Available online at www.elixirpublishers.com (Elixir International Journal)

Food Science

Elixir Food Science 68 (2014) 22683-22687

ISSN: 2229-712X

Comparative evaluation of nutritive values of seeds, kernels and defatted products of indigenous *Jatropha Curcas* cultivated in Ghana as possible feed source for livestock

Chikpah Solomon K* and Bawa Demuyakor

Department of Biotechnology, Faculty of Agriculture, University for Development Studies, Box TL 1882, Tamale, Ghana.

ARTICLE INFO

Article history:

Received: 1 November 2013;

Received in revised form:

15 March 2014;

Accepted: 26 March 2014;

Keywords

Jatropha curcas,

Correlation,

Nutritive values,

Physical parameters

ABSTRACT

The study was conducted to compare the nutritive values of *Jatropha curcas* seeds and kernels and the defatted products as well as to determine the correlation between the physical parameters of seeds/kernels and the chemical compositions. Jatropha seeds were collected from four different parts of Ghana where the plant is popularly grown (1. Nyankpala, Northern Region; 2. Wa, Upper West Region; 3. Dambai, Volta Region; and 4. Techiman, Brong Ahafo Region). The seeds were harvested in November, 2012 and the physical parameters of 1000 seed samples were determined. Jatropha seeds and kernels were also defatted to obtain seed and kernel meals respectively. The average whole seed and kernel weights were 0.69 ± 0.04 g and 0.43 ± 0.02 g respectively. The percentage kernel and shell of whole seed weight were in the ranges 61.19 - 62.74 % and 37.26 - 38.81 % respectively. The Kernels were significantly high ($P < 0.05$) in crude protein, CP (24.56 ±0.45 %) and lipid (56.14 ± 0.28 %) as compared to the whole seed CP (18.66 ± 0.11 %) and lipid (38.09 ± 0.29 %) respectively. The crude fibre was however significantly higher ($P < 0.05$) in the whole seed (15.70 ± 0.60 %) than the kernel (4.52 ± 0.26 %). The kernel weight had strong positive correlation with lipid value (correlation coefficient, r = 0.862) whereas shell weight showed strong negative correlation with CP and, lipid contents (r = - 0.857 and -0.759 respectively). More also, shell weight showed strong positive correlation with crude fibre content (r = 0.935). The *J. curcas* whole seeds contained significantly high ($P < 0.05$) amounts of antinutritional factors like crude phorbol ester (CPE), tannins and phytic acid as compared to the kernel. The *J. curcas* whole seed meal (WSM) and kernel meal (KM) varied in their nutritional compositions. The KM was very rich in crude protein, CP (64.04 ± 0.16 %) as compared to the WSM (28.60 ± 0.32 %). However, the crude fibre content was significantly low ($P < 0.05$) in the KM (6.79 ± 39 %) than the WSM (22.96 ± 51 %). The antinutritional factors were also higher in the WSM than the KM. The phytic acid value was significantly higher ($P < 0.05$) in WSM (9.45 %) than the KM (8.70 %). The CPE concentrations in both WSM (5.92 mg/g) and KM (5.55 mg/g) did not vary significantly ($P > 0.05$). The tannic acid concentration was however higher in the WSM (0.83 % tannic acid equivalent) while the value in the KM was negligibly lower (0.07 % tannic acid equivalent). The two Jatropha meal types (WSM and KM) contained considerable amounts of macro-minerals like phosphorus, potassium, calcium and magnesium. The correlations found between some physical parameters (kernel and shell weights) and nutritional characteristics of whole seed and kernels and their respective meal types (WSM and KM) show that some of these parameters could be used as indicators to predetermine both quality and process requirements for Jatropha seeds for use as animal feed.

Introduction

In Ghana, cultivation of cereal crops such as maize and sorghum and rearing of livestock are encouraged as measures to ensure food security. The challenge with livestock production is that open pastoral grazing is practiced with its consequential socio-ecological negative impacts. Intensive or semi-intensive system is the alternative, but the major constrained is feeding which constitutes about 60 % of the cost of production. More also the animals compete with humans for the already limited supply of cereals and other grains as energy feeds which are main staple foods for the people of Ghana. Fish meal (FM) and soybean meals are generally utilized in poultry and fish feeds as the main sources of dietary protein. However in Ghana, these feed products are sometimes imported which makes them expensive for most farmers to afford and hence negatively affects the growth of the livestock industry. In recent years, due to the increasing cost, decreasing availability in the demanding market and poor quality of fish meal (FM) and soybean meal required, several researches must be carried out on other inexpensive protein sources which would be beneficial in reducing feed cost (Kaushik *et al*., 1995; Fournier *et al*., 2004; SOFIA, 2007). For these reasons, *Jatropha curcas* which was initially investigated for biodiesel production has also been found to have the potentials for use as feed for animals. The seeds of *Jatropha* is reported to contain 6.62 % moisture; protein (18.2 %); lipid (38.0 %); carbohydrates (17.3 %); fibre

Tele:

E-mail addresses: schikpah@uds.edu.gh

(15.5 %); and 4.5% ash (Gübitz *et al*., 1999). The kernel is composed mainly of lipid (53.9 – 58.5 %) and proteins (22.2-27.7 %), with very little moisture (< 6 %) and ash. The shell of *Jatropha curcas* seed is composed mainly of fiber with very little (< 6 %) protein (Makkar *et al*., 1998). Four (4) tons of Jatropha seeds can produce approximately 1 ton of kernel meal rich in protein (Makkar and Becker, 1997). The seed kernel contains about 60% oil (Makkar *et al*., 2007), which consist of 21 % and 79 % saturated fatty acids and unsaturated fatty acids respectively (Raja *et al*., 2011). The seed cake left as a by-product after oil extraction from whole seed by screw press has approximately, 22 % crude protein and high content (50%) indigestible shells (Makkar and Becker, 2009). However, Jatropha kernel meal which is obtained after the kernel (seed without shells) is defatted has a high crude protein content of between 56.1- 64.4 % (Makkar *et al*., 1998; Chikpah and Demuyakor, 2012a) of which about 91 % is true protein (Makkar *et al*., 1998). *Jatropha curcas* seeds and products were also reported to contain macro minerals (Kumar and Sharma, 2008; Chikpah and Demuyakor, 2012a). Products from *Jatropha curcas* were also reported to contain anti-nutrients such as trypsin inhibitor, lectin, phytic acid, saponins, tannins, and phorbol ester as the main toxic agent (Makkar *et al.,* 1998). However, studies have shown that the physico-chemical characteristics of Jatropha seeds and meals vary with respect to genotype and environment (Martinez-Herrera *et al*., 2006). Chemical composition of Jatropha seeds and meals from some selected locations of Ghana has been reported (Chikpah and Demuyakor, 2012a). The objective of this study was to compare the nutritive values of the whole seed and kernel; whole seed meal and kernel meal of indigenous Jatropha cultivated in Ghana and to determine the correlation between the physical parameters of the seed/kernel and the chemical compositions of the Jatropha seeds and its products.

Figure 1: Regional Map of Ghana showing locations of *Jatropha curcas* seeds collection.

Materials and Methods

Collection of *Jatropha curcas* seed samples

Ripped fruits were harvested from *Jatropha curcas* plants in November, 2012. The Jatropha samples were collected from four geographical zones in Ghana where the plant is popularly cultivated. Selected areas include: 1. Nyankpala in the Northern region (Guinea savanna zone, Lat. 09° 25'N, long. 00° 58' W; average temperature 28.3°C; annual rainfall 1043 mm); 2.Wa in the Upper West region (Guinea Savanna, Lat. 10° 4' N, long. 02° 30' W, average temperature 29.0 °C, Annual rainfall 900 mm); 3.Dambai in the Volta region (Transitional zone, Lat. 07° 40'N, long. 00° 6'E; average temperature 27.0 °C; annual rainfall 1120 mm); 4.Techiman in the Brong Ahafo region (Transitional forest, Lat.07° 35' N, long. 01° 56'W average temperature 24.5 °C, annual rainfall 1140 – 1270 mm). Figure 1 shows the Regional map of Ghana with the Jatropha cultivated areas. Soon after harvesting the fruits, the seeds were manually removed from the husk and transported to the laboratory for determination of physical parameters and for further processing.

Determination of physical parameters of whole seeds and kernels

The average whole seed, kernel, and shell weights, percentage kernel and shell weights of whole seed weight of *Jatropha curcas* seed samples were determined according to the method described by Chikpah and Demuyakor (2012b) with few modifications. A total of 1000 seeds (250 seeds from each zone) were randomly selected from the four (4) zones. The 1000 seeds were sampled in 20 lots (5 lots from each zone). Each of the 20 lots of seeds consists of fifty (50) seeds. The weight of the 50 seeds for each of the 20 lots was measured and used to estimate the average whole seed weight. The 50 seeds of each lot were cracked manually and the shells carefully separated from the kernel. The weight of the 50 kernels obtained for each lot was taken and used to calculate the average kernel weight. The average shell weight was determined from the average of the differences between the whole seeds weights of each 20 lots of seeds and their respective kernel weights. The weights of shells and kernels were then expressed as percentage of whole seed weight.

Defatting of seeds and kernels

Approximately 1 kg of whole seeds and kernels each were randomly picked from each zone and defatted separately as described in our earlier work (Chikpah and Demuyakor, 2012a). The whole seed meals and kernel meals were both air-dried and stored separately in labeled zip lock plastic bags at 2 °C in a refrigerator for later analysis.

Analysis of proximate composition and mineral concentrations

The moisture, crude protein, ether extract (lipid), crude fibre, soluble carbohydrate, total ash contents and macro-minerals including total nitrogen, phosphorus, potassium, calcium and magnesium were determined in accordance to the methods described by Chikpah and Demuyakor (2012a). The analyses were conducted in triplicate and all reagents were of analytical grade.

Determination of Antinutritional Factors

Crude phorbol esters, tannins and phytic acid concentrations were some of the antinutritional factors analyzed in the *Jatropha curcas* seeds and meals. Each analysis was conducted in triplicate and all reagents were of analytical grade.

Analysis of tannins and phytic acid

The titrimetric methods described by the International Pharmacopoeia (2003) and Lucas and Markakes (1975) were used to determine tannic acids and phytic acid concentrations respectively.

Extraction and estimation of crude phorbol esters

The crude phorbol esters in Jatropha samples were extracted according to the method described by Hass and Mittelbach (2000) as shown in figure 2. Briefly, approximately 5 g of finely ground Jatropha sample was mixed with 20 ml of methanol and agitated at 250 rpm for 5 minutes. The mixture was then filtered using Whatman No. 4 filter paper to obtain the methanol phase. The residue was repeatedly extracted four additional times each in 20 ml of methanol. All the methanol phases collected from the five extractions were pooled together. The methanol was then evaporated and the weight of the dried crude phorbol ester rich fraction was measured by the method reported by Chikpah and Demuyakor (2012a).

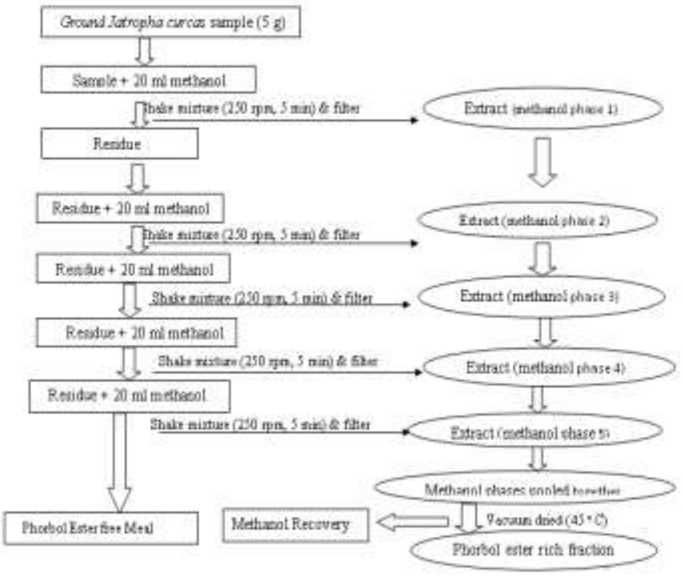

Figure 2: Flow diagram for extraction of phorbol ester rich fraction from Jatropha curcas samples

Results and Discussion

Physical characteristics of Ghanaian grown *Jatropha curcas* seeds and kernels

The physical properties of whole seed (WS) and the kernel (KN) of Jatropha grown locally in Ghana are shown in Table 1. The average whole seed weight (g) of the Jatropha from Ghana (0.69 ± 0.04g) was the same as the seeds from Cape Verde (0.69 g) but higher than those grown in Ife-Nigeria (0.53 g) and lower than that of Nicaragua (0.86 g) as reported by Makkar *et al*. (1998). The average kernel weight and shell weight of *J. curcas* grown in Ghana were similar to those reported (Martinez-Herrera *et al*., 2006). The percentage kernel of whole seed (61.19- 62.74 %) was much higher than the percentage shell (37.26 – 38.81 %) recorded. These values were within the ranges of those reported (Makkar *et al*., 1998).

Table 1: Physical properties of whole seeds and kernels

Item	[a] Ghana	[b] Cape Verde	[b] Nicaragua	[b] Ife-Nigeria
	Mean ± SD			
Average WS wt (g)	0.69 ± 0.04	0.69	0.86	0.53
Average KN wt (g)	0.43 ± 0.02	-	-	-
Average Shell wt (g)	0.26 ± 0.02	-	-	-
KN, % of whole seed wt	61.19-62.74	62.7	62.7	60.0
Shell, % of whole seed wt	37.26 – 38.81	37.3	37.3	40.0

[a] primary data; [b] data taken from Makkar *et al*. (1998). WS = whole seed; KN= kernel; SD = Standard deviation, g = gram, wt = weight

Proximate composition of Jatropha seed and kernel

The proximate composition of whole seed and kernel of *J. curcas* varied significantly (P < 0.05) as indicated in Table 2. The moisture, crude fibre, total ash/mineral, and soluble carbohydrates contents were higher in the whole seed (WS) than the kernel (KN). However, crude protein and ether extract (lipid) compositions were significantly higher (P < 0.05) in the KN than WS. The high crude fibre content of the Jatropha whole seed may be attributed to the shells which were reported to compose mainly fibre with little (< 6%) protein (Makkar *et al*., 1998). The high amount of soluble carbohydrates in the whole seeds as compared to the kernels could be as result of carbohydrates in the shells. The lipid and crude protein values recorded in *J. curcas* seeds and kernels from Ghana were within the ranges reported (Makkar *et al*., 2008; Raja *et al*., 2011). The higher lipid and crude protein values of the kernel as compared to the whole seed is an indication that when the kernel is extracted would give higher lipid yield and protein meal than the whole seed.

Table 2: Proximate composition of Ghanaian *Jatropha curcas* seed and Kernel

Parameters (%)	Samples		P-value
	Whole Seed (WS)	Kernel (KN)	
Moisture	6.24 ± 0.14^a	4.80 ± 0.13^b	0.001
Dry matter	93.76 ± 0.14^b	95.20 ± 0.13^a	0.001
Crude protein	18.66 ± 0.11^b	24.56 ± 0.45^a	0.001
Ether Extract (lipid)	38.09 ± 0.29^b	56.14 ± 0.24^a	0.001
Crude Fibre	15.70 ± 0.60^a	4.52 ± 0.26^b	0.001
Total ash/mineral	5.33 ± 0.10^a	4.15 ± 0.25^b	0.002
Soluble Carbohydrate	15.99 ± 0.25^a	5.82 ± 0.49^b	0.001

Mean = Mean ± SE, where SE = Standard error. Means within a row with different superscripts are significantly different (P < 0.05).

Correlation between physical parameters and proximate composition of *J. curcas* seed

There was correlation between all the physical parameters and the proximate composition of *Jatropha curcas* seeds/kernels as shown in Table 3. Seed, kernel and shell weights were strongly correlated with each other (p < 0.05). Kernel weight and shell weight had strong positive correlation with seed weight (correlation coefficient, r = 0.891 and 0.643 respectively) while Kernel weight and shell weight were highly negatively correlated (r= -0.956). More also kernel weight had strong positive correlation with ether extract (r = 0.862) whereas shell weight showed strong negative correlation with crude protein and ether extract (r = - 0.857 and -0.759 respectively). This shows that the higher the weight of the kernel the greater its lipid value while increasing shell weight reduces lipid content. Shell weight and crude fibre had strong positive correlation (r = 0.935). This further explains why the whole seeds contained higher crude fibre content as compared to the kernels since the seeds contained shells which were not present in the kernel. Therefore removal of the shells from the seeds would help to reduce fibre content.

Table 3: Matrix Correlation between physical properties and proximate composition of *J. curcas* seed

Parameters	Seed wt	Kernel wt	Shell wt	CP	EE	CF	Ash	SC
Seed wt		0.891	0.643	0.681	0.754	0.186	0.233	0.179
Kernel wt			-0.956	0.338	0.862	0.127	0.115	0.320
Shell wt				-0.857	-0.759	0.935	0.458	0.413
CP					0.471	-0.816	-0.529	0.489
EE						-0.914	-0.646	0.365
CF							0.147	-0.867
Ash								-0.702
SC								

All the parameters were correlated (p < 0.05). CP= crude protein; EE= ether extract; CF= crude fibre; SC = soluble carbohydrates; wt = weight

Antinutritional composition of *J. curcas* seeds and kernels

The Crude phorbol ester (CPE), tannins, and phytate values in whole seeds (WS) and kernels (KN) of *J. curcas* is shown in Table 4. There was no significant difference (P > 0.05) between the CPE content of WS and KN. However, the WS samples had higher values of CPE (5.92 ± 0.24 mg/g) than the KN (5.55 ± 0.22 mg/g). More also the whole seed contained significantly higher (P < 0.05) tannins and phytate concentrations than the kernel. The tannic acid value in the Jatropha kernel was negligibly low (0.07 % tannic acid equivalent). The higher values of tannic acid and phytate in the *Jatropha curcas* whole seed may be attributed to the shells which were not present in the kernel samples.

Table 4: Crude phorbol ester, tannin, and phytic acid concentrations in *J. curcas* Whole seed and kernel

Samples	CPE (mg/g)	Tannins (% tannic acid equivalent)	Phytic acid (% DM)
Whole Seed	5.92 ± 0.24	$0.83 \pm 0.03_a$	$9.45 \pm 0.25_a$
Kernel	5.55 ± 0.22	$0.07 \pm 0.01_b$	$8.70 \pm 0.26_b$
P-value	0.282	0.001	0.040

Mean = Mean ± SE, where SE = Standard error; CPE= crude phorbol ester. Means in the same column with no subscript in common are significantly different (P < 0.05).

Correlation between physical parameters and antinutrients content of Jatropha seeds

There was positive correlation between all the physical properties and antinutritional factors of the Jatropha seed as shown in Table 5. Phytate and crude phorbol ester (CPE) concentrations in the seeds were highly positive correlated with the kernel weight (r = 0.865 and 0.843 respectively) while tannin concentration showed strong positive correlation with the shell weight of the *J. curcas* seed. The high positive correlation between the kernel weight and its CPE content firms the fact that greater proportion (about 70 %) of phorbol ester (PE) is contained in the oil (Makkar *et al*., 2008), which is the main component of the kernel. The high positive correlation between shell weight and tannic acid value of the Jatropha seed further explains that *J. curcas* whole seed will contain more tannins than the kernels as earlier observed. Therefore removal of shells from the seed of *J. curcas* will lead to significant reduction in tannic acid value of the Jatropha seed and its meal product as reported earlier (Chikpah and Demuyakor, 2012a).

Table 5: Correlation values between physical parameters and antinutritional composition of *J. curcas* seeds

Parameters	Tannins	Phytate	Crude phorbol ester
Seed weight	0.325	0.357	0.194
Kernel weight	0.217	0.865	0.843
Shell weight	0.878	0.351	0.416

All the parameters were positively correlated (P < 0.05)

Nutritional composition of *J. curcas* whole seed and kernel meals Proximate composition

The percentage dry matter, crude protein, crude fibre, and total ash (mineral) composition of defatted whole seed were significantly different (P < 0.05) from the kernel meal (Table 6). The difference between the soluble carbohydrate values of the two meal types was however insignificant (P > 0.05). The dry matter value, crude protein, and total ash contents of *J. curcas* kernel meal (KM) were statistically higher (P < 0.05) than the values recorded in the whole seed meal (WSM). The crude protein in the kernel meal was approximately 55.3 % higher than that of the whole seed meal. However, crude fibre content of the WSM (22.96 %) was significantly higher (about 70 % more) than that of the KM (6.79 %). The differences in the proximate composition of the whole seed meal and kernel meal of *J. curcas* could be attributed to differences in the physical characteristics and proximate compositions of the seeds and kernels from which the respective meals were obtained. The higher crude fibre content of *J. curcas* WSM can mainly be as a result of the shells of the seed that were incorporated into the meal during processing. Therefore deshelling of the seed before processing will reduce the fibre content of the meal that would be obtained. The higher crude protein content and lower value of crude fibre in the kernel (KM) suggests that the kernel meal is a better choice for use as an animal feed than the whole seed meal (WSM) if detoxified.

Table 6: Proximate composition of defatted *Jatropha curcas* whole seeds and kernels

Parameters (%)	WSM	KM	P-value
Dry matter	93.13 ± 0.30^b	95.08 ± 0.07^a	0.001
Crude protein	28.60 ± 0.32^b	64.04 ± 0.16^a	0.001
Ether Extract (lipid)	17.98 ± 0.45	-	-
Crude Fibre	22.96 ± 0.51^a	6.79 ± 0.39^b	0.001
Total ash (mineral)	8.03 ± 0.29^b	8.97 ± 0.24^a	0.026
Soluble Carbohydrate	15.57 ± 1.00	15.29 ± 0.15	0.787

Mean = Mean ± SE, where SE = Standard error; WSM = Whole seed meal; KM = Kernel meal. Means with different superscripts within a row are significantly different (P < 0.05).

Macro- mineral composition

Some macro-mineral compositions determined in the defatted whole seeds and kernels of *J. curcas* are shown in Figure 3. Both the whole seed meal and kernel meals contained rich amounts of total nitrogen, phosphorus, potassium, calcium, and magnesium. The mineral compositions recorded were similar to values reported (Makkar and Becker, 1997). With the exception of total nitrogen which was significantly high (P <0.05) in the kernel meal (about 55.3 % more), than the whole seed meal, all the other macro-mineral values were similar in the two meal types. The significant improvement in the total nitrogen value of the kernel meal reflected its high crude protein content. This suggests that the process of seed deshelling can be used to improve the protein value of Jatropha seed meal without affecting P, K, Ca, and Mg contents of the meal product.

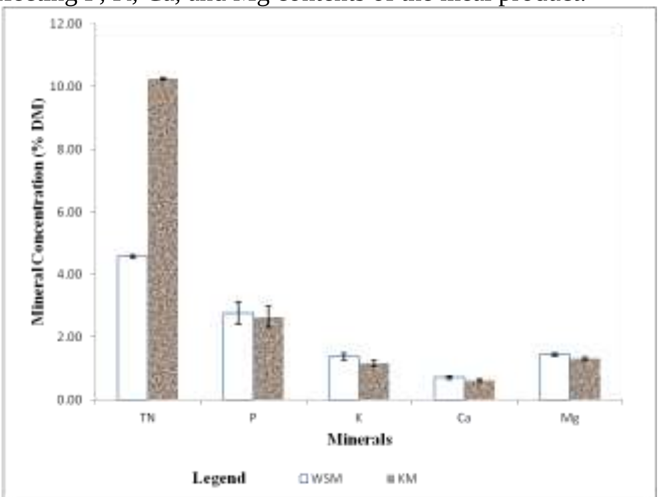

Figure 3: Macro - mineral compositions of J. curcas whole seed and kernel meals. WSM= whole seed meal; KM = kernel meal; DM = Dry matter; TN = Total nitrogen.

Antinutritional factors

The meals obtained from seeds and kernels of Jatropha grown in Ghana contained variable amounts of antinutrients such as crude phorbol ester (CPE), tannins, and phytic acid (Table 7). The concentrations of these antinutritional factors were significantly lower (P< 0.05) in kernel meal (KM) as compared to the whole seed meal (WSM). The tannin content in KM is negligibly low (0.05 % tannic acid equivalent). Even though, the values of CPE and phytic acids reduced in the KM, the levels of these antinutrients were still high in both WSM and KM and therefore must be detoxified before use as animal feed.

Table 7: Crude phorbol ester (CPE), tannic acid and phytic acid concentrations in defatted seed and kernel

Parameters	WSM	KM	P-value
CPE (mg/g)	5.49 ± 0.29[a]	3.19 ± 0.26[b]	0.001
Tannins (% tannic acid equivalent)	0.81 ± 0.05[a]	0.05 ± 0.01[b]	0.001
Phytic acid (% dry matter)	8.93 ±0.46[a]	6.96 ± 0.21[b]	0.008

Mean = Mean ± SE, where SE = Standard error; WSM = Whole seed meal; KM = Kernel meal. Means with different superscripts within a row are significantly different ($P < 0.05$).

Conclusion

The local variety of *Jatropha curcas* cultivated in Ghana has seeds and seed products that are comparable to those varieties reported in other countries (Makkar *et al*., 1998). Greater percentage of the seed is kernel which is high in lipid and crude protein. The study also revealed that strong correlation exists between the physical parameters of the seeds and their nutritional and antinutritional compositions. The correlations found between some physical parameters and nutritional characteristics of whole seed and kernels and their respective meals showed that some of these parameters could be used as indicators to predetermine both quality and process requirements for Jatropha seeds for use as animal feed. The Jatropha kernel meal has higher crude protein value and lower fibre content than the whole seed meal. Therefore, the kernel meal is better choice for animal feed than the whole seed meal. Both the whole seed and kernel meals contained considerable amounts of antinutrients which must be detoxified to levels that will be non-toxic to animals when consumed. Research is still ongoing to find a cheaper means of detoxifying the kernel meal for use as animal feed.

References

Chikpah, SK, and Demuyakor, B (2012a). Evaluation of nutritional and antinutritional composition of whole seed and kernel meals of *Jatropha curcas* obtained from four different Agro-climatic areas of Ghana. *International Journal of Current Research:* 4 (12) pp. 424-429.

Chikpah, SK, and Demuyakor, B (2012b). Evaluation of physicochemical properties of *Jatropha curcas* seeds from four different Agro-climatic areas of Ghana. *International Journal of Current Research:* 4 (12), pp. 446-450.

Fournier, V, Huelvan, C and Desbruyeres, E (2004). Incorporation of a mixture of plant feedstuffs as substitute for fish meal in diets of juvenile turbot (Psetta maxima). Aquaculture 236, 451–465.

Gübitz, GM, Mittelbach, M and Trabi, M (1999). Exploitation of the tropical oil seed plant *Jatropha curcas* L. Bioresource Technology 67: 73-82.

Hass, W and Mittelbach, M (2000). Detoxification experiments with the seed oil from *Jatropha curcas* L. Ind. Crop Prod. 12: 111-118.

International Pharmacopoeia (2003). World Health Organization, 3rd ed., v.5, Geneva.

Kaushik, SJ, Cravedi, JP, Lalles, JP, Sumpter, J, Fauconneau, B and Laroche, M (1995). Partial or total replacement of fish meal by soybean protein on growth, protein utilization, potential estrogenic or antigenic effects, cholesterolemia and flesh quality in rainbow trout, Oncorhynchus mykiss. *Aquaculture 133, 257–274.*

Lucas, GM, and Markakes, P (1975). Phytic acid and other phosphorus compounds of nevy bean (*Phaseolous vulgaris*). J. Agric., Food Chem., 23:13-15.

Makkar, HPS., Aderibigbe, AO, and Becker, K (1998). Comparative evaluation of non- toxic and toxic Jatropha curcas for chemical composition, digestibility, protein degradability and toxic factors. Food Chemistry, 62(2), 207-215.

Makkar, HPS, and Becker, K (1997). Potential of *Jatropha curcas* Seed Meal as Protein Supplement in Livestock Feed, Constraints to its Utilisation and Possible Strategies to Overcome Constraints. Developed from the Symposium “Jatropha 97”. 23–27 February 1997, Managua, Nicaragua. Biofuel and Industrial Products from J. curcas, pp. 190–205.

Makkar, HPS, Francis, G and Becker, K (2007). Bioactivity of phytochemicals in some lesser-known plants and their effects and potential applications in livestock and aquaculture production systems. Animal 1(9):1371–1391.

Makkar, HPS, Martinez-Herrera, J and Becker, K (2008). Variations in Seed Number per Fruit, Seed Physical Parameters and Contents of Oil, Protein and Phorbol Ester in Toxic and Non-Toxic Genotypes of *Jatropha curcas*, *Journal Plant Science*, 3(3): 260-265.

Makkar, HPS, and Becker, K (2009). Challenges and Opportunities for Using Byproducts from the production of Biodiesel from Jatropha oil as Livestock Feed. Proceedings of Animal Nutrition Association World Conferences, 14-17 February 2009, New Delhi, India: 168- 170.

Martinez-Herrera, J, Siddhuraju, P, George, F, Davilá-Ortíz G and Becker, K (2006). Chemical composition, toxic/anti-metabolic constituents and effects of different treatments on their levels in four provenances of *Jatropha curcas* L. from Mexico. *Food Chemistry* 96: 80-89

Raja, Antony S, Robinson, Smart DS, and Lindon, Robert Lee C (2011). Biodiesel production from jatropha oil and its characterization. *Research Journal of Chemical Science*, Vol.1 (1): pp. 81-87.

SOFIA (2007). The state of world fisheries and aquaculture 2006. FAO Fisheries and aquaculture Department, Rome, pp 1–180