Effects of substitution of groundnut meal by defatted and boiled *Jatropha curcas* seed kernel in diet of broiler chicks in Senegal

*NESSEIM Thierry Daniel Tamsir[1], FALL Abdou Khadre[2], DIENG Abdoulaye[1], MERGEAI Guy[3], HORNICK Jean-Luc[4]

Abstract

This study was conducted to determine, in a growth diet, the effect of a substitution of groundnut meal by *Jatropha curcas* kernel meal physico-chemically treated on viability, feed intake and growth performances of broiler chicks.

The feed experiment lasted for seven days with twenty Ross 308 strain unsexed chicks, seven-days old. Kernels, manually obtained from *J. curcas* seed, were defatted and boiled in order to obtain the treated jatropha kernel meal. This latter was used to replace the groundnut meal contained in a premix which was then incorporated in a commercial diet to warrant iso-nitrogenous and iso-caloric characteristics of the diets. The results revealed that animals that received the diet incorporating jatropha kernel meal had numerically higher live weight (272.6 vs. 259.3 g/animal) (P>0.05) and average daily weight gain (15.9 vs. 13.5 g/day/animal) (P>0.05) than the control ones, at the end of experiment. The average daily feed intake was a bit similar for the two groups (34.1 vs 34.5 g/day/animal) (P>0.05) as well as the feed conversion ratio (2.2 vs. 2.7 respectively for the jatropha group and the control group). The survival rate, at the end of the experiment, was 100% for the two groups of animals.

Keywords: broiler chicks; *Jatropha curcas*; defatted kernel; Senegal

Résumé

Effets de la substitution du tourteau d'arachide par l'amande de la graine de *Jatropha curcas* déshuilée et bouillie dans l'alimentation de poussins de chair au Sénégal

Cette étude a été conduite pour déterminer, dans un aliment croissance, l'effet de la substitution du tourteau d'arachide par du tourteau d'amande de *Jatropha curcas* ayant subi un traitement physico-chimique sur la viabilité, l'ingestion et les performances de croissance de poussins chair.

L'expérience de nutrition a duré sept jours avec vingt poussins non sexés de souche Ross 308, âgés de sept jours. Les amandes, obtenues manuellement à partir de graines de *J. curcas*, ont été déshuilées puis bouillies afin d'obtenir un tourteau d'amande de jatropha traité. Ce dernier a été utilisé pour remplacer le tourteau d'arachide contenu dans un prémélange qui a ensuite été incorporé à un aliment de type commercial pour maintenir les caractéristiques iso-azotées et iso-caloriques des régimes. Les résultats ont révélé que les animaux ayant reçu le régime contenant du tourteau d'amande de jatropha ont obtenu un poids vif (272,6 *vs* 259,3 g/animal) (P>0,05) et un gain pondéral quotidien moyen plus élevés (15,9 *vs* 13,5 g/jour/animal) (P>0,05) que les animaux du groupe témoin. L'ingestion quotidienne moyenne était presque similaire pour les deux groupes (34,1 *vs* 34,5 g/jour/animal) (P>0,05) ainsi que l'indice de conversion alimentaire (2,2 *vs* 2,7 respectivement pour le groupe jatropha et le groupe témoin). Le taux de survie, à la fin de l'expérience, était de 100% dans les lots expérimentaux.

Mots clés: poussins de chair ; *Jatropha curcas* ; amande déshuilée ; Sénégal

[1]Université de Thiès, Ecole Nationale Supérieure d'Agriculture, Département des Productions Animales, Km 3 route de Khombole, BP A 296 Thiès, Sénégal ; tnesseim@univ-thies.sn, abdoulaye.dieng@univ-thies.sn

[2]Université Alioune Diop de Bambey, Institut Supérieur de Formation Agricole et Rurale, Département de Productions Animales, BP 54 Bambey, Sénégal ; khadre.fall@uadb.edu.sn

[3]Université de Liège, Gembloux Agro-Bio Tech, Département Phytotechnie Tropicale et Horticulture, 2 Passage des déportés, 5030 Gembloux, Belgique ; gmergeai@ulg.ac.be

[4]Université de liège, Faculté de Médecine Vétérinaire, Département de Productions Animales, 20 Boulevard de Colonster, 4000 liège, Belgique ; jlhornick@ulg.ac.be

*Corresponding author: NESSEIM Thierry Daniel Tamsir,
Tel : +(221) 77 633 61 63,
Email : tnesseim@univ-thies.sn,
7612 SICAP Mermoz, BP 25473 Dakar-Fann (Sénégal)

1. Introduction

Broiler chicken production remains one of the veritable ways of achieving sustainable and rapid production of high quality protein to meet the demand of the population (Apata & Ojo, 2000) especially in several developing countries like Senegal. In this country, the poultry sector has experienced significant development in its semi-industrial and industrial sector as well as in the family sector (Traoré, 2014). However, the dependence and the import of soybean have increased substantially the costs of poultry feed ingredients (Willems *et al*., 2013). To overcome this, several non-conventional food sources have been proposed to be incorporated into poultry feed (Akinmutimi & Okwu, 2006; Dahouda *et al*., 2009; Ayssiwede *et al*., 2010; Diaw *et al*., 2012; Kenis *et al*., 2014). Based on that, *Jatropha curcas* was proposed to be incorporated into rations for poultry (Ojo *et al*., 2013; Ojediran *et al*., 2014; Nesseim *et al*., 2015; Nesseim *et al*., 2019).

This plant belongs to the *Euphorbiaceae* family, distributed all over the tropics and subtropics, able to grow on degraded soils (Heller, 1996). If most genotypes are toxic (Martinez-Herrera *et al*., 2010), there are non-toxic genotypes which seeds can be consumed by humans (Makkar *et al*., 1998b) and are also an excellent fish feed (Makkar *et al*., 1999). The meal obtained after oil extraction is an excellent source of

nutrients (Devappa & Swamylingappa, 2008) despite the presence of anti-nutrients and toxic components (Makkar *et al*., 2008). The toxicity of the seed from *J. curcas* was suggested to be due to phorbol esters, which are most concentrated in the kernel of the seed (He *et al*., 2011), have been shown to be the most important toxic molecules (Makkar *et al*., 1997; Becker & Makkar, 1998; Makkar *et al*., 1998a; Roach *et al*., 2012). Outside phorbol esters, jatropha meal contain, not only curcin (Asseleih *et al*., 1989) that is capable of inhibiting protein synthesis (Lin *et al*., 2003), but also anti-nutrients including trypsin inhibitor, phytate and saponins (Francis *et al*., 2002). The toxic genotype could be utilized as a fertilizer (Nithiyanantham *et al*., 2012) but efforts are under way to detoxify jatropha seed by removing phorbol esters or develop varieties that are deprived of this molecule so that the meal could be used as an ingredient in livestock diet (Makkar & Becker, 2009). Chemical de-oiling of jatropha kernel, followed by a physico-chemical treatment did not cause a complete removal of phorbol esters (Kumar *et al*., 2010b) and so many processing methods have been explored to detoxify meal of *J. curcas* with different levels of success. These include physical (Aregheore *et al*., 1998) and chemical (Haas & Mittelbach, 2000; Aregheore *et al*., 2003) methods; the combination of these two (Martinez-Herrera *et al*., 2006); and biological methods (Belewu & Sam, 2010; Joshi *et al*., 2011; Nesseim *et al*., 2019). Otherwise, curcin and trypsin inhibitor could interfere with physiological process of monogastrics causing severe growth depression (Palacios *et al*., 2004) but they may be removed by heat and biological treatment (Aderibigbe *et al*., 1997; Aregheore *et al*., 1998; Abou-Arab & Abou-Salem, 2010; Sumiati *et al*., 2012).

The objective of this study was to evaluate the impact of groundnut meal substituted by *J. curcas* kernel meal from Senegal that was subjected to combined chemical and thermal treatments in order to remove anti-nutritional compounds out of the product in a diet, on viability, ingestion and growth performance of broiler chicks.

2. Materials and methods

2.1. Location of the experiment

Experiment was conducted in *Ecole Nationale Supérieure d'Agriculture* (*ENSA*), University of Thies (Senegal) just after the rainy season (November) with a temperature ranging from 26.9 to 37.8°C and a relative humidity ranging from 34 to 38%.

2.2. Collection and processing of jatropha seeds

Five hundred grams of mature and dry seeds of *Jatropha curcas* were collected from Dialacoto, geographical coordinates 13°19′0″ N and 13°18′0″ W, in the Tambacounda region (Senegal). The jatropha seeds cracked individually to remove the kernels. The kernels were washed with tap water to remove shells, drained properly and sun dried to a constant weight. These were milled into powder using WARING®-type speed blender with timer grinder and then defatted for 6 hours, by 20 g amounts each in a series Soxhlet-type extractor, using diethyl ether (boiling point, 60–80°C) as solvent.

The substrate, consisting of jatropha kernel meal, was spread into a dish and boiled at 120°C for 30 minutes. The spent substrate, 239.6 g of boiled jatropha kernel meal (BJKM) was later used in the formulation of diet.

2.3. Diets preparation

Two broiler starter diets were formulated. The control diet (0BJKM) contained 2/3 of a complete starter commercial feed (SEDIMA S.A., Dakar, Senegal) for broiler chicks. This commercial feed was mainly composed of maize, cereal issues, soybean meal, peanut meal, fish meal, calcium carbonate, and vitamin-mineral complex. To formulate the control diet, 1/3 of a premix contained groundnut meal (160 g), corn (480 g), disodium phosphate (32 g), and calcium carbonate (32 g) was added to the commercial feed and the experimental diet (8BJKM) was formulated similarly but the groundnut meal of the previous mixture was replaced with boiled jatropha kernel meal (160 g) (Table I). These final mixtures were iso-nutrients for ME, CP, Ca, P, and Na, and in agreement with the recommendations of N.R.C. (1994).

Table I: Composition of diets incorporating *J. curcas* kernel meal

Raw materials (%)	0BJKM	8BJKM
Complete starter diet	68.0	68.0
Groundnut meal	8.0	-
BJKM	-	8.0
Maize	20.0	20.0
Phosphate disodium	2.0	2.0
Calcium carbonate	2.0	2.0
Total	100.0	100.0

Complete starter commercial feed (SEDIMA) composed of maize, cereals issues, soybean meal, peanut meal, fish meal, calcium carbonate, and vitamin-mineral complex.

BJKM Boiled Jatropha Kernel Meal, *0BJKM* control diet, *8BJKM* diet incorporating 8% of boiled jatropha kernel meal.

2.4. Experimental animals and management

Twenty unsexed broiler chicks Ross 308 strain of seven-days old were used for the study. The birds were divided into two groups of ten chicks (control group -CG- and jatropha group -JG-) assigned to any of the two diets in a completely randomized design. Animals were kept in a naturally well-ventilated broiler chicken barn divided into two areas separated by a fence of 0.75 m in height. Each area was 2.25 m².

During the test, all day and all night, animals were heated by electric light (100 watts) ensuring luminosity and thermal comfort. The average temperature inside the experimental room was 31.6°C while the relative humidity was 37.7%.

Feed was weighted early in the morning; provided once a day and water was available *ad libitum*. Feed Refusals were collected and weighed the day after the distribution.

The study was carried out for seven days.

2.5. Data collection

Data were collected on feed intake, weight gain, feed conversion ratio and mortality.

The daily feed intake was estimated as the difference between the feed supplied and the feed rejected over 24 hours' period.

The Average Daily Feed Intake (ADFI) was then estimated.

Birds in each replicate were individually weighed at the beginning and at the end of the experiment. This weighing was done in the morning, before the distribution of diets. The Average Daily Weight Gain (ADWG) was estimated.

An electronic scale with a weighing capacity of 50 kg and a precision of 0.01 g was used for all weight data.

The Feed Conversion Ratio (FCR) was determined as the feed intake per unit weight gain.

Mortality was recorded in each replicate and expressed as a percentage of the total number of birds in the replicate at the beginning of the experiment.

2.6. Chemical analyses

Samples of jatropha kernel meal, boiled jatropha kernel meal, control diet and diet incorporating the boiled jatropha kernel meal were analyzed. Dry matter (DM) was determined by oven-drying at 70°C for 15 hours, 90°C for 5 hours, and 102°C for 5 hours consecutively. Diets were analyzed for crude protein (CP; Method 954.01; AOAC, 1990), ether extract (EE; Method 920.39; AOAC, 1990) with petroleum ether solvent, ash (Method 942.05; AOAC, 1990), and crude fiber (CF; Method 962.09; AOAC, 1990).

The following values were calculated from those measured (Sibbald, 1976):

Organic matter (OM) = 100 – Ash

Non-Nitrogen Extract (NNE) = OM – EE – CP – CF

ME = metabolic energy (kcal/kg DM) = 3951 + (54.4 × EE) – (88.7 × CF) – (40.8 × Ash)

2.7. Statistical analysis

The presence or not of boiled jatropha kernel meal in diets is used to evaluate effects on ingestion and growth performance. Data generated were analyzed by one-way analysis of variance using the General Linear Model (GLM) procedure of SAS 9.1 software package. Significance was determined at $p<0.05$ and where this was indicated, Duncan's option of the same software was used to separate the means.

3. Results

3.1. Chemical composition of feed

Table II shows the analytical composition of the experimental diets. Both 0BJKM and 8BJKM showed almost similar value, with regard to the DM, CP, EE, ash and CF. The true metabolic energy of each diet was 3552.2 and 3366.5 kcal/kg DM for respectively 0BJKM and 8BJKM. Analytical results showed that diets were almost iso-proteinic and iso-energetic even if the metabolic energy of the control diet was higher than the boiled jatropha kernel diet.

Table II: Proximate analytical composition of the diets used during the experimentation

	DM	Chemical composition (% in DM)						ME
	(%)	OM	CP	EE	CF	Ash	NNE	(kcal/kg DM)
JKM	91.6	90.1	61.8	5.0	8.2	9.9	15.1	3091.7
BJKM	97.4	90.6	54.0	4.3	7.5	9.4	24.8	3135.8
0BJKM	91.8	91.0	21.5	4.5	3.1	9.0	61.8	3552.2
8BJKM	90.1	89.2	22.4	3.5	3.7	10.8	59.5	3366.5

3.2. Growth performance and feed intake

Based on the visual observation during feeding time, palatability or acceptability of feed was good and the behavior of chicks was normal. There was no mortality during the entire experimental period.

Figure 1 shows synthetic body weight changes over the experiment. During the seven days, it was found that the control group showed a linear weight growth, evolving from 164.1±28.8 g on day 8 (d8) to 259.3±64.4 g on day 14 (d14). For the same period, animals that received the boiled jatropha kernel meal diet had the same profile, from 165.9±11 g to 272.6±35.4 g.

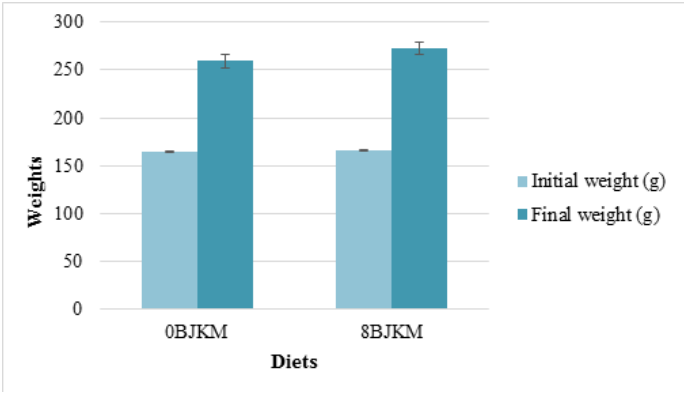

Figure 1: Weight performances of broiler chicks receiving or not 8% boiled *J. curcas* kernel meal

Figure 2 shows the daily individual feed intake of broiler chicks during the experimental sequence. No significant differences were observed in the feed intake of the two groups of animals (34.5±4.9 g/d/animal in CG vs. 34.1±4.4 g/d/animal in JG). For both groups of animals, a similar feed intake was noted. ADWG per animal did not change significantly for both groups regardless of the rate of boiled jatropha kernel meal incorporation, from 13.5 g/d/animal for CG to 15.9 g/d/animal for JG. The FCR presented the same mean values, 2.7 and 2.2, respectively for CG and JG without significant difference ($P>0.05$).

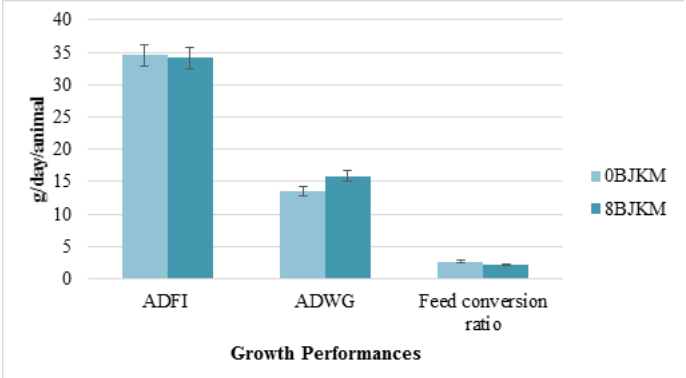

Figure 2: Growth performances of broiler chicks receiving or not 8% boiled *J. curcas* kernel meal.

4. Discussion

Mechanical extraction of oil, from *Jatropha curcas* seeds, by means of a screw press is the method used generally in developing countries because of the simplicity of the equipment required (Eckart & Henshaw, 2012). This method makes it possible to recover more than 80% of the oil (Tambunan *et al*., 2012). However, solvent extraction could be regarded as the most ideal extraction method since it could recover 95-98% mass fraction of the available oil in the seed (Gübitz *et al*., 1999). In our study, because of the non-digestibility of hulls' fibers for monogastrics (Jørgensen *et al*., 1996), the jatropha seeds were manually shelled before being processed. The kernel obtained was crushed and completely de-oiled by the Soxhlet method. By choosing this method of de-oiling, our aim was to obtain a significant reduction of toxic compounds (Gandhi *et al*., 1995), allowing animals to ingest the jatropha meal. Our results were in line with those of Gübitz et al. (1999). But later studies (Makkar *et al*., 1998a; Martinez-Herrera *et al*., 2006) have shown that de-oiling did not allow this significant reduction.

An additional boiled treatment of jatropha kernel meal was done at 120°C for 30 minutes. The aim was to inactivate toxic and anti-nutritional compounds. Martinez-Herrera *et al*. (2006), by heat treatment in an autoclave (121°C for 20 mn), significantly inactivated trypsin inhibitor activity that is anti-nutritional factor but essentially inhibiting lectin activity which is considered to be another toxic factor in *J. curcas* seeds. In the same way, Abo El-Fadel *et al*. (2011) decreased the concentration of trypsin inhibitor and lectin by about 75 and 83% respectively. These results were in agreement with Haas & Mittelbach (2000) and Makkar *et al*. (2008) who reported also that heat treatment has a positive effect on reducing trypsin inhibitor and lectin concentration in *J. curcas* meal.

The chemical composition of jatropha kernel meal and boiled Jatropha kernel meal showed that the kernel meal contained almost the same ether extract as the boiled kernel meal of 5.0 and 4.3% DM respectively. The crude protein of Jatropha kernel meal was higher (61.8% DM) than boiled jatropha kernel meal (54.0% DM). This is an indication that during the soaking process, some nitrogenous substances in the meal were solubilized. Similar result was reported by Emenike *et al*. (2016) when they subjected raw jackbean to boiling process. However, the metabolic energy showed higher value for the boiled Jatropha kernel meal (3135.8 kcal/kg DM) than Jatropha kernel meal (3091.7 kcal/kg DM). Fakunle *et al*. (2013) obtained similar results with regard to metabolic energy; however, they obtained a higher crude protein level for the boiled jatropha kernel meal than the kernel meal.

Despite the BJKM incorporation, the daily feed intake per broiler chick that received this diet did not vary significantly compared to those who received the control diet (34.1 vs 34.5 g/d/animal). At the end of the experiment, the daily weight gain showed better values for the diet incorporating the boiled jatropha kernel meal than the control diet (15.9 vs 13.5 g/d/animal), a better final weight (272.6 vs 259.3 g) and a better feed conversion ratio (2.2 vs 2.7) for the tested diet compared to the control diet. These results are better than those obtained by Chandrasekar *et al*. (2009), Ojediran *et al*. (2014) who determined the growth performance of broiler chicks that fed from differently processed jatropha kernel meal. Antyev *et al*. (2017) obtained, even if they were lower than those of the control group, better final weight, daily weight gain and feed conversion ratio for broilers fed with diets incorporating either fermented jatropha kernel meal, or boiled jatropha kernel meal, compared to groups of animals that received diets incorporating kernel meal that had undergone other treatment.

Our results have, however, confirmed those of Alatise *et al*. (2014), Abozaid *et al*. (2016) and Musa *et al*. (2018) who evaluated on one hand, the effect of incorporating two levels of boiled jatropha kernel meal in place of soybean meal as a new source of protein on growth performance and carcass composition of Nile tilapia fingerlings, and an other hand, the growth response of *Clarias gariepinus* fingerlings using boiled jatropha kernel as a source of protein. Thus, Musa *et al*. (2018) by processing in boiling water, also have improved the nutritional profile of jatropha kernel meal and its utilization by African catfish *Clarias gariepinus* fingerlings in consonance with the studies of Adebayo *et al*. (2004) and Solomon *et al*. (2017). Our study, like that of these authors, has shown that a thermal regime for processing jatropha kernel meal ensured the improvement of the nutritional content and caused a significant reduction in most anti-nutritional factors of the unconventional feedstuff. These results do not correspond to those obtained by Jimoh *et al*. (2016) where the growth of *clarias gariepinus* reduced with the increase inclusion of cooked *jatropha curcas* due to the presence of anti-nutritional factors and poor digestibility of protein.

Our study did not allow measuring the levels of phorbol esters as well as curcin, but given the reaction of the chicks, without applying a chemical or biological detoxification treatment. It is possible that the presence of toxic factors was not sufficient to cause poor consumption and therefore poor weight gain.

The thermal regime for processing of *J. curcas* kernel meal ensured the improvement of the nutritional content and caused a significant reduction in most anti-nutritional factors of the unconventional feedstuff. In addition, the growth performance of chicks was improved, which was not the case in our previous study where we observed a growth depression and a poor feed conversion ratio in broiler chicks fed with jatropha kernel meal dry heat treated and incorporated in a diet (Nesseim *et al*., 2017).

This study reveals the possibility of utilizing boiled jatropha kernel meal in the diet of chicks. Moreover, the treatment has even positively affected feed intake and weight and it had no impact on the viability of animals.

5. Conclusion

This study was the first field experiment on evaluation of boiled jatropha kernel meal in broiler chicks feeding in Senegal. The results showed that, after a total dehulling, a chemical de-oiling with diethyl ether as well as a heat treatment, jatropha kernel meal did not affect viability, feed intake and growth of

chicks. Further studies must be performed in order to confirm the use of the thermal processes to allow detoxification of *Jatropha curcas* meal.

Acknowledgements

Authors gratefully acknowledge the financial grant provided by the University Commission for Development (*CUD*) of Belgium for carrying out this study, through the inter-university program focused on improvement of agro ecological techniques of agricultural production systems integrating jatropha in the western part of the Senegalese groundnut basin.

References

Abou-Arab A .A. & Abou-Salem M. F., 2010: Nutritional quality of *Jatropha curcas* seeds and effect of some physical and chemical treatments on their nutritional factors. *African Journal of Food Science*, **4**(3), 93-103.

Abo El-Fadel M. H., Hussein A. M. & Mohamed A. H., 2011: Incorporation *Jatropha curcas* meal on lambs ration and it's effect on lambs performance. *Journal of American Science*, **7**(2), 129-132.

Abozaid H., El-Nadi A. S. M., Abusinna G., El-Rahman H. H., Mohamed M. I. & Abedo A. A., 2016: Effect of different levels of boiled jatropha kernel meal on growth performance and carcass composition of Nile tilapia (*Oreochromis niloticus*). *Research Journal of Fisheries and Hydrobiology*, **11**(10), 10-15.

Adebayo O. T., Fagbenro O. A. & Jegede T., 2004: Evaluation of *Cassia fistula* meal as a replacement for soybean meal in practical diets of *Oreochromis niloticus* fingerlings. *Aquaculture Nutrition*, **10**(2), 99-104.

Aderibigbe A. O., Johnson C. O. L. E., Makkar H. P. S., Becker K. & Foidl N., 1997: Chemical composition and effect of heat on organic matter- and nitrogen-degradability and some antinutritional components of jatropha meal. *Animal Feed Science and Technology*, **67**(2), 223-243.

Akinmutimi A. H. & Okwu N. D., 2006: Effect of quantitative substitution of cooked *Mucuna utilis* seed meal for soybean meal in broiler finisher diet. *International Journal of Poultry Science*, **5**(5), 477-481.

Alatise S. P., Adedokun M. A., Adelodun O. B. & Ajiboye G. E., 2014: Effects of boiled jatropha kernel meal as substitute for soybean meal in diet of African Mud Catfish (*Clarias gariepinus*) fingerlings. *Journal of Fisheries and Aquatic Science*, **9**(6), 446-454.

Antyev M., Yakubu B., Aliyara Y. H. & Wafar R. J., 2017: Effects of Processing Methods of *Jatropha curcas* seed Meal on Growth Performance and Blood profile of broiler finisher chickens. *Asian Research Journal of Agriculture*, **4**(4), 1-9.

AOAC, 1990: *Official Methods of Analysis* of the Association of Official Analytical Chemists 15th edn, Arlington, Virginia, 69p.

Apata D. F. & Ojo Y., 2000: Efficacy of the *Trichoderma viride* enzyme complex in broiler starter fed cowpea Testa Based Diets. *Proceedings of 25th Annual Conference of Nigerian Society for Animal Production*. March 19-23, 2000: 132-134.

Aregheore E. M., Makkar H. P. S. & Becker K., 1998: Assessment of lectin activity in a toxic and a non-toxic variety of *Jatropha curcas* using latex agglutination and haemagglutination methods and inactivation of lectin by heat treatments. *Journal of the Science of Food and Agriculture*, **77**(3), 349-352.

Aregheore E. M., Becker K. & Makkar H. P. S., 2003: Detoxification of a toxic variety of *Jatropha curcas* using heat and chemical treatments, and preliminary nutritional evaluation with rats. *The South Pacific Journal of Natural Science*, **21**(1), 51-56.

Asseleih L. M. C., Plumbley R. A. & Hylands P. J., 1989: Purification and partial characterization of a hemagglutinin from seeds of *Jatropha curcas*. *Journal of Food Biochemistry*, **13**(1), 1-20.

Ayssiwede S. B., Chrisostome C., Ossebi W., Dieng A., Hornick J.-L. et Missohou A., 2010: Utilisation digestive et métabolique et valeur nutritionnelle de la farine de feuilles de *Cassia tora* (Linn.) incorporée dans la ration alimentaire des poulets indigènes du Sénégal. *Revue de Médecine Vétérinaire*, **161**(12), 549-558..

Becker K. & Makkar H. P. S, 1998: Effects of phorbol esters in carp (*Cyprinus carpio* L.). *Veterinary & Human Toxicology*, **40**(2), 82-86.

Belewu M. A. & Sam R., 2010: Solid state fermentation of *Jatropha curcas* kernel cake: proximate composition and antinutritional components. *Journal of Yeast and Fungal Research*, **1**(3), 44-46.

Chandrasekar S., Reddy V. R. & Reddy A. R., 2009: Effect of feeding differently processed jatropha (*Jatropha curcas*) cake on the performance of broilers. *Indian Journal of Poultry Science*, **44**(3), 352-357.

Dahouda M., Toleba S. S., Youssao A. K. I., Mama Ali A. A., Ahounou S. et Hornick J.-L., 2009: Utilisation des cossettes et des feuilles de manioc en finition des pintades (*Numida meleagris* L.) : performances zootechniques, coûts de production, caractéristiques de la carcasse et qualité de la viande. *Annales de Médecine Vétérinaire*, **153**, 82-87.

Devappa R. K. & Swamylingappa, 2008: Biochemical and nutritional evaluation of jatropha protein isolate prepared by steam injection heating for reduction of toxic and antinutritional factors. *Journal of the Science of Food and Agriculture*, **88**(5), 911-919.

Diaw M. T., Dieng A., Mergeai G., Camara A. et Hornick J.-L., 2012: Effet de la substitution totale du tourteau d'arachide par la fève de coton glandless sur les performances zootechniques de poulets de chair au Sénégal. *Revue d'Elevage et de Médecine Vétérinaire des Pays Tropicaux*, **65**(1-2), 17-23.

Eckart K. & Henshaw P., 2012: *Jatropha curcas* L. and multifunctional platforms for the development of rural sub-

Saharan Africa. *Energy for Sustainable Development*, **16**(3), 303-311.

Emenike H. I., Udedibie A. B. I. & Emenalom O. O., 2016: Effects of differently processed jackbean (*Canavalia ensiformis*) meals on the performance of grower pigs. *British Journal of Applied Science & Technology*, **13**(6), 1-8.

Fakunle J. O., Alatise S. P., Effiong B. N. & Tiamiyu K., 2013: Effects of replacing soyabeans meal with graded levels of boiled jatropha kernel meal in diets of *Clarias gariepinus* fingerlings. *Bulletin of Environment, Pharmacology and Life Sciences*, **2**(9), 112-117.

Francis G., Makkar H. P. S. & Becker K., 2002: Products from little researched plants as aquaculture feed ingredients. AGGRIPA [Online] Available at http://www.fao.org/DOCREO/ARTICLE/AGRIPPA/SSIEN.HTMLTOP (Accessed: 19 march 2020)

Gandhi V. M., Cherian K. M. & Mulky M. J., 1995: Toxicological studies on ratanjyot oil. *Food and Chemical Toxicology*, **33** (1), 39-42.

Gubitz G. M., Mittelbach M. & Trabi M., 1999: Exploitation of the tropical oil seed plant *Jatropha curcas* L. *Bioresource Technology*, **67**(1), 73-82.

Haas W. & Mittelbach M., 2000: Detoxification experiments with the seed oil from *Jatropha curcas* L. *Industrial Crops and Products*, **12**(2), 111-118.

He W., King A. J., Khan M. A., Cuevas J. A., Ramiaramanana D. & Graham I.A., 2011: Analysis of seed phorbol-ester and curcin content together with genetic diversity in multiple provenances of *Jatropha curcas* L. from Madagascar and Mexico. *Plant Physiology and Biochemistry*, **49**(10), 1183-1190.

Heller J., 1996: Promoting the conservation and use of underutilized and neglected crops. 1. Physic nuts *Jatropha curcas* L. International Plant Genetic Resources Institute, Rome, 66p. http://www.bionica.info/biblioteca/Heller1996Jatropha.pdf (Accessed: 19 march 2020)

Jimoh W. A., Aderolu Z. A., Oladele-Bukola M. O., Abdulasalami S. A. & Okermakin F. Y., 2016: Growth performance of *Clarias gariepinus* fingerlings fed graded levels of dietary cooked *Jatropha curcas* seed meal-based diets. *The Egyptian Journal of Experimental Biology (Zoology)* **12**(1): 87-91.

Jørgensen H., Zhao X.-Q., Knudsen K. E. B. & Eggum B. O., 1996: The influence of dietary fibre source and level on the development of the gastrointestinal tract, digestibility and energy metabolism in broiler chickens. *British Journal of Nutrition*, **75**(3), 379-395.

Joshi C., Mathur P. & Khare S. K., 2011: Degradation of phorbol esters by *Pseudomonas aeruginosa* PseA during solid-state fermentation of deoiled *Jatropha curcas* seed cake. *Bioresource Technology*, **102**(7), 4815-4819.

Kenis M., Kone N., Chrysostome C. A. A. M., Devis E., Koko G. K. D., Clottey V. A., Nacambo S., Mensah G. A., 2014: Insects used for animal feed in West Africa. *Entomologia*, **2**(218), 107-114.

Kumar V., Makkar H. P. S. & Becker K., 2010b: Nutritional, physiological and haematological responses in rainbow trout (*Oncorhynchus myskiss*) juveniles fed detoxified *Jatropha curcas* kernel meal. *Aquaculture Nutrition*, **17**(4), 451-467.

Lin J., Fang Y., Lin T. & Fang C., 2003: Antitumor effects of curcin from seeds of *Jatropha curcas*. *Acta Pharmacologica Sinica*, **24**(3), 241-246.

Makkar H. P. S., Aderibigbe A. O. & Becker K., 1998a: Comparative evaluation of non-toxic and toxic varieties of *Jatropha curcas* for chemical composition, digestibility, protein degradability and toxic effects. *Food Chemistry*, **62**(2), 207-215.

Makkar H. P. S. & Becker K., 2009: *Jatropha curcas*, a promising crop for the generation of biodiesel and value-added coproducts. *European Journal of Lipid Science and Technology*, **111**(8), 773-787.

Makkar H. P. S., Becker K., Nitis I. M. & Shin M. T., 1999: Plant toxins and detoxification methods to improve feed quality of tropical seeds. *Asian-Australasian Journal of Animal Sciences*, **12**(3), 467-480.

Makkar H. P. S., Becker K. & Schmook B., 1998b: Edible provenances of *Jatropha curcas* from Quintana Roo state of Mexico and effect of roasting on antinutrient and toxic factors in seeds. *Plant Foods for human nutrition*, **52**(1), 31-36.

Makkar H. P. S., Becker K., Sporer F. & Wink M., 1997: Studies on nutritive potential and toxic constituents of different provenances of *Jatropha curcas*. *Journal of Agricultural and Food Chemistry*, **45**(8), 3152-3157.

Makkar H. P. S., Martinez-Herrera J. & 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 of Plant Sciences*, **3**(4), 260-265.

Martinez-Herrera J., Ayala A. L. M., Makkar H. P. S., Francis G. & Becker K., 2010: Agroclimatic conditions, chemical and nutritional characterization of different provenances of *Jatropha curcas* L. from Mexico. *European Journal of Scientific Research*, **39**(3), 396-407.

Martinez-Herrera J., Siddhuraju P., Francis G., Davila-Ortiz G. & Becker K., 2006: Chemical composition, toxic/antimetabolic constituents, and effects if different treatments on their levels, in four provenances of *Jatropha curcas* L. from Mexico. *Food Chemistry*, **96**(1), 80-89.

Musa S. O., Tiamiyu L. O., Solomon S. G., Ayuba V. O. & Okomoda V. T., 2018: Nutritional value of hydrothermally processed *Jatropha curcas* kernel and its effect on growth and hematological parameters of *Clarias gariepinus* fingerlings (Burchell, 1822). *Aquaculture Reports*, **10**, 32-38.

Nithiyanantham S., Siddhuraju P. & Francis G., 2012: Potential of *Jatropha curcas* as a biofuel, animal feed and products. *Journal of the American Oil Chemists' Society*,

89(6), 961-972.

Nesseim T. D. T., Dieng A., Mergeai G., Ndiaye S. & Hornick J.-L., 2015: Digestibility of solvent-treated *Jatropha curcas* kernel by broiler chickens in Senegal. *Tropical Animal Health and Production*, **47**(8), 1553-1560.

Nesseim T. D. T, Dieng A., Mergeai G. & Hornick J.-L., 2017: Effects of defatting combined or not to heating of *Jatropha curcas* kernel meal on feed intake and growth performance in broiler chickens and chicks in Senegal. *Tropicultura*, **35**(3), 149-157.

Nesseim T. D. T, Benteboula M., Dieng A., Mergeai G., Marechal F. & Hornick J.-L., 2019: Effects of partial dietary substitution of groundnut meal by defatted, *Aspergillus niger*–fermented and heated *Jatropha curcas* kernel meal on feed intake and growth performance of broiler chicks. *Tropical Animal Health and Production*, **51**(6), 1383-1391.

National Research Council, 1994: Nutrient Requirements of Poultry Ninth Revised Edition, 176p.

Ojediran T. K., Adisa Y. A., Yusuf S. A. & Emiola I. A., 2014: Nutritional evaluation of processed *Jatropha curcas* kernel meals: effects on growth performance of broiler chicks. *Journal of Animal Science Advances*, **1**(11), 1110-1121.

Ojo R. J., Oguche P. L., Kube G. D., & Udzer T. E. L., 2013: Effect of *Jatropha curcas* supplemented diet on broilers. *Scholars Academic Journal of Biosciences*, **1**(6), 329-336.

Palacios M. F., Easter R. A., Soltwede K. T., Parsons C. M., Douglas M. W., Hymowitz T. & Pettigrew J. E., 2004: Effect of soybean variety and processing on growth performance of young chicks and pigs. *Journal of Animal Science*, **82**(4), 1108-1114.

Roach J. S., Devappa R. K., Makkar H. P. S. & Becker K., 2012: Isolation, stability and bioactivity of *Jatropha curcas* phorbol esters. *Fitoterapia*, **83**(3), 586-592.

Sibbald, I. R., 1976: The true metabolizable energy values of several feeding stuffs measured with roosters, laying hens, turkeys and broiler hens. *Poultry Science*, **55**(4), 1459-1463.

Solomon S. G., Okomoda V. T. & Onah R. E., 2017: Nutritional profile of soaked *Cajanus cajan* (L.) Millsp. and its utilization as partial replacement for soybean meal in the diet of *Clarias gariepinus* (Burchell, 1822) fingerlings. *Journal of Applied Ichthyology*, 33(3), 450-457.

Sumiati S., Mutia R. & Damansyah A., 2012: Performance of layer hen fed fermented *Jatropha curcas* L. meal supplemented with cellulose and phytase enzyme. *Journal of Indonesian Tropical Animal Agriculture*, **37**(2), 108-114.

Tambunan A. H., Situmorang J. P., Silip P. P., Joelianingsih A. & Araki T., 2012: Yield and physicochemical properties and mechanically extracted *Jatropha curcas* L. oil. *Biomass and Bioenergy*, **43**, 12-17.

Traore E. H., 2014: Secteur avicole Sénégal. Revues nationales de l'élevage de la division de la production et de la santé animales de la FAO, **7**, Rome, 70p.

Willems O. W., Miller S. P. & Wood B. J., 2013: Aspects of selection for feed efficiency in meat producing poultry. *World's Poultry Science journal*, **69**(1), 77-88.