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Review Article

CASTOR BEAN CAKE: A PARADOX OF TOXICITY AND NUTRIENT SOURCE IN FARM ANIMALS AND AQUACULTURE

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Castor bean (*Ricinus communis* L.) though indigenous to Africa, has become endemic to many Asian, African, European and American countries. Castor is an industrial oilseed crop, wide spread in the tropical region as a spontaneous plant and widely being cultivated in India, China and Brazil. The main advantage of castor is its tolerance to drought stress and adaptation to variable agro-climatic conditions. The castor bean contains 40% oil, 1–5% ricin and 0.3–0.8% ricinin and nutritionally rich as it contains 4.3% nitrogen (N_2), 1.8% phosphorus (P_2O_5) and 1.3% potassium (K_2O). However, the great paradox of castor poisoning haunts globally before commercial application of such nutrient rich natural product in animal husbandry sector including aquaculture. The present paper reviewed the prospects of castor bean as nutrient source in animal husbandry considering its poisonous effects and processing mechanisms.

Key words: Antinutritional factors, Castor bean, Nutrient Imput, Toxicity

Castor bean (*R. communis* L.), also known as castor oil bean, mole bean and wonder tree, is a member of the Spurge family (Euphorbiaceae) which is originated from tropical Africa and is currently cultivated as an oilseed crop. In many countries of Asia, Central and North America, Africa and Europe it is also grown as an ornamental plant (Doan, 2004). Although apparently indigenous to Africa, *R. communis* L. grows so extensively in India that there has been a lot of speculation as to whether it is really a native of India (Chopra *et al.*, 2006). India is currently the leading producer of castor with the annual production of 1.42 million tonnes in the year 2017-18 (SEA, 2019). Castor is an industrial oilseed crop belonging to the Euphorbiaceae family, widespread in the tropical region as a spontaneous plant, having its main cultivated area in India, China and Brazil (Weiss, 1983; Miller *et al.*, 2009). As a crop, the main advantage of castor is its tolerance to drought stress and adaptation to several growing conditions (Babita *et al.*, 2010). The castor bean contains 40% oil, 1–5% ricin and 0.3–0.8% ricinin (Johnson *et al.*, 2005). Castor bean contains not only the toxic substances, but also it has a good nutritional profile. It contains total

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nitrogen (N_2): 4.3%, phosphorus (P_2O_5): 1.8% and potassium (K_2O): 1.3% (Ghimire, 2002).

History and origin of castor plant

Castor beans were used in the classical Egyptian and Greek medicine, and were described in the Sanskrit work on medicine, Susruta Ayurveda from the sixth century B.C. (Olsnes, 2004). Castor seeds have been found in Egyptian tombs dating back to 4000 B.C. and the oil extracted from the seed was used in wick lamp for lighting (Durowaiye, 2015). The name *Ricinus* is a Latin word for tick. The seed is so named because it has markings and a bump at the end which resembles certain ticks (Ombrello, 2007). Castor plant grows as perennial in the tropics and as an annual crop in the temperate climate. The common name *castor oil plant* is probably derived from its use as a replacement for castoreum, a perfume-base made from the dried perennial glands of the beaver (Adedapo and Babalola, 2017). Its other common name is palm of Christ (or *Palma Christi*) which is derived from castor oil's reputed ability to heal wounds and cure ailments (Durowaiye, 2015).

Anti nutritional factors of *Ricinus communis* L.

Castor plant have been shown to contain a number of anti-nutritional factors in its seeds, which include toxic glycoprotein ricin, alkaloid ricinine, ricinoleic acid (12-hydroxyoleic acid) and allergens, but the most dangerous of the toxin is ricin which varies depending on the variety of castor seed, large size seed contains 3.7 Hu mg/mL while small size variety contains 3.1 Hu mg/mL (Durowaiye, 2015). Ricinin is often used as an indicator of the presence of material from castor beans in press cakes in feeding stuffs (Darby *et al.*, 2001).

Ricin: The toxic effect of pressed *R. communis* L. (Euphorbiaceae) seeds may be due to the naturally occurring lectin, ricin (Baleta *et al.*, 2015). Ricin is synthesized in the castor bean endosperm (Lamb *et al.*, 1985; Frigerio *et al.*, 2001; Lord *et al.*, 2003). Ricin is a highly toxic, naturally occurring lectin (a carbohydrate-binding protein) produced in the seeds of the castor oil plant. All parts of the plant contain the ricin but the seeds are particularly rich with it and are extremely toxic and are most often associated with clinical toxicosis (Albertson *et al.*, 2000). Ricin, a highly toxic protein present in castor beans, inhibits protein synthesis in a cell-free system even when it is present in extremely small concentrations (Olsnes and Pihl, 1973). The castor seed consists of 20% of husk and 80% of soft kernel. The kernels apart from containing oil also contain ricin which is a toxic glycoprotein belonging to the type II group of ribosome inactivating proteins (type II RIP). Ricin is one of the most potent and deadly plant toxins (Aslani *et al.*, 2007) though it is used for the treatment of cancer and AIDS, in bone marrow transplantation and in cell biological research (Johnson *et al.*, 2005; Audi *et al.*, 2005; Tyagi *et al.*, 2015). It is a cytotoxic protein, and its toxicity results from the inhibition of protein synthesis which would lead to cell death (Audi *et al.*, 2005). According to Lin and Liu (1986) there are two toxic ricins: ricin D and E. Ricin E appears to be present in small grain castor bean plant types (Woo *et al.*, 1998).

Toxicity of ricin: The toxicity of *Ricinus* seeds has been recognised since ancient times, and its toxicity to humans has been reviewed by Olsnes (2004) and Audi *et al.* (2005). Lectins were discovered in 1888 by Stillmark, who observed that crude extract of castor beans that contain a toxic principle named ricin that agglutinated human and some animal red blood cells. More recent studies established that Stillmark's ricin preparations were a mixture of two proteins, namely the potent cytotoxin (ricin) and a haemagglutinin (Lord *et al.*, 1994). The seeds of castor been are poisonous and even 2-3 seeds can be fatal (Chopra *et al.*, 1984). Ricin, the toxic protein of castor bean itself being an inhibitor to protein synthesis (Miahal, 2000), is a blood poison and characterized by the properties of agglutinating and precipitating the red blood corpuscles (Borah and Talukdar, 2002). It is also known as teratogenic which can affect the somatic cells of growing embryos leading to disorders in the organ system (Walter and Elvin Lewis, 1977). This may produce synosis, echymosis and discoloration of the skin (Chopra *et al.*, 1984).

Ricinin: Ricinin, another toxic substance of castor bean is an alkaloid which is found in the leaves and the pericarps of the fruit and small amounts of ricinin can be extracted along with ricin (Humphreys, 1988; Audi *et al.*, 2005). Ricinin is known as a central nervous system stimulant (Ferraz *et al.*, 1999). Ricinine is a small alkaloid and the only natural source for ricinine is from castor beans (Waller and Henderson, 1961). However, it has also been reported from some other plants like *Piper nigrum*, *Discocleidion rufescens*, *Aparisthmium cordatum* and *Nicotiana tabacum* (Patel and Patel, 2016). Therefore, exposure to castor beans, extracted ricin or other castor bean products, such as castor oil would result in the presence of ricinine in urine. Therefore it is used as a bio-marker in castor-bran poisoning (Waller and Yand, 1967; Darby *et al.*, 2001). Ricinine ($C_8H_8N_2O_2$) has also been used as biopesticide. Bullangpoti *et al.* (2011) demonstrated that as a bioactive compound, ricinine may be used as an alternative for the minimal application of chemical insecticides for *Spodoptera exigua*. Wachira *et al.* (2014) found that extracts from *R. communis* showed the highest bioactivity against females of *Anopheles gambiae s.s.* acting as malaria vector.

In addition to ricin, the seeds of *R. communis* L. also contain the *Ricinus communis* agglutinin (RCA). Together these compounds make up around 5% of the total protein in the mature seeds. RCA is a tetrameric protein with stronger agglutinating properties than ricin but is less toxic (Lord *et al.*, 1994; Bigalke and Rummel, 2005).

Ricinoleic acid: Another plant compound highly irritating to the gastrointestinal mucosa is ricinoleic acid, a fatty acid present in *R.communis* L. seeds, considered to be responsible for the cathartic properties of ricin oil (Diaz, 2011). Ricinoleic acid is an irritant that alters the intestinal epithelium causing loss of water and electrolytes, increased loss of luminal DNA, and decreased enzymatic activity of enterocytes (Bretagne *et al.*, 1981). Teomim *et al.* (1999) hypothesized the use of ricinoleate-based polymers as drug carriers due to their lack of toxicity when tested in rats. Topical application of ricinoleic acid resulted in exceptional analgesic and anti-inflammatory activity in rats (Vieira *et al.*, 2000). These features made castor oil derivatives eligible for nanoparticle synthesis, provided that the 18-carbon fatty acid is capable of preventing aggregation and excessive nanoparticle growth. So far, studies have employed castor oil or ricinoleic acid as dispersive media for stabilization of a variety of nanostructures that include gold nanoparticles produced by sputtering (Wender *et al.*, 2010) and wet chemistry process (Morais *et al.*, 2015), quantum dots fabricated through thermolysis (Shombe *et al.*, 2016), and silver and gold nanoparticles in paints (Kumar *et al.*, 2008) as well as silver nanoparticles synthesized via ablation of metallic silver (Zamiri *et al.*, 2011).

Toxicity of castor seed

Castor oil cake which is used as manure is reported to be toxic for cattle and fish (Sandhu and Brar, 2000). In a static bioassay test, the 96 hour median lethal concentration (LC50) of *O. mossambicus* fingerlings against castor bean seed was 1.887 mg L^{-1} found by Mondal and Das (2019a) and also the fishes exhibited various behavioural abnormalities like surfacing, erratic swimming, vertical and uncoordinated movement, tilted positioning and settling at the bottom after the introduction of toxicant. Baleta *et al.* (2015) in a static bioassay test observed various forms of abnormal behaviours which included erratic swimming behaviour, rapid opercular movement, settling at the bottom, gasping or trying to escape from the toxicants in *Gambusia affinis* when exposed to different concentrations of fresh and dried *R. communis* bean extracts and ultimately settled at the bottom leading to mortality. For both fresh fruit and dried bean extract 96-h LC100: 0.42 mL L^{-1} was observed. A direct comparison of lethal concentration values suggests that dried castor bean extract has higher value of LC50 and LC100 than fresh bean extract (Baleta *et al.*, 2015). Mondal and Das (2019b) in a comparative study of mahua oil cake and castor bean seed as piscicides for one identical dose of 250 mg L^{-1} on tilapia and panchax observed a delayed response of castor bean seed compared to mahua oil cake as first and total mortality of tilapia was encountered at fourth and tenth hour of application, against twenty six hour and forty two hour in panchax respectively. The acute toxicity of ricin is very variable depending on the animal species, the strain and the route of exposure. Oral LD50s in rodents have been reported in the literature with 20-30 mg kg-1 in rats and 30mg kg-1 by weight in mice (Audi *et al.*, 2005; Cook *et al.*, 2006). The median lethal dose (LD50) of the aqueous seed extract was calculated to be 1587 mg kg-1 body weight in rats (Muhammad *et al.*, 2015). According to Cruz *et al.* (2012), the analyzed biodiesel water soluble fraction from castor was found to be toxic to fishes, indicating that biodiesel may be not strictly a biocompatible fuel. Ricin consists of two polypeptide chains each of approximately 30 kDa and joined by a disulfide bond (Lord *et al.*, 1994; Fredriksson *et al.*, 2005). Ricin is comprised of two subunits: Unit B (for binding) is the actual lectin that binds to galactosyl residues in cellular membranes (Lord *et al.*, 1994), whereas unit A (for activity) is an enzyme capable of inactivating ribosomes in eukaryotic cells (Endo *et al.*, 1987; Barbieri *et al.*, 1993; Spooner *et al.*, 2004). The three-dimensional structure of ricin and its chains has been elucidated by X-ray crystallography (Montfort *et al.*, 1987; Rutenber *et al.*, 1991; Katzin *et al.*, 1991). It is a powerful poison having a definite effect on the coagulation of blood; it has no purgative effect but produces haemorrhagic inflammation of the gastro-intestinal tract even when given subcutaneously (Chopra *et al.*, 2006).

Detoxification of castor seed cake

Castor cake, which is the remaining industrial sub-product generated after extraction of the oil from castor bean grains, is rich in valuable proteins and fibre and could be used as animal feed (Sousa *et al*., 2017) but due to the presence of ricin, it is generally used only as an organic fertilizer. Several physical, chemical and biological detoxification methods of castor cake have been developed by many researchers with limited success. Though from the economic point of view, these processes are still not practical and efficient enough to be used on a large scale (Severino *et al.*, 2012).

Anandan *et al.* (2005) tested different physical and chemical methods for the detoxification of castor, e.g., physical processing methods like soaking, steaming, boiling, autoclaving and heating at different time intervals and chemical treatments like, ammonia, formaldehyde, lime, sodium chloride, tannic acid and sodium hydroxide at different concentrations. Among the methods tested, only autoclaving at 15 psi for 60 minutes and calcium hydroxide treatment (40 g calcium hydroxide per kg castor residue) eliminated the toxin completely. Many researchers in their study used above stated physical and chemical processes for detoxification with slight modifications, e.g., autoclaving with different time period (15 minutes or 30 minutes), use of CaO instead of calcium hydroxide or combination of both autoclaving and CaO treatment (Borja *et al.*, 2017) with achieving partial or almost complete detoxification. There are also various simple, low-cost, biological detoxification methods that convert toxic waste into potential feed material. Godoy *et al*. (2009) detoxified castor residue by fermentation with *Penicillium simplicissimum*. Madeira Jr. *et al*., 2011 observed that, the wild Brazilian *Paecilomyces variotii* strain was able to grow in castor bean residue by solid-state fermentation, which resulted in detoxification of castor and simultaneously the production of the extracellular enzymes tannase and phytase. Although there are several processes for castor cake detoxification, there are no standardized methods to validate them.

There are few experiments aiming to generate detoxified genotype. Sousa *et al*. (2017) explored the RNA interference (RNAi) concept to silence the ricin gene in castor bean seeds in order to generate a non-toxic castor bean genotype, resulting in effectively silencing the ricin coding genes in genetically modified (GM) plants where ricin proteins were not detected by ELISA. Also two approaches are being described by Auld *et al.* (2003) to develop castor cultivars with reduced levels of toxin, e.g., conventional sexual hybridization used to develop F_6 lines of castor that have a 75-70% reduction in ricin and other toxins present in castor, e.g., ricinine, RCA toxins, 2S albumin etc., and plants combined with transgenic castor plants which have a potential for more than 99% reduction in ricin content.

Castor bean cake as nutrient resource

Live stock farming and aquaculture takes an important role among the several approaches that are being adopted to guarantee food security for people worldwide. This has always led to increasing interest to source for inexpensive alternative ingredients in replacement as feed, since it is the prime expenditure in any scientific farming system. The conventional protein sources are not only becoming more expensive but have high competitive use by humans and other industrial users. Therefore, nutritionists have intensified approaches to substitute with certain non conventional feedstuffs in order to reduce the high cost of feeding livestock and competition for the conventional ingredients. Studies on alternative feedstuffs have allowed considerable reduction in production costs (Albuquerque *et al.*, 2014) as the partial or total replacement of expensive ingredients contributes for the economic viability of animal production (Santos *et al.*, 2013).

Castor bean meal is one of such non-conventional sources having great potential to be used as a protein supplement in livestock farming. The residue, cake that is left after the extraction of the oil represents about one half of the weight of the castor bean (Robb *et al.*, 1974) and it has a protein content of 34 - 42% and with decortications, protein content of the cake can further be increased to 60% (Mottola *et al.*, 1968). It is found that the methionine and tryptophan contents in castor bean meal to be much higher than either of soybean meal or ground nut cake (Agarwal, 2001). Castor oil bean (*R. communis* L.) is grown in tropical and temperate regions, where the dehulled seeds are processed for use as flavour enhancing food conditioner (Oso *et al.*, 2011).

Castor seed has potential as animal feed because of its high crude protein and energy comparable to the conventional ones but limited because of three potent antinutritional factors: ricin, ricinin and thermo-stable castor allergen (Darby *et al.*, 2001; Olsnes, 2004; Audi *et al.*, 2005; EFSA, 2008). Although there are claims that toxic protein ricin is destroyed by heat in the oil extraction and desolventisation processes (Kim, 2001; Barnes *et al.*, 2009), there are also contradictory claims that the normal processing methods are not capable of destroying the toxin totally and there is a need to detoxify this for further use as livestock feed. Based on the fact that ricin is both heat labile and soluble in water, many researchers (Anandan *et al.*, 2005; Madeira Jr. *et al.*, 2011; Godoy *et al.*, 2009; Gomes De Silva *et al.*, 2018) have standardised various physical and chemical method of detoxification of castor seed cake. Although, various processing techniques have been proposed to combat the challenges posed by feed toxins, varying degree of success have been realised. Considering the nutritional potential of castor seed as animal feed, a concerted effort is required in getting rid of the impediments.

Use as feed of ruminants: After suitable detoxification, processed castor bean meal can be readily used as protein source for ruminants (Reddy *et al.,* 1986; Rao *et al.,* 1986). Ruminants seem to be more tolerant to the effects of castor meal feeding as the bacterial flora of ruminant animals may detoxify raw castor containing ricinine (Bris and Alego, 1970). However, Reddy *et al.* (1986) did not find any adverse effect on replacing ground nut cake with castor bean meal at 30 percent (w/w) level in concentrate mixture of buffaloes. Robb *et al.* (1974) reported that castor bean meal would be a satisfactory protein supplement for dairy cows during lactation and the milk from cows on long term castor bean meal intake at 10 to 20 percent was not injurious when fed to calves. However, in an earlier study Popovic (1967) reported that dairy cattle when fed 30 per cent castor bean meal in concentrate mixture though appeared healthy, butter fat showed slightly increased viscosity, low iodine and Reichertmeisel and Polensky values. Purushotham *et al.* (1986) applied autoclaved castor bean meal at 10 per cent level in the concentrated mixture of Deccani lambs without any adverse effects.

Use as feed of non-ruminants: Castor bean meal after NaCl treatment could be a wholesome substitute of costly oil cake in growing rabbit diets without any adverse effect on feed intake, nutritional performance of rabbits (Agarwal, 2001). Hot water extracted castor bean meal properly supplemented with the limiting amino acids like lysine and tryptophan is acceptable protein source for chicks (Vilhjalmsdottir and Fisher, 1972). Akande and Odunsi (2012) reported that, heat combined with lye treatment, best detoxified castor seed cake and could be safely used to replace about 50% of ground nut cake in diets of broiler birds.

Use as feed of aquatic species: Unlike terrestrial animals, information on the use and effect of using castor seed cake as non-conventional feed ingredient for fish and shell fish is relatively meagre. Balogun *et al.* (2005) found that the feed conversion ratio, protein efficiency ratio and apparent net protein utilization and growth indices increased when castor seed meal boiled for a specific time fed to *O. niloticus* as experimental diets and concluded that *R. communis* L. have very high nutrient potentials as feed supplement after heat treatment to destroy the anti-nutrient contents. Cai *et al.* (2005) used castor seed to replace fishmeal at 0, 40 and 100%, in which inclusion with 40% in fish feed performed the most. The result of this study on effect of dietary inclusion of castor seed meal on the growth performance, body composition and haematology of *Clarius gariepinus* fingerlings (Adedapo and Babalola, 2017) revealed that 10% inclusion of castor seed meal can be done in the diet without any negative impact on those health indices.

Use of castor as manure input

Soil organic matter dynamics plays a major role in natural, agricultural as well as aquatic ecosystem. In modern culture systems with high fertilization rates, the various organic components have potential for acting as an important source nutrients. The use of organic matter either alone or in combination with fertilizers has been considered as a highly desirable practice for the two major reasons of increasing the nutrients use efficiency and for sustaining the soil fertility (Ratnayake, 2008). The degradation and disintegration of the organic components of the soil occurs rapidly under tropical conditions (Lathwell and Bouldin, 1981). Organic fertilizer has an impact effect on agriculture sector as well as fish culture. Organic residues are increasingly being used not only as fertilizer, but also as substrate in horticulture for growing seedlings and vegetables, due to the declining availability and increasing cost of peat (García-Martínez *et al.*, 2009). Application of organic manures in general, improves the availability of N, P and K in soils apart from serving as a potential source of micronutrients. The use of organic by-products to improve yields of agricultural crops and to recycle nutrients is a traditional alternative for disposal of industrial residues with additional advantages of avoiding environmental impacts, generating incomes for industries and farms as well as can supply macro and micronutrients, improve physical properties of soil, immobilize toxic elements like aluminium and promote microorganisms activity (Zuchi *et al.*, 2007; Cavaleri *et al.*, 2004; López-Pin˜eiro *et al.*, 2008).

Production of oil from castor generates two main by-products, viz., husks, produced when the seeds are separated from the fruits and meal, produced when the oil is extracted from the seed. Assuming that the seed weight corresponds to 62% of the fruit weight (Severino *et al.*, 2006), and the efficiency of oil extraction is 47% (w/w), the production of 1 tonne of castor oil results in 1.31 tonnes of husks and 1.13 tonnes of meal. Castor meal is the most important by-product due to its high nitrogen content, and presently it is predominantly used as an organic fertilizer. Most of the castor meal produced in the world is used as organic fertilizer (Gupta *et al.*, 2004; Udeshi, 2004).

The nutrient composition of different organic manures and oil cakes like, castor cake, pongamia cake, jatropha cake and neem cake are different and they affect soil differently. Nitrogen content in castor meal (7.54%) is similar to cotton meal (8.21%) (Vaughn *et al.*, 2010; Severino *et al.*, 2006). Caster cake produced by mills in Brazil varied in composition and has N, P_2O_5, K_2O and CaO to the extent of 4.8-5.2%, 1.8- 2.5%, 1.3- 2.5% and 6.4%, respectively (Santos, 1966). The castor cake produced in Kenya was found to have 3.87% N, 0.4% P_2O_5, 5.69% K_2O, 0.28% Ca, 44.92% crude fibre and 33-39% carbohydrates on dry weight basis. While, Tandon (1992) reported that castor cake produced in India contains 4.37% N, 1.85% P_2O_5 and 1.39% K_2O. Greenhouse study optimized blends of castor husks and meal as organic fertilizer for growth of castor plants (Lima *et al.*, 2011). When both mahua oil cake and castor been cake is used at identical doses, both contributed positively to the nutrient pool of water in which castor bean cake provided more nitrogen compared to mahua oil cake with some P limitation in the prior (Mondal and Das, 2019b).

Conclusion

In spite of the plenty literatures on castor bean dealing primarily on toxicity and industrial use, literatures on the use of castor bean by-products as nutrient source particularly as crude protein in animal husbandry sector is scarce. This is more so in the field of fisheries and aquaculture where cheap source of valuable protein source is a priority area to reduce production cost and environmental sustainability. The present review has enlighten the possibility of using castor bean cake as protein input in aquaculture and animal husbandry sector following cheap processing techniques. It has the potential at least partially to replace costly conventional protein inputs in the feed manufacturing sector concerned with animal husbandry including aquaculture.

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