https://doi.org/10.22319/rmcp.v11i3.5797

Article

Detoxified castor meal in broiler chickens' diets

Anabel Maldonado Fuentes [a]

Juan Manuel Cuca García [a]

Arturo Pro Martínez [a]*

Fernando González Cerón [b]

José Guadalupe Herrera Haro [a]

Eliseo Sosa Montes [b]

Pablo Alfredo Domínguez Martínez [c]

[a] Colegio de Postgraduados, Campus Montecillo, PRGP- Ganadería, Estado de México, México.

[b] Universidad Autónoma Chapingo, Departamento de Zootecnia, Estado de México, México.

[c] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Departamento de Producción Animal, Estado de Durango, México.

*Corresponding author: aproma@colpos.mx

Abstract:

Castor (*Ricinus communis* L.) meal contain highly toxic substances. Three detoxification methods were evaluated for their effectiveness and their inclusion in diets for broilers. Five treatments (experimental diets) were evaluated: control diet based on corn and soybean meal (SM), non-detoxified castor meal (NDC), autoclaved castor meal (AC), chemically treated castor meal (ChC) and autoclave and chemical methods treated castor meal (AChC). Each treatment was randomly assigned to seven experimental units with 10 chickens each. The variables evaluated were: feed consumption (FC), feed conversion ratio (FCR), weight gain (WG), carcass yield (CY), breast yield (BY), leg to thigh yield (LTY), digestive system development, walking ability (WA), valgus-varus angulation (VVA), and latency to lie down (LLD). Chickens

fed NDC and ChC had lower FC and WG (P<0.05). However, there was no difference among treatments for CA. There were differences among treatment (P<0.05) for WA and VVA, but there were not for LLD (P>0.05). The results showed that autoclave treatment (1 atm, 121 ºC for 60 min) decreased toxicity in castor meal, since birds in the AC treatment had a similar productive behavior (P>0.05) to those in the control diet.

Key words: *Ricinus communis* L., Detoxification methods, Autoclave, Calcium hydroxide, Broiler chickens.

Received: 29/08/2018

Accepted: 28/08/2019

Introduction

Castor oil plant (*Ricinus communis* L.) is native to Africa. It belongs to the family of Euphorbiaceae; it is distributed worldwide, mainly in India, China and Brazil, and is noted for its hardiness, drought tolerance and high oil content of its seeds[1]. In Mexico, there are favorable agro-ecological conditions for the cultivation of castor oil plants, especially in the south and southeast[2]. Castor plant has been used for the production of biodiesel, as a result of this process castor meal is obtained[3].

Due to its nutritional composition, castor meal[4,5] can be included in animal feeds as an alternative to substitute protein ingredients and thereby decrease production costs. However, its use must be limited because it contains toxic products and allergens, mainly ricin, ricinine, and the allergen CB-1A, the former being the most toxic[6]. Nevertheless, there are efficient methods for detoxifying castor meal, these are focused on decreasing or eliminating ricin, such as autoclave and calcium hydroxide treatments[7,8]. Furthermore, fermenting the seeds in water and cooking them decreases the toxicity of castor meal and allows its inclusion in poultry diets without affecting the productive performance[9,10].

Ricin is inactivated at high temperatures and in strong alkalis; according to Anandan *et al*[7] no ricin residues were found in autoclaved castor meal (1 atm, 121 °C, 60 min) or calcium hydroxide (40 g/kg) samples, analyzed by polyacrylamide gel electrophoresis. Thus, the combination of these methods may potentiate their effect on the inactivation of toxic compounds in castor meal. No studies have been carried out where castor meal treated by these methods is included in the feed of broiler chickens. Probably, the use

of autoclave (1 atm,121 °C for 60 min), and chemical treatment (with 40 g $Ca(OH)_2$/kg castor meal) methods, or their combination, would allow the inclusion of castor meal in broiler diets, without affecting the production and animal welfare variables. Thus, the aim of the present study was to evaluate the effect of autoclave and chemical treatment methods, or their combination on the productive performance and welfare variables of broilers.

Material and methods

Detoxification of castor meal

Three methods described by Anandan *et al*[7] were used to detoxify the castor meal: Autoclave method (A), chemical method (Ch), and their combination (ACh).

Autoclave method

Forty samples of castor meal of 1,000 g each were placed in a Felisa autoclave, applying one atmosphere of pressure for 60 min, at 121 ºC. They were sun-dried 48 h and stored at room temperature[7].

Chemical method with calcium hydroxide $Ca(OH)_2$

Twenty castor meal samples of 1,000 g each were treated with calcium hydroxide at a concentration of 40 g/kg, for 8 h and then they were sun dried 48 h, grounded with a hand mill (Estrella®, Mexico), and stored at room temperature. The calcium hydroxide was diluted in water before being mixed with the castor meal[7].

Combination of autoclave and chemical methods

The autoclave and calcium hydroxide methods described by Anandan *et al*[7] were used in consecutive order.

Birds and treatments

The experiment was conducted at the poultry facilities of the Postgraduate College (Colegio de Posgraduados), Campus Montecillo, Texcoco, State of Mexico. Located at an altitude of 2,247 m asl[11]. Five treatments (experimental feeds) were evaluated: control diet corn and soybean meal (SM), non-detoxified castor meal (NDC), autoclaved castor meal (AC), chemical method treated castor meal (ChC) and autoclave and chemical methods treated castor meal (AChC). Each treatment was randomly assigned to seven experimental units with 10 chickens each. The birds were housed in 1.5 m^2 pens with wood litter shavings. A 23 h light regime was provided during the first two weeks and then decreased to 12 h. The ambient temperature at the beginning of the experiment was 33 °C, which was reduced by 2 °C per week to a temperature of 21 °C. This study was conducted in accordance with the Guide for the Care and Use of Experimental Animals approved by the General Academic Council of the Postgraduate College.

The feeding program was divided into two phases: starter diet (1-21 d) containing: 3,025 kcal of metabolizable energy (ME) kg^{-1}, 22 % of crude protein (CP), 0.96 % of Ca and 0.48 % of available P, and finisher diet (22-42 d) containing: 3,100 kcal of ME kg^{-1}, 19 of CP, 0.80 % of Ca and 0.40 % of available P (Table 1). The diets were formulated to cover or exceed the nutritional recommendations of the Ross 308 line[12].

Table 1: Composition of the experimental diets for broiler chickens

Ingredients (%)	Starter diet (1-21 days)					Finisher diet (22-42 days)				
	SM	NDC	AC	ChC	AC ChC	SM	NDC	AC	ChC	AC ChC
Soybean meal	35.41	33.34	33.34	33.34	33.34	30.44	28.36	28.36	28.36	28.36
Corn	56.29	53.94	53.94	54.08	54.08	61.91	59.56	59.56	59.70	59.70
Castor meal	0.00	4.16	4.16	4.13	4.13	0.00	4.16	4.16	4.13	4.13
Calcium carbonate	1.25	1.22	1.22	1.16	1.16	1.07	1.04	1.04	0.98	0.98
Calcium phosphate	2.03	2.06	2.06	2.06	2.06	1.61	1.64	1.64	1.64	1.64
L-lysine	0.32	0.36	0.36	0.36	0.36	0.12	0.17	0.17	0.17	0.17
DL-methionine	0.49	0.49	0.49	0.49	0.49	0.34	0.34	0.34	0.34	0.34
L-threonine	0.13	0.14	0.14	0.14	0.14	0.02	0.03	0.03	0.03	0.03
L-tryptophan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oil	3.43	3.64	3.64	3.60	3.60	3.49	3.70	3.70	3.66	3.66
Coccidiostat	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Pigment	0.00	0.00	0.00	0.00	0.00	0.35	0.35	0.35	0.35	0.35
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Vitamins, minerals*	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Total	100	100	100	100	100	100	100	100	100	100
Calculated analysis (%)										
Crude protein	21.0	21.0	21.0	21.0	21.0	19.0	19.0	19.0	19.0	19.0
EM, kcal/kg	3025	3025	3025	3025	3025	3100	3100	3100	3100	3100
Calcium	0.96	0.96	0.96	0.96	0.96	0.80	0.80	0.80	0.80	0.40
Available phosphorus	0.48	0.48	0.48	0.48	0.48	0.40	0.40	0.40	0.40	0.40
Lysine	1.44	1.44	1.44	1.44	1.44	1.15	1.15	1.15	1.15	1.15
Methionine	0.83	0.83	0.83	0.83	0.83	0.47	0.66	0.66	0.66	0.66
Methionine+cystin	1.08	1.08	1.08	1.08	1.08	0.90	0.90	0.90	0.90	0.90
Threonin	0.97	0.97	0.97	0.97	0.97	0.78	0.78	0.78	0.78	0.78
Tryptophan	0.30	0.30	0.30	0.30	0.30	0.18	0.27	0.27	0.27	0.27

SM= Control diet corn and soybean meal. NDC= Non-detoxified castor meal. AC= Autoclaved castor meal. ChC= Chemical method treated castor meal. AChC= Autoclave and chemical methods treated castor meal.

[1]Vitamins and minerals premix per kilogram of feed: A, 12,000 UI; D3, 1,000 UI; E, 60 UI; K, 5.0 mg; B_2, 8.0 mg; B_{12}, 0.030 mg; pantothenic, 15 mg; niacin, 50 mg; folic acid, 1.5 mg; choline, 300 mg; biotin, 0.150 mg; thiamin, 3.0 mg. Fe, 50.0 mg; Zn, 110 mg; Mn, 100 mg; Cu, 12.0 mg; Se, 0.3 mg; I, 1.0 mg.

Productive performance, animal welfare and carcass yield traits

Feed consumption, weight gain, and feed conversion ratio were recorded from day one through d 42. At d 43, 35 birds per treatment were randomly selected to evaluate walking ability, valgus-varus angulation, and prostrate latency. Walking ability was evaluated according to the methodology described by Kestin *et al*[13] as modified by Garner *et al*[14]. The measurement was carried out simultaneously by two assessors who

rated each bird on a scale of 0 to 5 where: 0. Birds that walk normally; 1. Birds with a slight difficulty for walking; 2. Birds with a defined and identifiable defect in their gait, but whose injury or damage does not impair movement or consumption of food and water; 3. Birds with an obvious defect that affects the ability to move; 4. Birds with a severe defect, and 5. Birds incapable of walking.

Valgus-varus angulation was evaluated according to the methodology described by Leterrier and Nys[15]. Depending on the tibia-metatarsal angle, 4 scores were defined: 0, normal chicken; 1, chicken with low angulation (tibia-metatarsal angle between 10 and 25 °); 2, bird with evident angulation (angle between 25 and 45 °) and 3, severe angulation (angle greater than 45 °).

The birds were subjected to the latency-to-lie-down test as described by Berg and Sanotra[16]. This test is based on the chicken's body contact with water, which is a novel and adverse experience for broilers. The birds were placed in a plastic container with water at 32 °C at a height of 3 cm. The time elapsed in seconds until each bird lay down was recorded. If the bird stood up after 600 seconds, the test was stopped. The birds were assessed individually, without visual contact among them.

At 42 d of age, seven birds per treatment were randomly selected in order to assess the carcass yield, breast weight and leg-to-thigh weight. Feed was withdrawn 8 h before slaughter, and the chickens were slaughtered using a stun knife (model VS-200, input power 120 V-1 A, output power 50 V-0.1 A, Midwest Processing Systems, Minneapolis, MN, USA), according to the Mexican Official Standard NOM-033-SAG/ZOO-2014[17].

Development of the digestive system and accessory organs

The chickens selected for the evaluation of carcass yield were used to assess the development of the digestive system. The length of the small intestine and the cecum was obtained with a measuring tape, and the empty weight of the proventricle, gizzard, small intestine and cecum were determined. The weight of liver, spleen, bursa of Fabricius, pancreas and heart was also estimated. The small intestine and the cecum were measured on a wet cloth in order to prevent them from contracting.

Statistical analysis

Feed consumption, weight gain, and feed conversion ratio were analyzed with a completely randomized design with a significance level of 0.05, using the SAS GLM procedure[18]. Treatment means were compared using the Tukey adjusted test ($P<0.05$). The variables walking ability and angulation were analyzed with a completely randomized design using PROC GLIMMIX (for non-parametric data) and SAS PROC FREQ[18]. The relative weights of the digestive system, accessory organs and prostrate latency were analyzed with a completely randomized experimental design with five treatments and seven repetitions per treatment using the GLM procedure of the SAS[18]. Treatment means were compared using the Tukey test and presented as mean ± standard error.

Results

Productive performance and carcass yield

Chickens in the NDC and ChC treatments had lower ($P<0.05$) feed consumption and weight gain, compared to birds in the other treatments. No differences ($P>0.05$) were observed between treatments in feed conversion ratio. (Table 2). There were no differences between treatments in the carcass, breast, and leg and thigh yield variables.

Table 2: Productive performance of broilers fed castor meal treated with different detoxification methods, from 1 to 42 d of age

	Treatment						
Variable	**SM**	**NDC**	**AC**	**ChC**	**AChC**	**SE**	***P*-value**
FC, g	4499 a	3272 b	4492 a	3181 b	4575 a	66.41	0.0001
WG, g	2811 a	1980 b	2835 a	1923 b	2835 a	44.69	0.0001
FCR, g/g	1.60	1.65	1.58	1.65	1.61	0.03	0.2322
CY, %	79.96	78.31	78.91	78.03	79.91	0.66	0.1467
BY, %	28.31	25.28	25.86	25.01	26.85	0.81	0.0510
LTY, %	20.16	21.02	21.18	20.11	20.11	0.74	0.7002

SM= Control diet corn and soybean meal. NDC= Non-detoxified castor meal. AC= Autoclaved castor meal. ChC= Chemical method treated castor meal. AChC= Autoclave and chemical methods treated castor meal.

FC= feed consumption; WG= weight gain; FCR= feed conversion ratio; CY= carcass yield; BY= breast yield; LTY= leg and thigh yield.

ab Means with different letters are different ($P<0.05$). SE=Standard error.

Walking hability

Differences were found ($P<0.05$) by effect of the treatments on the walking ability; broilers fed the NDC and ChC diets exhibited a higher proportion of healthy birds (rating 0) compared to the birds of the other treatments. Birds rated 4 and 5 were not observed in this experiment (Table 3).

Table 3: Walking ability, valgus/varus angulation, and latency to lie down of broilers fed castor meal treated with different detoxification methods, from 1 to 42 d of age

Treatment	SM	NDC	AC	ChC	AChC
Score	Walking ability				
0	0.00	25.71	5.71	28.57	14.29
1	42.86	51.43	51.43	48.57	31.43
2	37.14	22.86	34.29	22.86	40.00
3	20.00	0.00	8.57	0.00	14.29
4	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00
P-value	0.0009				
Score	Valgus-varus angulation				
0	14.29	48.57	34.29	60.00	34.29
1	65.71	42.86	60.00	40.00	60.00
2	20.00	8.57	5.71	0.00	5.71
3	0.00	0.00	0.00	0.00	0.00
P-valor	0.0024				
	Latency to lie down				
Seconds (s)	84	118	103	103	114
P-value	0.6681				

SM= Control diet corn and soybean meal. NDC= Non-detoxified castor meal. AC= Autoclaved castor meal. ChC= Chemical method treated castor meal. AChC= Autoclave and chemical methods treated castor meal.

Valgus-varus angulation

Valgus/ varus angulation was affected by treatments ($P<0.05$) on the degree of valgus-varus angulation. The highest proportion of birds with a 0 rating was found in the NDC and ChC treatments and, to a lesser proportion, in birds with a score of 1. No broilers with a degree of angulation rated 3 were observed (Table 3).

Latency to lie down

There was no difference (*P*>0.05) between treatments in latency to lie down (Table 3).

Development of the digestive system and accessory organs

There were not differences (*P*>0.05) in terms of relative weight of spleen and heart; however, the relative weight of liver was lower (*P*<0.05) in broilers fed the SM diet, compared to birds fed the treatments that included castor meal. Relative weight of bursa of Fabricius was lower (*P*<0.05) in chickens fed the NDC and ChC diets compared to chickens fed the SM, AC and AChC diets (Table 4).

Relative weight of pancreas, gizzard, and small intestine and length of small intestine were greater (P <0.05) in chickens fed NDC and ChC diets, with respect to SM, AC and AChC. Relative weight of cecum of chickens fed SM, AC and AChC diets were lower (P <0.05) compared to the chickens of the ChC treatment and the length of the cecum was greater (P <0.05) in the chickens fed with NDC compared to AChC.

Table 4: Relative weight (g/kg) and length (cm/kg) of the different sections of the digestive system and accessory organs of broilers fed castor meal treated with different detoxification methods, from 1 to 42 d of age

	Treatments						
	SM	**NDC**	**AC**	**ChC**	**AChC**	**SE**	***P*-value**
Spleen	1.65	1.79	2.00	1.77	1.99	0.17	0.5189
Heart	4.08	4.38	4.15	4.35	4.26	0.12	0.3394
Liver	18.27b	24.16a	21.78a	24.34a	21.78a	0.72	0.0001
Bursa of Fabricius	1.62 a	0.70 b	1.49 a	0.81 b	1.32 a	0.08	0.0001
Pancreas	1.63 b	2.19 a	1.82 b	2.19 a	1.50 b	0.08	0.0001
Proventricle	2.94c	3.84ab	3.35bc	4.22a	2.94c	0.14	0.0001
Gizzard	10.50b	14.24a	10.50b	14.24a	8.61b	0.65	0.0001
Small intestine	19.46b	25.17a	21.12b	23.60a	20.49b	0.56	0.0001
Cecum	4.91b	5.78ab	5.43b	7.13a	5.21b	0.39	0.0047
Cecum length	6.36bc	7.93a	6.65bc	7.57ab	6.10c	0.30	0.0007
Intestine length	62.22b	84.19a	69.88b	86.50a	63.81b	1.95	0.0001

SM= Control diet corn and soybean meal. NDC= Non-detoxified castor meal. AC= Autoclaved castor meal. ChC= Chemical method treated castor meal. AChC= Autoclave and chemical methods treated castor meal.

ab Means with different letters are different (*P*<0.05). SE=Standard error.

Discussion

The response of animals fed detoxified castor meal is determined by the effectiveness of the detoxification process, the concentration of castor meal in the diet, the feeding time, and the animal species[19]. It has been recorded in the literature that heat treatments applied to castor seed meal reduce its toxic compounds, especially ricin which is the most toxic: high temperatures seem to inactivate it[20]. These treatments have allowed the inclusion in diets for broilers up to 10% without affecting the productive performance or the carcass yield[21,22]. In this study, birds fed AC and AChC had similar productive performance to that of birds fed SM, indicating that the heat and pressure used in the autoclave decreased the toxicity of the castor meal. In contrast, chickens fed NDC and ChC had a lower consumption and a lower weight gain, which could be attributed to the content of toxic substances[23]. Treatment with $Ca(OH)_2$ apparently did not reduce the toxic compounds which inhibit protein synthesis and mainly affect the digestive system, causing desquamation and a decrease in the length of the intestinal villi that prevents the absorption of nutrients and, therefore, the normal development of the birds[10,24]. The use of 5% non-detoxified castor meal decreases feed consumption and weight gain in broilers[9,22,25].

No studies on the use of castor meal in diets for broilers about animal welfare variables were found in the literature; however, in this study it was found that the degree of walking ability decreased in birds from the SM, AC and AChC treatments and the valgus/varus angulation was greater in these birds. This can be explained by the fact that birds with higher weight have lower ability to walk compared to lighter birds[26], since weight influences these characteristics[27]. Broiler chickens with higher weight remain prostrate longer. Consequently, the balance and angulation condition of these birds are affected, causing discomfort when walking and deterioration in their well-being[28].

The inclusion of castor meal in the diet leads to kidney damage (inflammation and congestion), enlargement of the liver, inflamed lungs, atrophy of the bursa of Fabricius, and necrosis of the spleen[21,29]. In the present study, the size of the liver was larger in chickens fed castor meal; this may be accounted for by the increase in the metabolic activity in the face of residues of the toxic compounds[29]. In addition, an increase in the size of pancreas, gizzard, proventricle, and intestine was observed in chickens fed NDC and ChC with respect to the control (corn-soybean meal). Organ weights have been studied in other species that were administered non-detoxified castor meal and castor meal treated with calcium hydroxide in the feed, and no differences were found in the weight of the liver, the heart, the kidneys and the spleen with respect to those of the animals fed the control diet (soybean meal)[30].

The weight or size of the bursa of Fabricius is an indicator of the state of immunocompetence or immunosuppression in birds at the level of the lymphoid organs[31]. The ratio of the weight of the bursa of Fabricius to the body weight (BFW/BW) may be correlated with immunosuppression. Birds aged 3 to 6 wk normally have a BFW/BW ratio of 2 to 4; values of 1 or less to 1 are indicative of immunosuppression and are observed in clinically ill birds[32]. In this study, the BFW/BW ratio of chickens fed NDC and ChC was less than 1, which indicates that the toxic compounds present in castor meal may have caused immunosuppression in the chickens. Okoye *et al*[21] observed a decrease in lymphoid organ size and necrosis of the bursa of Fabricius in chickens consuming feed with 10 and 15 % heat-treated castor meal.

Conclusions and implications

It is possible to include castor meal detoxified with the autoclave method in the feeds of broilers without affecting the productive performance and welfare variables. However, since this study did not quantify the ricin resides in the meat, it was not possible to determine whether or not the meat of these chickens is suitable for human consumption. Therefore, it is suggested carrying out studies to quantify the ricin residues in the meat.

Acknowledgements

The first author thanks the National Council for Science and Technology (CONACYT) for the financial support to carry out his postgraduate studies, as well as the Postgraduate College (Colegio de Postgraduados), Campus Montecillo, for the opportunity provided.

Literature cited:

1. Silva-Lima RL, Severino LS, Silva LMS, Ferreira JJ, Silva VL, Macedo BNE. Substratos para produção de mudas de mamoneira compostos por misturas de cinco fontes de matéria orgánica. Ciênc Agrotec 2006; 30(3):474-479.

2. Rodríguez RH, Zamarripa CA. Competitividad de la higuerilla (*Ricinus communis*) para biocombustible en relación a los cultivos actuales en el Edo. de Oaxaca, México. Rev Mex Agr 2013;32:306-318.

3. Azevedo DM, Lima EFO. Agronegócio da mamona no Brasil. Brasília: Embrapa Informação Tecnológica 2001;350.

4. Jiménez OR, Cervantes MR, Vallejo VJA, Rosales RS, Ríos SJC. Perfil de aminoácidos de pastas residuales de piñón tropical (*Jatropha curcas*) e higuerilla (*Ricinus communis*). Agrofaz 2011;12(3):173-176.

5. Rostagno HS, Albino LFT, Donzele JL, Gomes PC, Oliveira RF, Lopes DC, *et al*. Tabelas brasileiras para aves e suínos: composição de alimentos e exigências nutricionais. 2a ed. Viçosa, Brasil: Editora Universitária; 2011.

6. Matos JJB, Días AN, Bueno CFD, Rodríguez PA, Veloso ALC, Faria DE. Metabolizable energy and nutrient digestibility of detoxified castor meal and castor cake for poultry. R Bras Zootec 2011;40(11):2439-2442.

7. Anandan S, Anil KGK, Ghosh J, Ramachandra KS. Effect of different physical and chemical treatments on detoxification of ricin in castor cake. Anim Feed Sci Tech 2004;120:159-168.

8. Oliveira AS, Oliveira MRC, Campos JMS, Machado OLT, Valadares SC, Detmann E, *et al*. Eficácia de Diferentes Métodos de Destoxificação da Ricina no Farelo de Mamona Conferencia: En: II Congreso de la Red Brasileña de Tecnología y Producción de Biodiesel de 2007. Brasilia.

9. Oso AO, Olayemi WA, Bamgbose AM, Fowoyo OF. Utilization of fermented castor oil seed (*Ricinus communis* L) meal in diets for cockerel chicks. Arch Zootec 2011;60(229):75-82.

10. Ani AO, Okorie AU. Effects of processed castor oil bean (*Ricinus communis* L) meal and supplementary dl- methionine on nutrient utilization by broiler chicks. J Anim Plant Sci 2013;23(5):1228-1235.

11.Vázquez JC, Pérez PR. Valores gasométricos estimados para las principales poblaciones y sitios a mayor altitud en México. Rev Inst Nal Enf Resp Mex 2000;13(1):06-13.

12. Aviagen. Ross Broiler Management Manual. Aviagen Ltd., Midlothian, UK. 2017.

13. Kestin SC, Knowles TG, Tinch AE, Gregory NG. Prevalence of leg weakness in broiler chickens and its relationship with genotype. Vet Rec 1992;131:190-194.

14. Garner JP, Falcone C, Wakenel P, Martin M, Mench JA. Reliability and validity of a modified gait scoring system and its use assessing tibial dyschondroplasia in broilers. Br Poultry Sci 2002;43(3):355-363.

15. Leterrier C, Nys Y. Clinical and anatomical differences in varus and valgus deformities of chick limbs suggest different aetio-pathogenesis. Avian Pathol 1992; 21(3):429-442.

16. Berg C, Sanotra GS. Can a modified latency-to-lie test be used to validate gait-scoring results in commercial broiler flocks. Anim Welf 2003;12(4):655-659.

17. Norma Oficial Mexicana. NOM-033-SAG/ZOO-2014. Métodos para dar muerte a los animales domésticos y silvestres. Diario Oficial de la Federación. México. 26 de agosto de 2015.

18. SAS Institute, Inc. SAS User's Guide: Statistics version. SAS Institute, Inc. Cary, NC. 2011.

19. Souheila A, Harinder PSM. Potential and constraints in utilizing coproducts of the non-edible oils-based biodiesel industry -an overview. Biofuel co-products as livestock feed Opportunities and challenges. FAO. Rome. 2012.

20. Gardner H, D'Aquin EL, Koltun SP, McCourtney EJ, Vix HLE, Gastrock EA. Detoxification and deallergenization of castor beans. J Amer Oil Chem Soc 1960;37(3):142-148.

21. Okoye JOA, Enunwaonye CA, Okorie AU, Anugwa FOI. Pathological effects of feeding roasted castor vean meal (*Ricinus communis*) to chicks. Avian Pathol 1987;16(2):283-290.

22. Nsa EE, Ukachukwu SN, Akpan IA, Okon B, Effiong OO, Oko OOK. Growth performance, internal organ development and hematological responses of broiler

birds fed diets containing different thermal treated castor oil seed meal (*Ricinus communis*). Glob J Agr Sci 2010;9(2):27-34.

23. Ani AO, Okorie AU. Effects of graded levels of dehulled and cooked castor oil bean (*Ricinus communis*) meal and supplementary l-lysine on performance of broiler finishers. J Trop Agr Food 2007;6(1):89-97.

24. Audi JMD, Belson MMD, Patel MMD, Schier JMD, Osterloh JMD. Ricin Poisoning. A Comprehensive Review. J Amer Med Assoc 2005;294(18):2342-2351.

25. Agbabiaka LA, Esonu BO, Madubuike FN. Effect of processing on nutrients and anti-nutrients of castor oil bean (*Ricinus communis*) seeds and by-products. Pak J Nutr 2011;10(6):561-563.

26. Toscano MJ, Nasr MAF, Hothersall B. Correlation between broiler lameness and anatomical measurements of bone using radiographical projections with assessments of consistency across and within radiographs. Poul Sci 2013;92(9):2251-2258.

27. Alves MCF, Almeida PICL, Nääs IA, García RG, Caldara FR, Baldo GAA, *et al*. Equilibrium condition during locomotion and gait in broiler chickens. Rev Bras Cienc Avic 2016;18(3):419-426.

28. Almeida ICL, Garcia RG, Bernardi RIA, Caldara FR, Freitas LW, Seno LO, *et al*. Selecting appropriate bedding to reduce locomotion problems in broilers. Rev Bras Cienc Avic 2010;12(3):189-195.

29. Mustapha GG, Igwebuike JU, Kwari ID, Adamu SB, Abba Y. The Effect of replacement levels of boiled and fermented castor seed (*Ricinus cummunis*) meal on the productive performance, nutrient digestibility, carcass characteristics and cost effectiveness in broilers. Int J Sci Nat 2015;6(4):675-682.

30. Gowda NkS, Pal DT, Bellur SR, Bharadwaj U, Sridhar M, Satyanarayana ML, *et al*. Evaluation of castor (*Ricinus communis*) seed cake in the total. J Sci Food Agric 2008;89(2):216–220.

31. Cheema MA, Qureshi MA, Havenstein GB. A Comparison of the immune response of a 2001 commercial broiler with a 1957 randombred broiler strain when fed representative 1957 and 2001 broiler diets. Poul Sci 2003;82(10):1519-1529.

32. Giambrone JJ, Clay R. Evaluation of the immunogenicity, stability, pathogenicity, and immunodepressive potential of four commercial live infectious bursal disease vaccines. Poul Sci 1986;65(7):1287-1290.