

REVIEW ARTICLE

A review of nutritional and toxicological implications of castor bean (*Ricinus communis* L.) meal in animal feeding systems

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Summary

The nutrient-rich defatted castor meal has been tested as a potential source of protein in diets of many livestock species but has limitation due to challenges of toxins. This review was conducted to compile the relevant research information on advances in the use of raw and differently processed castor seed meal in animal feed. In this article, distribution and uses of castor and its products were identified. Research findings on the nutrients profile, principal toxins, various detoxification strategies, nutritional value and toxicity on common livestock species were compiled and reviewed. The defatted seed meal had crude protein range of 32–48%, gross energy of about 3200 kcal/kg. Ricin content was 9.3 mg/g seed, and the average RCA content was 9.9 mg/g. The meal had high activity of lectin, which produced agglutination at about 4.70 mg/ml minimum assays. Reports of detoxification strategies showed varying degrees of success but high pH, moist heating and microbial techniques appeared to exert greater effect on deactivating ricin. Detoxification strategy for the allergen component is inconclusive. Tannins and the phenolic contents were present at trace level and did not constitute notable threat. It was concluded that castor seed holds great potential as feedstuff when upgraded but such upgrading must be safe, cost-effective and labour efficient for commercial acceptability.

Keywords castor seed meal, detoxification, nutrient, toxins, feed, animal performance

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Background

The perennial and critical shortfalls in livestock feed in most developing countries of the world have made the subject of feed resources and their utilization the most compelling task facing producers and scientists in livestock industry today. The continuous short supply of animal protein in this region (FAO, 2013) is a clear evidence of these challenges. The gap between local supply and demand for conventional ingredients is also expected to widen over the coming years. Attempt to mitigate some of these challenges has provided compelling reason for the continued search for locally available alternatives or additional feedstuffs to support limited and highly priced ones. The development and utilization of the vast quantities of unconventional feed resources as affordable accessory animal feeds would be of tremendous benefit to stakeholders in the feed industry.

Castor (*Ricinus communis*) has remained the most important non-edible oilseed crop of the arid and

semi-arid regions (Dange et al., 2005). Reports on feeding of castor seed meal showed that it has huge potential as a tropical feed resource because of its high nutrient profile (Ghandi et al., 1994; Puttaraj et al., 1994; Ani and Okorie, 2009; Akande et al., 2012b; Rama Rao, 2012). The vast quantities of defatted meal generated from oil processing industries particularly in Asia and Africa are capable of reducing cost of feeding farm animals. However, its use as animal feed has been largely restricted because of inherent toxins. The plant was listed as an undesirable substance in the Annex of Directive 2002/32/EC; however, more data on nutritional and toxicological effect of castor were needed to consider a full risk assessment of the plant (Alexander et al., 2008). This review intends to delineate the use of castor seed in animal feed with emphasis on nutritional value, toxicological status and detoxification strategies for the principal toxins. Attempt was also made to identify gaps in the literature for future research consideration in the use of castor seed

meal in animal feed and to encourage further exploration of castor seeds.

Distribution and uses of castor

Castor bean (*Ricinus communis* Linn.) belonging to *Euphorbiaceae* family is an annual and perennial oilseed found across all the tropical and semi-tropical regions of the world (Weiss, 2000) originating from (i) East Africa (Ethiopia), (ii) north-west and south-west Asia and Arabian Peninsula, (iii) India and (iv) China (Severino et al., 2012). Global production of castor seeds reached 2.72 million and 1.85 million metric tons in 2011 and 2013 respectively (FAO, 2013). The major producing countries are India, China, Brazil and Mozambique and (FAO, 2013).

Today, there are five major products from castor plant: seeds, oil, seed meal or cake, the herbs and possibly the fifth, ricin. Castor oil is one of the few naturally occurring fatty acids that approach being a pure compound, as the fatty acid composition comprises about 80–90% ricinoleic acid (Ogunniyi et al., 1996; Jumat et al., 2010). Medicinally, the oil has been used for many years as a purgative and laxative (Duke and Wain, 1981; FDA, 2003). The use of the seeds as oral contraceptive has been documented (Dafallah and Al-Mutairy, 1994; Isieche et al., 1997; Kabele-Toge, 2003). Castor toxin, ricin itself is being studied for therapeutic use in cancer chemotherapy, in bone marrow transplantation and in cell-based research (Lord et al., 1994; Bies et al., 2004). The protein-rich deoiled residue is commonly used as a fertilizer (Antonio et al., 2008). Castor plant is an attractive addition to many landscapes due to its big leaves, fast growth, drought tolerance and diversity of colours in stem and fruits. The leafy plant has been found with great potential in removing the green gas accumulation to the tune of

35t/ha of CO₂ in two growing seasons (Dovebiotech.com).

Nutrient composition of castor seed meal

The chemical composition of castor seed is as shown in Table 1. Seed meal contained 21–48% crude protein (CP) depending on levels of decortifications and de-oiling (Adedeji et al., 2006; Annongu and Joseph, 2008; Matos et al., 2011; Akande et al., 2012b; Rama Rao, 2012) and the whole and defatted seed contained gross energy ranging between 3.2 and 6.5 kcal/g (Annongu and Joseph, 2008; Akande et al., 2012b). A comparison between the amino acid composition of castor meal and soya beans (Vasconcelos et al., 1997) revealed an almost similar pattern for all essential amino acids, except lysine and sulphur amino acids; lysine is lower and sulphur amino acids higher in castor meals. It was also observed that detoxified castor meal worth about 85% of soya bean meal value based on evaluations of animal performance. Supplementing CBM with both lysine and tryptophan showed similar results with methionine supplemented isolated soya protein in chicks' diet and markedly improved the net protein utilization value (Vilhjaldsdottir and Fisher, 1971). The mineral content particularly calcium and phosphorous are comparable with other plant proteins used in animal feed. The mechanically pressed meal was characterized with high fat content and contains high energy (Akande et al., 2011). The defatted meal also contained high fibre if the seeds are not dehulled (Okoye et al., 1987; Adedeji et al., 2006). It was observed that castor seed meal could be improved by adequate dehulling, defatting, detoxification strategies and supplementation with limiting amino acids (Vilhjaldsdottir and Fisher, 197; Gowda et al., 2009; Diniz et al., 2010; Akande et al., 2011, 2012b).

Table 1 Nutrient levels in castor seed meal

Nutrients	Range	Authors
Moisture (%)	5–12	Annongu and Joseph (2008), Ani and Okorie (2009), Oso et al. (2011), Akande et al. (2012b)
Crude protein (%)	21–48	Annongu and Joseph (2008), Ani and Okorie (2009), Oso et al. (2011), Matos et al. (2011), Akande et al. (2012b)
Crude fat (%)	1.9–50	Annongu and Joseph (2008), Matos et al. (2011), Nsa et al. (2011), Akande et al. (2012b)
Soluble carbohydrate, %	9.1–20.5	Annongu and Joseph (2008), Matos et al. (2011), Akande et al. (2012b)
Crude fibre (%)	2.5–24.5	Annongu and Joseph (2008), Matos et al. (2011), Nsa et al. (2011), Akande et al. (2012b)
Total ash (%)	8.1–19.2	Annongu and Joseph (2008), Matos et al. (2011), Nsa et al. (2011), Akande et al. (2012b)
GE kcal/kg	3218–5690	Matos et al. (2011), Akande et al. (2012b)
Calcium, %	1.06–5.67	Matos et al. (2011), Akande et al. (2012b)
Phosphorous, %	0.3–0.73	Matos et al. (2011), Akande et al. (2012b)

Nutrient density varies with level of dehulling and deoiling.

Toxins in castor seed

Castor contains a complex cocktail of toxic substances including ricin; *Ricinus communis* agglutinin-RCA120; the alkaloid ricinine; and the allergen (Borchers, 1949; Deus-de-Oliveira et al., 2011; Severino et al., 2012; Bozza et al., 2015).

Ricin is a glycoprotein lectin composed of 2 chains, A and B, linked by a disulphide bond. The understanding of ricin, a potent cytotoxin was complicated by the presence of a homologous protein, identified as *Ricinus communis* agglutinin RCA, an effective haemagglutinin and a much less toxic dimeric protein with high sequence identity to ricin (Olsnes et al., 1974; Roberts et al., 1985). Later, an isoform of ricin named ricin E (while the original ricin is termed ricin D) was discovered both on protein and on DNA levels to contain a hybrid B-chain of ricin and RCA, adding further complexity to the issue (Araki and Funatsu, 1987; Ladin et al., 1987; Deus-de-Oliveira et al., 2011). Whereas ricin is a monomeric toxin of about 60 kDa, *R. communis* agglutinin is a 120 kDa homodimer of two A and B subunits (Lord et al., 1994). On amino acid levels, both the A- and the B-chains of RCA60 and RCA120 show a high degree of homology of 93% and 84%, respectively (Roberts et al., 1985), reflecting similar, but not identical structures and biochemical properties (Brandt et al., 2001; Deus-de-Oliveira et al., 2011). Radial immunodiffusion (RID) and the enzyme-linked immunosorbent assay (ELISA) are two antibody-based methods commonly used to quantify ricin and RCA; however, antibodies used in these methods cannot distinguish between ricin and RCA due to the high sequence homology of the respective proteins (Bozza et al., 2015; Schieltz et al., 2015). RCA agglutinates red blood cells, but does not cross the intestines easily and is not considered toxic by ingestion (Helmenstin, 2015). Hence, ricin becomes the primary concern when castor seed are fed to animals.

Schieltz et al. (2015) in their study recently separated ricin and RCA and reported the average ricin content was 9.3 mg/g seed and the average RCA content was 9.9 mg/g seed among 18 cultivars. Ricin is found only in the endosperm of castor seed, but does not go into the oil because this protein is insoluble in oil (Lord et al., 1994; Severino et al., 2012; Akande et al., 2011). Reports on the ricin content of castor seeds vary but probably is in the range of 1–5% of seed weight (Bradberry et al., 2003). According to Pinkerton et al. (1999) ricin concentration varied from 1.9 to 16 g/kg among 263 accessions from the USDA germplasm bank. Report of Akande et al.

(2012b) showed that about 4.7 mg/ml of castor seed meal sample assay produced agglutination. Comparing this value with 66.7 mg/ml cursin, a lectin from *Jathropa* seed (Aderibigbe et al., 1997) indicates high toxicity of ricin. In Europe, United States and other parts of the world ricin has been a major concern in castor seed and perhaps the principal toxin that limit its use as animal feed (Audi et al., 2005; Alexander et al., 2008; Akande and Odunsi, 2012).

Another toxic compound is the low molecular weight alkaloid ricinine (MW = 164.2 g/mol). Ricinine or 3-cyano-4-methoxy-*N*-methyl-2-pyridone (CAS 524-40-3) belongs to the group of piperidine alkaloids. Castor seeds contain approximately 0.2% of the alkaloid (Hussein et al., 2015). Ricinine is a relatively harmless alkaloid, which is usually regarded as marker of ricin. It occurs at a minimal level in castor seed and has not been reported to constitute threat to man or animals. Ricinine content varies but contains 2.3–32.9 g/kg in leaves, 2.4 g/kg in stems, 3 g/kg in roots and 0.43–7.0 g/kg in seeds (Leite et al., 2005; Xu et al., 2007; Wen et al., 2008; Cazal et al., 2009). It could however be lethal if ingested in high dosage (Dobereiner et al., 1981).

The allergenicity of *Ricinus communis* L. is associated with components of its seeds and pollen. Castor bean allergy has been described in many industrial fields such as laboratory workers, oil processing mills, fertilizer retail, the upholstery industry. Siddiqi and Freedman (1963) identified Chlorogenic acid (3-caffeoylquinic acid) as an allergen present in castor seeds which is similar to that of coffee beans and oranges. More recently, three allergens have been identified in castor named as Ric c 1, Ric c 2 and Ric c 3 (Thorpe et al., 1988; Irwin et al., 1990; Machado and da Silva, 1992). Specific IgE antibody to Ric c 1 indicated it as the major allergen in castor (Thorpe et al., 1988). Deus-de-Oliveira et al. (2011) who described the critical amino acids in the IgE-binding epitopes in Ric c 1 and Ric c 3 concluded that the identification of glutamic acid residues with critical roles in IgE-binding to Ric c 3 and Ric c 1 supports the potential use of free amino acids in allergy treatment. The allergens in castor cause medical problems such as conjunctivitis, rhinitis and urticaria (Garcia-Gonzalez et al., 1999). A sample of untreated castor meal contained 12.5% of allergen (Gardner et al., 1960). The allergen is more heat stable and not easily denatured unlike ricin.

Other toxicants include ricinoleic acid, 12-hydroxyoleic acid (Alexander et al., 2008) and high fibre level in the dehulled castor seed between 11.4 and 38.21% (Okorie et al., 1985; Browning et al., 1990) while other trace compounds reported in castor

include tannin, phytate and oxalate (Yashim et al., 2007; Akande et al., 2012b).

Detoxification strategies of castor seed meal for feeding farm animals

Among the toxins listed above, ricin is the most toxic and attempt to detoxify the meal should principally address this toxin. Various detoxification methods have been used by different researchers with varying degree of success and limitations (Table 2). The various methods attempted by researchers may be classified as follows:

- (i) Physical method: heating (wet or dry), pressure, dehulling etc.
- (ii) Chemical method: use of alkali, acid, lye water, phosphate mono/dicalcium, urea, ammonia, salt, tannin etc.

- (iii) Biotechnology (microorganism and genetics)
- (iv) Combination of two or more of the above techniques

Physical and chemical methods

It was considered that heating castor meal in water inactivated the ricin component which would be safe for feeding purpose but the allergenic activities were not destroyed (Breese, 1947). Ricin in flaked castor seed was detoxified at 100–102 °C when held for 12 to 15 min (Gardner et al., 1960). Ricin was inactivated by heat, 80 °C in aqueous solution for 1 h and requires higher temperatures or longer periods for inactivation when in powdery or crude forms (Parker et al., 1996). Moist heat treatments are more effective than dry heat treatments in inactivating lectins of *Jatropha curcas* meals (Aregheore et al., 1998). Ricin

Table 2 Summary of various detoxification techniques and its effect on farm animals

Methods	Inclusion levels, %	Animal used	Results	Authors
Raw	8	Sheep	No notable changes	Furtado et al. (2012)
Raw	5	Rabbit	Mortality recorded	Olayeni et al. (2006)
Raw	5	Rat	Mortality recorded	Akande et al. (2012a,b)
Raw	10	Broilers	Mortality recorded	Akande et al. (2012a)
Heat treatment	15, 30	Adult sheep	No ill health, but changes in liver histology	Bornemann (2010)
Moist heat/boiling	15	Rabbit	Slow growth	Adedeji et al. (2006), Robb et al. (1974)
Dehulling & cooking	10	Broiler chicks	Depressed performance	Ani and Okorie (2005)
Two-stage cooking for 50 min.	10	Broiler finisher	Depression in feed intake	Ani and Okorie (2009)
Roasting at 140 °C for 20 min.	10	Broiler chicks, Ducks	Reduced feed intake and weight gain	Okoye et al. (1987), Okorie et al. (1985)
Moist heat & autoclaving	33 repl.	Sheep	Sub optimal performance	Purushotham et al. (1985)
Autoclaving	10	Chicks	Depressed growth	Borchers (1949)
Boiling & suppl. with β -xylanase	15	Broiler Finisher	Compared with control	Babalola et al. (2006)
Hot water extraction & AA supplm.	40	Chicks	No deleterious effect	Vilhjalmisdottir and Fisher (1971)
Fermentation and autoclaving	10	Pig	Low performance	Apata et al. (1999)
Water soaked and fermented for 5 days	5	Broiler finisher	No deleterious effect	Oso et al. (2011)
Lime treatment		Adult sheep	No deleterious effect	Gowda et al. (2009)
CaO treatment	9.14	Cattle	Replace soybean meal without negative effect	Diniz et al. (2010), Cobianchi et al. (2012)
Lye treatment	<10	Rats	No deleterious effect found	Akande et al. (2011)
Boiling and lye treatment	<15	Broiler chicken	No deleterious effect found	Akande and Odunsi (2012)
Mixing with sal seed meal (Tannin)	–	Rat	Resulting product was innocuous	Ghandi et al. (1994)
Treated with Cao, Ca(OH) ₂		Sheep	No deleterious effect, ricin was destroyed	De Oliveira et al. (2010)
Solid state fermentation using <i>Paecilomyces variotii</i>		Not fed	Reduction in ricin bands with simultaneous production of tannase and phytase	Madeira et al. (2011)
Thermal inactivation under different pH		Not fed	Thermal stability for ricin at pH 4.5	Zhang et al. (2013)

retained half of its toxicity after heating for 2 min at 90 °C in liquid infant formula (Jackson et al., 2006). Hot water extraction was most successful of all the treatments applied which remove most of the toxic component in castor meal (Vilhjalmsdottir and Fisher, 1971). Dry heating of castor pomace to 205 °C inactivated the allergen but also charred the meal. It appears that moist heating at temperature of 100 °C for half to one hour will be adequate to detoxify the seed for animal use. The high energy costs for processing the meal is, however, worrisome and may constitute barrier for industrial and commercial processing.

Various physical and chemical treatments were employed by (Kirk-Othmer, 1979; Horton and Williams, 1989; Anandan et al., 2005; Gowda et al., 2009) such as soaking in water, steaming, boiling, heating, use of ammonia, salt and NaOH treatments. NaOH treatment was reported to be more potent in detoxifying the meal. The possible counter-interaction between tannin and ricin was reported by Ghandi et al. (1994) by wet mixing of castor seed meal with sal (*Shorea robusta*) seed meal. The thermal stability at 75 °C for the cytotoxic activity of ricin and thermal stability for ricin at pH 4.5 were reported by Parkouda et al. (2009). The results demonstrated the importance of considering pH in the thermal inactivation of toxic protein in foods. Puttaraj et al. (1994) and Akande et al. (2011) explored the use of lime or lye cum heat treatment and obtained a good response in rat assay.

It is important to note that most of the *in vivo* agglutination test used to determine the toxicity of the meal did not clearly separate ricin and RCA. Although both are protein lectin which are normally affected by heat, in situation whereby the detoxifying process reduces the ricin drastically and does not affect RCA content, there is tendency to misjudge the suitability of the detoxified product while in actuality, the meal would be far less toxic (as a food product) due to the decrease in ricin toxin.

Biotechnology

There were few reports on the use of microorganisms in detoxification of castor seeds. Xu et al. (2007) reported that ricinine and allergen content in castor bean meal treated by fungus for 5 and 15 days were significantly reduced. Incidentally, the soup flavouring condiment called *ogiri* in West Africa Parkouda et al. (2009) are prepared in the same manner. The use of *Paecilomyces variotiio* on castor meal revealed a reduction in ricin bands during fermentation and simultaneously induces the production of tannase and

phytase enzymes which have potential to decrease overall anti-nutritional factors (Madeira et al., 2011). Similarly, *Penicillium simplicissimum* generated lipase activity of 155 000 U/kg on castor seed meal while the allergenic potential was reduced by 16%, and all ricin was eliminated (Godoy et al., 2009, 2011).

Report of transformed castor has been described by Mc Keon and Chen (2003) and Sujatha and Sailaja (2005). Successful *in vitro* regeneration of castor stem tips was also obtained by Bertozzo and Machado (2010). The reference genome has allowed the identification of genes involved in oil biosynthesis and toxin formation (Cagliari et al., 2010) as well as facilitating the mining of sequence polymorphisms that allow rapid characterization of castor germplasm (Foster et al., 2010; Qiu et al., 2010; Rivarola et al., 2011). The use of genetic engineering to knock out or silence the expression of genes related to allergens and ricin could be highly productive indeed. However, commercial production of a transgenic castor is worrisome because of the costs involved in the deregulation of a transgenic trait.

Castor seed meal in animal nutrition

Non-ruminant animals

Detoxified and deallerginized castor meal was safely used up to 12% without any ill effects on the growth performance of fattening swine (Kasidit and Chainarong, 1997). Apata et al. (1999) used products of uncontrolled fermentation with autoclaving at 121 °C 1.05 kg/cm² for one hour on castor seed cake in diets of pigs. The performance of the pigs on 5 and 10% compared closely with control group fed 0%. Similarly, fermented castor seed meal could successfully be included in chick starter diets at 50 g/kg inclusion (Oso et al., 2011).

Growing chicks fed non-roasted castor seeds at 10% of the diet or roasted castor seeds at 10, 15 or 20% of the diet for 6 weeks showed 83% mortality in birds on non-roasted meal and significant reduced feed intake and weight gain across all treatments (Okorie and Anugwa, 1987). There were reported cases of mortality of some chicks fed with diets containing heat treated castor seed meal (Okoye et al., 1987 and Ani and Okorie, 2005). Dehulled and cooked castor seed was best included at 10% in diets of broilers without adverse effect Ani and Okorie, 2009).

Feeding hot water-extracted castor protein with appropriate amino acid supplementation produced gains that were comparable to those achieved using soya bean meal in broiler chickens (Vilhjalmsdottir and Fisher, 1971). In the study conducted by Akande

and Odunsi (2012) using differently processed castor seed cake for feeding broiler birds at graded level, results indicated that combined processing of boiling and lye treatment (pH = 9.5) was most potent for inclusion up to 15% rate. Okamoto *et al.* (1970) detoxified CBM by washing it with water and with dilute HCl, feeding as little as 5 or 10% produced retardation in growth of 2- to 7-week-old chicks whereas no detrimental effects were found in adult laying hens.

Ruminant animals

Non-detoxified castor meal is generally restricted to 5% of total ration for ruminants (Robb *et al.*, 1974). When untreated castor meal was included at 10% level in rations for growing cattle, feed intake and growth were depressed than for cattle fed cotton seed meal. It was concluded that incorporation of 10% castor meal in cattle ration was not safe and economical. In dairy cows, a fall in milk yield was typical as well as depression in appetite and severe diarrhoea. At autopsy, intense inflammation of abomasums and intestines with corrosion of the mucous membranes was found. Lime-treated castor meal successfully replaced soya bean meal in terms of intake of dietary nutrients and the average daily body weight gain of beef cattle (Diniz *et al.*, 2010). In sheep fed non-detoxified castor meal, there were no symptoms of animal intoxication, but growth was reduced when compared with animals fed detoxified castor meal. There was no histopathological damage to liver, kidney, spleen and intestine, but there was an increased level of plasma immunoglobulin indicative of an immunological response to the ricin in the untreated meal (Gowda *et al.*, 2009; Furtado *et al.* 2012; Gomes, 2010; Silva *et al.*, 2010; Vieira *et al.*, 2011).

Adult sheep fed 250 g of concentrate, which contained 15 or 30% (i.e. 38 or 75 g) castor bean meal for 8 months corresponding to a daily ricin dose of 83 or 165 mg/animal per day. The animals maintained their body weights and no signs of ill health due to ricin during the entire experimental period except colour change of urine and faeces. At autopsy, the mucous membrane of the intestines was congested and thick, and mucous exudates were seen within the lumen in most of the ricin exposed animals. Lime treatment had a positive effect in reducing ricin by 58%, and no adverse effect was noticed by feeding such treated castor meal to adult sheep in terms of body weight changes, nutrient utilization, blood biochemical and mineral profile, rumen fermentation pattern and car-

cass traits (Purushotham *et al.*, 1985). It was observed that castor bean meal supplemented with 60 g/kg of calcium oxide can fully replace soya bean meal in crossbreed finishing cattle diets (Diniz *et al.*, 2010).

Based on evaluations of animal performances, detoxified castor meal was worth 85% of soya bean meal value. This study also suggested that meal quality could be improved by sieving to remove fragments of the husks and seed coats (Gowda *et al.*, 2009; Diniz *et al.*, 2010). However, extreme caution and experimentation are desirable before detoxified castor cake could be fully recommended because accurate measure of ricin toxicity in the meal remains a challenge to the commercial use of castor meal in animal rations.

Research for future consideration

Attempt for future detoxification of castor should explore high temperature of about 100 °C and high pH above 9.5 and the use of specific organism in solid state fermentation. Accurate detection and quantification of castor toxins in feed and biological samples remains a challenge to the commercial use of castor meal in animal rations. Until recently, all analytical procedures particularly in *in vivo* agglutination test did not separate ricin and RCA. All analytical methods are expensive and inadequate. There have been growing awareness and concern about the potential of ricin for being used as a biological weapon; hence, research should be encouraged towards decontamination of castor toxins. Other issues that need to be further addressed by the scientific community to promote the use of castor meal as animal feed include:

- (i) Comprehensive physico-chemical characterization of various varieties of castor seed for animal feed.
- (ii) *In vitro*, *in vivo* and *in situ* digestibility of castor bean meal
- (iii) Simplified methods for monitoring ricin toxicity during processing, trading and feeding.
- (iv) Simplified laboratory procedure for detection and quantification of ricin toxicity in feed and biological samples.
- (v) Economic analysis of castor meal compared to conventional protein sources and its by-products in the castor value chain.
- (vi) Toxicokinetics and carry-over of ricin to meat, egg and milk harvested from animals fed castor meal.
- (vii) Developing vaccine to mitigate effect of castor toxins in farm animals and industrial workers.

Conclusion

Castor seed has tremendous future potential as feed for farm animals in addition to its prospect as bio-energy and industrial feedstock because of its wide distribution, eco-friendliness, high oil yield, medicinal properties and high nutrient density. It is important to note that the detoxified castor meal still remain as an allergenic factor which, in animal feed, does not cause problems but may produce allergic reactions in humans during handling. Therefore, it is recommended to use protective kits while processing castor

seeds. Application of free amino acids as prophylaxis to allergen exposed individuals is a possibility under investigation. It was also apparent from literature that elevated pH, high temperature and activities of certain microbes exert much influence on castor detoxification. The development of low toxin castor cultivars will facilitate the use of castor meal in animal rations. Other preventive measures for processors include vaccination and active monitoring to prevent abuse. More concerted effort is required to prepare safe and acceptable castor meal for feed industry.

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