assays. Seeds collected from Kangra in India were from one of the four sites that had the highest lectin activity by the latex agglutination assay, but the same sample had one of the two lowest lectin activities by the

**Table 5. Levels of Phorbol Esters in Seed Kernels of Different Provenances**

| serial no. | origin | phorbol esters (mg/g)[a] peak 1 | peak 2 | peak 3 | peak 4 | total |
|---|---|---|---|---|---|---|
| 1 | Cape Verde, Fogo | 0.77 | 0.32 | 0.24 | 0.17 | 1.50 |
| 2 | Senegal, Santhie Ram | 1.15 | 0.47 | 0.40 | 0.25 | 2.27 |
| 3 | Senegal, Nioro du Rip | 0.87 | 0.36 | 0.27 | 0.19 | 1.69 |
| 4 | Ghana, Nyankpala | 0.69 | 0.30 | 0.18 | 0.12 | 1.29 |
| 5 | Benin, Cotonou | 0.81 | 0.40 | 0.28 | 0.22 | 1.71 |
| 6 | Burkina Faso, Kongoussi | 0.97 | 0.31 | 0.26 | 0.17 | 1.71 |
| 7 | Kenya, Kitui | 1.80 | 0.64 | 0.53 | 0.35 | 3.32 |
| 8 | Tanzania, Mombo | 0.66 | 0.18 | 0.17 | 0.11 | 1.12 |
| 9 | Burma, Sink Gaing, Mandalay | 0.53 | 0.14 | 0.12 | 0.08 | 0.87 |
| 10 | India, Kangra | 0.67 | 0.25 | 0.21 | 0.15 | 1.28 |
| 11 | India, Kangra | 0.59 | 0.20 | 0.18 | 0.12 | 1.10 |
| 12 | Costa Rica, Rio Grande | 0.82 | 0.06 | 0.18 | 0.09 | 1.15 |
| 13 | Mexico, Veracruz | 0.55 | 0.19 | 0.17 | 0.11 | 1.02 |
| 14 | India, Nasik | 0.88 | 0.36 | 0.30 | 0.22 | 1.76 |
| 15 | Nicaragua (Cape Verde variety cultivated in Managua) | 1.61 | 0.47 | 0.37 | 0.25 | 2.70 |
| 16 | Nicaragua, (Nicaragua variety cultivated in Managua) | | | | | 2.17 |
| 17 | Mexico, Papantla | nd[b] | nd | nd | nd | nd |

[a] As phorbol-12-myristate 13-acetate equivalent. [b] nd, not detected.

hemagglutination assay (Table 4). In the latex agglutination assay, a glycoprotein ovalbumin was adsorbed onto the latex beads. A weak correlation between the values obtained by the latex and erythrocyte agglutination assays could be due to different affinities of *J. curcas* lectins to ovalbumin and various binding sites on the surface of trypsinized cattle erythrocytes. Tannins, amylase inhibitor, glucosinolates, and cyanogens were not detected. Phorbol esters were not detected in the seeds collected from Papantla, Mexico, whereas a highest level of 3.32 mg/g of kernel was observed in the Kenyan sample. There are at least four phorbol esters in *J. curcas*, the proportion of which substantially differed in different provenances (Table 5). These phorbol esters have not yet been chracterized, neither information on their relative toxicity is available.

## DISCUSSION

The seeds from *J. curcas* have been reported to be toxic to humans, rodents and livestock (Heller, 1996; Ghandi et al., 1995). Reports on the accidental intoxication of humans by ingestion of oil or seeds have appeared in Hawaii, Florida, and Philippines. The symptoms of intoxication in humans were burning and pain in the mouth and throat, vomiting, delirium, muscle shock, decrease of visual capacity, and a high pulse (Kingsbury, 1964). A high mortality rate has been reported for rodents (mice, rats) and domestic animals (sheep, goats, calves, and chicks) on feeding *J. curcas* seeds (Adam and Magzoub, 1975; Ahmed and Adam, 1979a,b; Liberalino, 1988; El Badwi, 1992, 1995; Ghandi et al., 1995). It has been suggested that there are two strains of *J. curcas*, one with toxic seeds and the other with nontoxic seeds (Kingsbury, 1964). In the present study, the seeds obtained from Papantla in Mexico were nontoxic. Using meal (oil-free) from these seeds, our feeding studies with rats and fish established that this meal is nontoxic whereas the meal from the Cape Verde and Nicaragua cultivated varieties is toxic (H. P. S. Makkar, and K. Becker, unpublished observations).

The contents of crude protein, lipid, gross energy, ME, and DOM of the nontoxic provenance from Papantla in Mexico were comparable to those of the toxic varieties (Cape Verde and Nicaragua) and of other provenances (Table 3). The amino acid composition of meals from the nontoxic provenance and the Cape Verde and Nicaragua varieties were also similar. The levels of essential amino acids except lysine were comparable with that of the FAO reference proteins (Makkar and Becker, 1997a). These results suggested that the nontoxic provenance from Papantla in Mexico is of as good a quality as the toxic provenances/varieties. Values for crude protein (63.8%), ME (10.7 MJ/kg), and DOM (77.3%) of the nontoxic meal equal those for the best oil cakes or expeller. The results suggest that *J. curcas* meal from this nontoxic provenance could be a good source of protein for both livestock and humans. The oil extracted from kernels of this nontoxic provenance might also be used for human consumption. However, further toxicological studies must be carried out before it can be recommended for human consumption because it might contain traces of phorbolesters and other antinutrients.

Among antinutritional/toxic factors, differences between toxic and nontoxic varieties were recorded only for phorbol esters, which were present in high concentrations in the toxic seeds but absent in the nontoxic seeds (Table 4). Lectin is generally considered to be another toxic factor in *J. curcas* seeds (Mourgue et al., 1961; Stirpe et al., 1976; Cano et al., 1989), but the lectin activity in the meal was slightly lower (1.70 vs 2.88 by the latex agglutination assay and 51 vs 102 by the haemagglutination assay) in the nontoxic provenance than in the toxic provenances, which does not support this contention. The lectin assays used in the present study are based on agglutination of latex and erythrocytes by serially diluted extracts of the sample. This implies that values of 1.70 and 2.88 by the latex agglutination and 51 and 102 by the haemagglutination methods are separated by a maximum of only one dilution and therefore are not much different from each other. The lectin (curcin) of *J. curcas* seeds has been reported to be much less toxic than the well-known lectins, ricin and abrin (Mourge et al., 1961; Oslnes and Phil, 1973). Trypsin inhibitor activity in *J. curcas* meals is very high (Table 4). Smith et al. (1980) reported trypsin inhibitor values (using the same method as used in the present investigation) of 18.6−30 mg of trypsin inhibited/g of fresh/raw soyabean meals which play an important role in protection of this plant, and the consumption of raw/fresh soyabean meal is known to produce adverse effects in animals. The phytate level in jatropha meals was also high (6.2%−10.1%). The phytate content of soyabean meal and peanut presscake

has been reported to be 1.5% and 1.4%, respectively (Aderibigbe et al., 1997). Phytate level is not affected by heat treatments. The high level of phytate present in jatropha meals might decrease the bioavailability of minerals (especially $Ca^{2+}$ and $Fe^{2+}$). 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). Phorbol esters have been found to be responsible for purgative and skin-irritant effects and for tumor promotion since they stimulate protein kinase C which is involved in signal transduction and developmental processes of most cells and tissues (Adolf et al., 1984; Hirota et al., 1988). Ingestion of plants from the Euphorbiaceae and Thymelaeaceae families that biosynthesize diterpene esters of the phorbol type cause severe symptoms of toxicity in livestock (Kingsbury, 1964). The results of the present study demonstrated that the toxicity of *J. curcas* seeds could be attributed to phorbol esters present in toxic provenances/varieties. Furthermore, the presence of high levels of lectins, trypsin inhibitors, and phytate might aggravate adverse effects but do not contribute to the short term toxicity. The nontoxic strain of *J. curcas* could be a suitable alternative to the toxic provenances/varieties, and its cultivation in different climatic zones is recommended. Presence of high levels of antinutritional factors such as trypsin inhibitors, lectin, and phytate in the nontoxic provenance (Table 4) is likely to provide resistance to this strain, and it is expected that it would survive and yield seeds under adverse conditions. Trypsin inhibitors and lectins are heat labile, and their adverse effects could therefore be mitigated by heat treatments before the meal or seeds from the nontoxic provenance are consumed by livestock or humans.

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