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REGULAR ARTICLES

Digestibility of solvent-treated *Jatropha curcas* kernel by broiler chickens in Senegal

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Abstract *Jatropha curcas* is a drought-resistant shrub belonging to the *Euphorbiaceae* family. The kernel contains approximately 60 % lipid in dry matter, and the meal obtained after oil extraction could be an exceptional source of protein for family poultry farming, in the absence of curcin and, especially, some diterpene derivatives phorbol esters that are partially lipophilic. The nutrient digestibility of *J. curcas* kernel meal (JKM), obtained after partial physicochemical deoiling was thus evaluated in broiler chickens. Twenty broiler chickens, 6 weeks old, were maintained in individual metabolic cages and divided into four groups of five animals, according to a 4×4 Latin square design where deoiled JKM was incorporated into grinded corn at 0, 4, 8, and 12 % levels (diets 0, 4, 8, and 12 J), allowing measurement of nutrient digestibility by the differential method. The dry matter (DM) and organic matter (OM) digestibility of diets was affected to a low extent by JKM (85 and 86 % in 0 J and 81 % in 12 J, respectively) in such a way that DM and OM digestibility of JKM was estimated to be close to 50 %. The ether extract (EE) digestibility of JKM remained high, at about 90 %, while crude protein (CP) and crude fiber (CF) digestibility were largely impacted by JKM, with values closed to 40 % at the highest levels of incorporation. *J. curcas* kernel presents various nutrient digestibilities but has adverse effects on CP and CF digestibility of the diet. The effects of an additional heat or biological treatment on JKM remain to be assessed.

Keywords Broiler chickens · *Jatropha curcas* · Digestibility

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Introduction

In tropical environment, nutrient and feed supplies are limiting factor in broiler production due to competition between man and poultry and also to poorly locally available or valuable feed resources (Steinfeld et al. 2006). Increasing need for high-quality protein in poultry livestock stresses the search for new sources of protein that do not interfere with the food security rights. Thus, the non-food oil seeds and their by-products could be feed of choice provided that they are free of toxic and anti-nutritional factors (Sivaramakrishnan and Gangadharan 2009).

Jatropha curcas is a wild drought-resistant shrub belonging to the *Euphorbiaceae* family, which can grow in marginal wastelands and is often used for soil erosion control (Levingston and Zamora 1983). It is easily propagated by cutting (Heller 1996) and planted as a fence to protect fields or concessions because it is not consumed by animals. Up to now, the plant has not yet been really domesticated, but all parts of the plant are used for traditional and veterinary purposes (Duke 2002). The nut of *J. curcas* is commonly known as *physic* or *purging nut* but also is called *pourghere* in French or *tabanani* in Senegal. The fruit, main crop material, contain one to four seeds, consisting of shells (35 %) and kernel (65 %). The oil content of the seeds is about 22 to 48 % (Becker and Makkar 2008), traditionally obtained by mechanical pressure (Beerens 2007) or extracted with solvents. It can be converted into biodiesel by transesterification (Foidl et al. 1996) or used in traditional oil lamps and for soap production (Henning 2003). About one fifth of the fatty acids are saturated (Vaknin et al. 2011). Jatropha cake is nitrogen-rich and a very good soil fertilizer (Heller 1996).

The kernel meal, obtained after oil extraction, contains about 500 g/kg dry matter (DM) of crude protein (Aderibigbe et al. 1997). Moreover, the amino acid profile, except lysine, is comparable with that for the FAO reference protein (Makkar et al. 1998).

The use of jatropha meal in animal feed remains however limited. The seed was found to be toxic for children (Abdu-Aguye and Sannusi 1986) and for several species such as cattle (Ahmed and Adam 1979a), sheep and goat (Ahmed and Adam 1979b), rat and rabbit (Gandhi et al. 1995), and fish (Becker and Makkar 1998).

Jatropha toxicity was initially suggested to be due to curcin, a lectin with a sharp inhibitory effect on protein synthesis (King et al. 2009). It was then established that the main toxic compounds in kernel, oil, and cake are diterpene derivatives classified as phorbol esters (Makkar et al. 1997). They act on biological membranes and directly activate protein kinase C, an enzyme which plays an essential role in the transduction signal regulating cell growth and differentiation (Aitken 1987). In addition, the nut by-products contain anti-nutritional factors such as trypsin inhibitors, saponins, and phytate which interfere with digestive process in animals (Aderibigbe et al. 1997).

Seeds, cake, or oil should be detoxified before being used as feed. Detoxification methods are essentially chemical. Martinez-Herrera et al. (2006) decreased the phorbol ester content in oil cakes by 98 %, using an ethanol extraction. The results were better than using methanol (Aregheore et al. 2003; Ahmed and Salimon 2009; Gaur 2009; Devappa et al. 2010) or hexane (Chivandi et al. 2004; Rakshit et al. 2008) for which authors reached out extraction rates of 92 and 89 %, respectively. Biological methods of detoxication were described. Belewu et al. (2010) reduced phorbol esters by 77 % and other anti-nutritional substances such as saponins by 95 % by inoculating jatropha cake with *Aspergillus niger*.

The objective of this study was to investigate in Senegal, the nutrient digestibility in broiler chickens of *J. curcas* kernel meal physicochemically deoiled in order to remove phorbol esters out of the product.

Materials and methods

Location of the experiment

The experiment was conducted in *Ecole Nationale Supérieure d'Agriculture* (*ENSA*), University of Thies (Senegal), in 2012 and was repeated in 2013 at the beginning of the rainy season (June–July). This period was characterized by an average temperature ranging from 25.9 to 35.4 °C and a relative humidity from 40.4 to 80.5 %.

Preparation of the jatropha kernel meal and diet formulation

Thirty-five kilograms of mature and dry seeds of *J. curcas* was collected each year from Dialacoto, Senegal. The seeds were cracked and unshelled manually to obtain kernels, which were grinded to get a jatropha kernel paste (JKP).

A residual level of ether extract (EE) lower than 100 g/kg dry matter (DM) was judged to be adequate to perform the trial. Oil extraction with petroleum ether (boiling range 40–60 °C) was assessed diluting 1 vol ether in 1 vol JKP, assuming a homogeneous distribution of the solvent in the mass. The residual oil content has peaked at 400 g/kg DM. Consequently, it was decided to combine a mechanical pressure with solvent extraction. Finally, the JKP was defatted by four alternated phases of 24-h soaking in a bucket of petroleum ether (1:1 vol) and pressing with a manual perforated cylinder press. After last soaking, the paste was spread left to dry for 24 h in order to remove the residual ether.

Defatted jatropha kernel meal (JKM) looked like a fine white powder. It was then incorporated into grinded corn at levels of 40, 80, and 120 g/kg (diets 4, 8, and 12 J). The control diet (0 J) consists of grinded corn.

Animals and housing

Two consecutive years, 20 unsexed broiler chickens, strain Ross white, 6 weeks old, initial weight 1848±314 g in 2012 and 1411±160 g in 2013, were used. Animals were divided into four groups of five subjects, corresponding to the four dietary treatments. They were distributed in a randomized complete experimental block consisting of metabolic cages with five repetitions. These metabolic cages, according to the model described by Dahouda et al. (2009), (L × w × h 75×40×45 cm), were installed in a ventilated room and placed 50 cm above the ground. Made of galvanized sheet metal, they presented a grilling on the upper and front and were sealed on the side and rear parts. Each cage was provided with a trough for the distribution of feed and water and was opened in the upper part while the lower part was equipped with a tray that allowed collecting separately feces as well as water and feed spills.

At the beginning of the experiments, animals were adapted to their new environment for 1 week during which they received the control diet. This period was planned to allow animals to accommodate to their environment and to estimate feed intake. Thereafter, each group received for 7 days a given ration which was then randomly re-allocated to another group the three following weeks, according to a Latin square design. Each week, measurements were performed from day 3 to day 7.

Feed was weighed early in the morning and provided two times per day. For each animal, food refusals were collected and weighed the day following the distribution. During the test, water was available ad libitum.

Fattening performance and nutrient digestibility

During the experiment, the weight of the broiler chickens was determined at the beginning and the end of each Latin square period. The daily individual amounts of feed intake (distributed—refused) and feces excreted were recorded and subsampled for dry matter determination. At the end of the experiment, materials collected were crushed and pooled by groups and by period for chemical analysis. Apparent digestibility coefficients (ADCs) were thus determined on each animal for dry matter and on group period for nutrients, following the formula:

$$\text{ADC }(\%) = [(\text{nutrient intake} - \text{nutrients in excretas})/\text{nutrient intake}] \times 100.$$

The differential apparent digestibility coefficient (Diff ADC) for the jatropha kernel meal incorporated at X% (Diff ADC at X) was also determined, compared to that of corn, on each animal for dry matter and on group periods for nutrients, following the formula:

$$\text{Diff ADC at } X(\%) = [\text{ADC nutrient at X\%}-(\text{ADC corn nutrient x }(1-X))]/(1-X)$$

Chemical analyses

Chemical analyses were performed according to the procedures of AOAC (1990). Crude protein (CP) was determined by the Kjeldahl method (N × 6.25), EE by the Soxhlet method, and crude fiber (CF) by the method of Weende.

Statistical analysis

Data were analyzed according to the following general linear model (proc GLM, SAS…):

$$Yijkl = \mu + Ti + Pj + Uk + Sl + Am(Sl) + Eijklm$$

where

Yijkl	The experimental data
Ti	Fixed effect of the treatment i (i=1 to 4)
Pj	Fixed effect of the period j (j=1 to 4)
Uk	Random effect of the experimental group k (k=1 to 4)
Sl	Random effect of the square (or year) l (l=1 to 2)
Am(S1)	Random effect of animal m (m=1 to 5) nested within square l
Eijklm	Random residual effect, N[0, 1]

Animal effect is optional according to the level of the experiment unit.

Multiple comparisons were performed according to Student's test, adjusted by Tukey method.

Results

Chemical composition of diets

Table 1 showed chemical composition of the raw and physicochemically deoiled kernels and of the different experimental diets.

The proximate compositions of refusals and feces are indicated in Table 2. Kernel contained more than 600 g/kg DM EE and about a quarter of CP, while CF, ash, and non-nitrogen extract (NNE) remained close to 50 g/kg DM. The level of EE in kernel meal was quite lower than the objective of 100 g/kg DM. As a consequence, CP represented more than a half of material, followed with NNE (about a quarter of DM). While CF remained close to 50 g/kg DM, ash increased to about 100 g/kg DM. As a consequence, the levels of CP in diets increased with kernel incorporation (from about 100 to 130 g/kg DM), by contrast to CF and EE, the value of which being close to 30 and 60 g/kg DM, respectively.

Overall, refusals were characterized by similar values as to feeds. Feces contained about twice the value of CP observed in feeds, i.e., increase with the level of kernel incorporation, and about the triple of CF. In parallel, the NNE remained close to 600 g/kg DM.

Table 1 Proximate composition of raw materials

	DM (%)	Chemical composition (% in DM)					
		OM	CP	EE	CF	Ash	NNE
Kernel	95.69	95.78	24.55	60.63	6.37	4.22	4.23
Kernel meal	90.92	89.41	51.77	6.53	4.72	10.59	26.39
Diet 0 J	89.44	98.14	8.95	4.95	3.02	1.85	81.23
Diet 4 J	89.69	97.75	10.36	5.41	2.97	2.25	79.01
Diet 8 J	89.68	97.30	11.37	5.00	2.58	2.70	78.36
Diet 12 J	89.78	96.91	12.94	6.34	3.27	3.09	74.36

DM dry matter, *MO* organic matter, *CP* crude protein, *EE* ether extract, *CF* crude fiber, *NNE* non-nitrogen extract, *diet 0 J* control diet (grinded corn), *diet 4 J* to *12 J* 4 to 12 % jatropha kernel meal in grinded corn

Table 2 Composition of refusal and feces of broiler chickens offered different incorporation level of *Jatropha curcas* meal in diet

	DM (%)	Chemical composition (% in DM)					
		OM	CP	EE	CF	Ash	NNE
Refusals 0 J	90.25	96.69	9.50	3.19	2.65	3.31	78.96
Refusals 4 J	91.50	96.99	11.50	3.51	2.57	3.01	78.06
Refusals 8 J	91.75	96.80	13.25	3.65	2.82	3.20	77.33
Refusals 12 J	90.75	96.77	14.25	4.44	2.67	3.23	77.06
Feces 0 J	92.78	94.03	19.40	4.99	7.69	5.97	63.68
Feces 4 J	92.90	93.23	21.87	4.99	7.66	6.77	58.71
Feces 8 J	92.94	92.11	22.61	5.04	7.14	7.89	60.32
Feces 12 J	92.94	92.09	23.64	6.25	7.91	7.91	54.29

DM dry matter, OM organic matter, *CP* crude protein, *EE* ether extract, *CF* crude fiber, *NNE* non-nitrogen extract, *diet 0 J* control diet (grinded corn), *diet 4 J* to *12 J* 4 to 12 % jatropha kernel meal in grinded corn

Fattening performance and digestibility

Table 3 presents animal performance of broiler chickens fed graded levels of processed jatropha kernel meal in grinded corn. Neither mortality nor signs of toxicity were recorded. Control animals had a higher level of daily intake at about 50 g/day than other groups. Feed intake decreased linearly with the level of jatropha incorporation: about 2 g per unit increase. Value in the 12 J group reached about half that of the control group. Fecal DM excretion also linearly decreased with jatropha incorporation, at about 1 g at each step of increase. The treatments had dramatic influences on weight gains. If a quasi-steady state was observed in the control group, animals from 4 J lost about 9 g/day, values doubled at levels 8 and 12 J.

Owing to a proportionally low level of DM fecal excretion when compared to feed intake, apparent dry matter digestibility (ADMD) coefficient was higher than 80 % in the different group (Table 4) but decreased significantly ($P<0.05$) and linearly with the level of incorporation of *J. curcas*, allowing to extrapolate a ADMD of 53.6 % at a theoretical 100 % incorporation of *J. curcas* meal.

The apparent organic matter digestibility (AOMD) followed a similar evolution as to DM, with close but slightly higher values. The apparent crude protein digestibility (ACPD), as for it, decreased sharply significantly ($P<0.05$) with the level

Table 4 Effect of different level of incorporation of *Jatropha curcas* meal in diet of broiler chickens on apparent nutrient digestibility

	Treatments				$P>F$	SEM
	Control	4 J	8 J	12 J		
ADMD (%)	84.85[a]	82.98[a]	82.58[a]	80.84[b]	0.030	0.38
AOMD (%)	86.19[a]	84.04[b]	85.06[ab]	81.44[c]	0.001	0.38
AEED (%)	83.53	87.43	77.90	85.89	0.618	5.29
ACPD (%)	51.69[a]	41.30[ab]	34.39[b]	39.36[ab]	0.019	2.74
ACFD (%)	37.56	29.22	0.48	38.22	0.166	11.45

ADMD apparent dry matter digestibility, *AOMD* apparent organic matter digestibility, *AEED* apparent ether extract digestibility, *ACPD* apparent crude protein digestibility, *ACFD* apparent crude fiber digestibility. Different superscripts within one column indicate differences between groups ($P<0.05$)

of *J. curcas* incorporation, with 34 % at the 8 J level of incorporation. The apparent ether extract digestibility (AEED) was high at about 84 % and did not show significant difference between groups ($P>0.05$) but without clear evolution, the 4 J diet showing the highest values at 87 %. The apparent crude fiber digestibility (ACFD) was the lowest out of all other components and showed similar evolution as to EE: The difference between groups was significant but values decreased with the levels of *J. curcas* incorporation, reaching 0 at the highest level.

The differential apparent digestibility coefficient (Table 5) of the jatropha kernel meal was obtained compared to the control diet which is the corn. Thus, values ranging from 52.70 % for 4 J to 63.99 % for 12 J were obtained from the dry matter. Concerning the organic matter, the values ranged from 51 % for 4 J and 68.81 % obtained for 8 J. As against, as regards the crude protein, the differential apparent digestibility remains negative whatever supplemented diet.

Discussion

The extract of vegetable oil from seeds is mainly based on two processes which are mechanical pressing and solvent extraction. Mechanical screw press is a mean of oilseed crushing to small and medium scale (Zheng et al. 2003). In order to fully remove weakly digestible sheathes and thus to study the

Table 3 Effect of different incorporation level of *Jatropha curcas* meal in diet of broiler chickens on dry matter feed intake and feces production and on weight gain

	Treatments				$P>F$	SEM
	Control	4 J	8 J	12 J		
DM feed intake (g/day)	49.3±2.9[a]	40.0±4.2[b]	31.8±4.6[c]	26.4±5.9[c]	0.000	1.20
DM feces (g/day)	7.5±0.6[a]	6.4±0.1[ab]	5.1±0.4[bc]	4.3±0.3[c]	0.005	0.39
Weight gain (g)	4.0±2.4[a]	−36.8±10.9[ab]	−72.0±56.2[b]	−74.8±13.8[b]	0.002	8.50

Table 5 Differential apparent digestibility coefficient of *Jatropha curcas* based on its incorporation in diets

	Treatments			$P>F$	SEM
	4 J	8 J	12 J		
Diff ADMD (%)	52.70[b]	61.73[b]	63.99[a]	0.010	9.73
Diff AOMD (%)	51.05[b]	68.81[a]	68.10[a]	0.000	5.46
Diff ACPD (%)	−70.14	−85.16	−0.36	0.800	77.68

Diff ADMD differential apparent dry matter digestibility, *Diff AOMD* differential apparent organic matter digestibility, *Diff ACPD* differential apparent crude protein digestibility

specific effects of kernels on poultry, seeds were shelled manually. After shell removing, the kernels contained between approximately 600 g/kg DM of EE. These values are somewhat higher than those obtained by Aderibigbe et al. (1997); Makkar et al. (1998); Martinez-Herrera et al. (1998); Achten (2010), and Kumar et al. (2010).

The following use of screw press did not permit oil extraction but grinded the jatropha kernel as a paste. This confirms the negative effect of shelling on oil yield during crushing (Beerens 2007). To overcome this difficulty, petroleum ether was used to allow oil extraction from the paste. The solvent is a special gasoline G type, colorless liquid, of low viscosity and very good solvent of greases (Brondeau et al. 1999). It allows direct extraction by exhaustion. However, its flammability, toxicity, and price indexed to oil prices are major disadvantages of its use (Johnson 2008).

The deoiling process used yielded a meal containing about 6.5 % ether extract in dry matter. This value is lower than those obtained by Aderibigbe et al. (1997) with a partial deoiling but higher than those obtained by the same authors and Makkar et al. (1998) with a totally defatted meal. These differences in results compared to the method used can be explained by the process of deoiling. Indeed, the last authors implemented a soxhlet deoiling which eliminates all the fat of the matter. Soaking method used presently, more compatible with a field experiment, left a significant amount of fat.

Chemical analyzes made on JKM showed that it mainly consist of crude protein and EE (580 g/kg in DM). The levels of crude protein and ash were similar with those obtained by Aderibigbe et al. (1997); Makkar et al. (1997); Makkar et al. (1998); Achten et al. (2008) and Lago (2009), but the values in EE and especially in crude fiber were higher.

Over the 2 years, the crude protein values remain higher than that the soybean meal, thus confirming the nutritional profile of deoiled jatropha kernel. Diets offered for digestibility showed a crude protein content of between 8 and 13 % DM, depending on the level of incorporation of the JKM. These values are far below those recommended for production (INRA 1989).

In our study, the daily intake per broiler chicken was inversely dependent on the incorporation rate of the JKM resulting in lower weight gain. This decline is probably related of palatability as animals systematically reduced their consumption whenever they were exposed to jatropha. It was reported that feed intake is influenced by a variety of factors, such as taste, smell, and texture of the diet (Temler et al. 1983). However, it must be noted that the experimenters did not detect any unpleasant smell or taste with regard to the kernel. It was also noted that the excretion of feces was mechanically proportional to the ingestion of diets. Thus, animals that ingested the control diet showed, as expected, the highest values of feces.

Dry matter intake and body weight gain were significantly ($P<0.05$) lower in all incorporated jatropha kernel groups in comparison with control group. This is probably due to the presence of phorbol esters and poor protein utilization in the diets (Aregheore et al. 2003). Phorbol esters which are the main toxins in *J. curcas* (Makkar and Becker 2009) were found to be responsible for purgative and skin-irritant effects (Adolf et al. 1984).

The reduced body weight during experiments was due to both reduced intake but also poor protein utilization. In this respect, trypsin inhibitors and curcin are known to decrease the weight gain performance of animals (Francis et al. 2001) and were related to the level of jatropha kernel in the diet. Tryspin inhibitors are anti-nutritional factors which interfere with the physiological process of digestion in non-ruminants, leading to severe growth depression (White et al. 2000). Oladunjoye et al. (2014) observed a similar growth depression due to residual anti-nutritional factors, by fermenting *A. niger* on jatropha kernel meal.

For defatted and untreated jatropha kernel meal, Aderibigbe et al. (1997) measured a trypsin inhibitor activity to about 20 mg/g of sample. Heat treatments reduced this activity to 0.2 mg/g of sample, showing the thermo labile character of the toxin. The effect of heat treatment was confirmed by Abou-Arab and Abu-Salem (2010). In our case, the kernel of jatropha was defatted without heat treatment. Trypsin inhibitors were still present and probably contribute to interference with the physiological digestive process in poultry. These observations are in agreement with those made by Makkar et al. (1998), Makkar and Becker (1999), and Kumar et al. (2010) who showed adverse physiological effects in monogastric and therefore a decrease in voluntary intake and reduced weight gain for animals subjected to diets with unheated jatropha kernel meal.

Furthermore, Makkar et al. (1997) showed that the most important toxic principle on jatropha seed is represented by phorbol esters which are thermo stable (Aregheore et al. 2003). In addition, the mode of extraction of oil has an impact on the level of phorbol esters which remain high with a press extraction (Beerens 2007). Chemical deoiling of jatropha kernel, followed by a physicochemical detoxification treatment does not cause a complete removal of toxic factors including phorbol esters (Kumar et al. 2010). Its inclusion in diets thus caused a decrease in feed intake and a weight gain reduction on monogastrics. In spite of chemical treatments (sodium chloride and calcium hydroxide) that decreased phorbol esters and hemagglutination activity, Katole et al. (2011) also observed a reduced nutrient intake. Also, Annongu et al. (2010), confirmed by Abdel-Shafy and Nasr (2010), showed a tolerance in diets containing physicochemically treated jatropha kernel meal up to 15 %. Beyond, mortality was recorded, showing a cumulative effect of toxic factors, including phorbol esters. Monogastrics show great sensibility to this compound in feed (Becker and Makkar 1998). They showed intestinal irritation and thus feed rejection due to the residual effects of the toxins.

The apparent digestibility of dry matter, organic matter, and ether extract remained over 80 % for all diets. As against, concerning the apparent crude protein and crude fiber digestibility, values ranged from 60 % to almost 0 by the rate of incorporation the JKM in the grinded corn. These results show a low nitrogen and fiber retention rate when compared of other nutrients.

Concerning the in vitro protein digestibility, lowest values were observed for defatted samples because of high content in trypsin inhibitor (Martinez-Herrera et al. 2006). Samples which were submitted to heat treatment, improved their digestibility by about 7 % owing to the denaturation and inactivation of protease inhibitors (Carbonaro et al. 1997). These results were confirmed with carp by Kumar et al. (2010) whose obtained a good apparent digestibility of protein (89–92 %) from the defatted jatropha kernel meal after phorbol ester removal and inactivation not only trypsin inhibitors but also lectin by heat treatment. Thus, the probable presence of trypsin inhibitors in the jatropha kernel meal used lowered apparent digestibility of proteins by interaction with proteolytic enzymes (Hajos et al. 1995). Using a enzymatic hydrolysis of phorbols, followed by washing with ethanol, Xiao et al. (2011) decreased by 100 % phorbol esters and anti-nutritional components to tolerable levels. They increased also the in vitro protein digestibility by 11 %. In the present experiment, not only the protein digestibility of the diet, per se, was weak but probably also toxins enhanced endogenous protein losses, explaining why the differential digestibility of jatropha was negative. Moreover, the lower crude fiber digestibility in diets containing jatropha suggests also a negative effect of jatropha on caeca flora.

Finally, the low protein digestibility in the present experiment is probably explained by the weak protein availability of the jatropha kernel meal (Kumar et al. 2010) incorporated in corn and the presence of anti-nutrients which could affect adversely feed utilization.

This study was the first field experiment of valuation of jatropha kernel seed in poultry feeding in Senegal. The results showed that, despite total dehulling and chemical deoiling using petroleum ether, jatropha kernel still has a strong negative effect of feed intake and on protein and fiber digestibility. The present approach to produce jatropha meal is not economically profitable, owing the amounts of solvent and work required. However, we hypothesize that when the sector of oil production will be mature, it will account for the use of this by-product the feed value of which is close to that of soybean meal and for all that it could be adequately detoxified.

Further studies must be performed in order to assess individual and combined effects of thermal, chemical, and biological detoxification processes on jatropha seeds.

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Conflict of interest The authors declare that they have no conflict of interest.

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