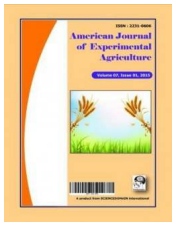

American Journal of Experimental Agriculture
10(6): 1-10, 2016, Article no.AJEA.21980
ISSN: 2231-0606

SCIENCEDOMAIN *international*
www.sciencedomain.org

Effects of Anti-nutritive Constituents of Unprocessed Jack Bean (*Canavalia ensiformis*) (L) (DC) Seed Meal on Poultry Performance

K. E. Akande[1*]

[1]Department of Animal Production, Faculty of Agriculture, Abubakar Tafawa Balewa University, Bauchi State, Nigeria.

Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

Article Information

DOI: 10.9734/AJEA/2016/21980
Editor(s):
(1) Anonymous.
Reviewers:
(1) Cinthia Maria Carlos Pereira, State University of Santa Cruz, USA.
(2) Anonymous, University of the South Pacific, Fiji.
(3) Marshall D. McCue, St. Mary's University, San Antonio TX, USA.
(4) Bergaoui Ridha, National Institute of Agronomy Tunisia, Tunisia.
Complete Peer review History: http://sciencedomain.org/review-history/12549

Review Article

Received 12th September 2015
Accepted 17th November 2015
Published 3rd December 2015

ABSTRACT

Jack bean *(Canavalia ensiformis)* is a good source of plant protein as well as a starch-storing seed and on the basis of the apparent nutrient content, it should be an extremely useful ingredient in animal feeds. The use of untreated *Canavalia ensiformis* seed as a feedstuff for poultry is restricted due to the presence of anti-nutritional factors, as is the case with the other tropical legumes. The anti-nutritional constituents of *Canavalia ensiformis* have been reported to include tryspin inhibitors and concanavalin A which are heat-labile and canavanine and canaline which are hydrosoluble. Other antinutrients are saponins, cyanogenic glycosides, and phenols. *Canavalia ensiformis* seeds can be used as an animal feed ingredient since they are a good source of starch and protein. However, in order to be used as animal feed ingredient, *Canavalia ensiformis* seeds would have to be thermally processed. Heat processing is universally accepted as an effective means of inactivating most, if not all of the heat-liable toxic constituents of legume grains. Research has showed that dietary inclusion of detoxified jack bean seed between 20-30% in feed ration is capable of supporting the growth of poultry birds without adverse effects on performance and

**Corresponding author: E-mail: kemi777akande@gmail.com;*

physiological parameters of the animals. Several research works had been carried out on how to improve the quality of legumes. These researchers have reported many processing methods. Interestingly, on many occasions, in order to achieve complete inactivation or detoxification of these anti-nutritional factors a combination of two or more processing methods may be needed.

Keywords: Canavalia ensiformis; tryspin inhibitors; concanavalin A; canavanine; canaline; saponins; cyanogenic glycosides; poultry.

1. INTRODUCTION

Jack bean *(Canavalia ensiformis)* has a great potential as an economic crop because of its excellent germination and initial growth, which makes its establishment relatively easy [1]. The use of untreated (raw) seeds of jack beans (*Canavalia ensiformis*) in diets of livestock animals is restricted by the presence of various factors which are toxic. However, properly processed jack bean seeds, an unconventional feedstuff have great potential for inclusion in animal diets. Generally, unconventional feed ingredients are very useful for compounding animal feed in geographical locations or in a situation or season when other sources of vegetable protein (soybeans, groundnut cake, and cotton seed meal) are either not available or are too expensive [2-4].

When considering anti-nutritive substances in the seeds of jack bean which may serve as a potential feedstuff for livestock, it is worth noting that it is particularly the toxic effect connected with the dietary intake of the factor that is significant nutritionally, and not the injection of the antinutrient into the body. This is due to the fact that the ingested substances may be subjected to possible modification by the gastro-intestinal tract [5].

It has been reported by [6] that both wet and dry thermal treatment resulted in a beneficial effect on protein quality with protein efficiency ratio (PER) increasing from raw seed value of 0.10 to 1.21 and 1.18 for wet and dry cooking. These workers also reported the protein quality to be 41.5% as compared with that of casein. The value is similar to that of common food legumes [6].

2. AVAILABILITY AND USES OF JACK BEAN

2.1 Geographical Distribution and Availability of Jack Bean

Jack bean has its origin in the Western part of India and Central America [7]. Jack bean varieties were originally grown in the drought-ridden regions of Arizona and Mexico in ancient times and used as high-protein food and forage crops for several centuries by the natives of Mexico, Southwestern United Stated, Central American countries, Peru, Ecuador, Bolivia, Brazil, West Indies, Paraguay and Argentina [8]. Jack bean is cultivated and distributed in Africa, Asia, the West Indies, Latin America and India [9].

2.2 Uses of Jack Bean

The mature seeds are cooked and eaten by the Indian tribal sects, Kurumba, Malayali, Erula and other Dravidian groups [10]. In western countries, this legume is used as a cover crop and also the seeds roasted and ground to prepare coffee-like drink [6].

In several homes in Nigeria, jack bean is grown as an ornamental plant, while in some areas in the country it is regarded as snake repellent [11]. In some tropical parts of the world where jack bean is available, its young leaves and green pods are used as vegetables [12,13].

Native starches in jack bean have been utilized for several years as a raw material in the preparation of various products. Jack bean has been used in foods because of its good thickening and gelling properties. They are also a good texture stabilizer and regulator in food systems [14]. Processed jack bean seeds have also been used as a feed ingredient in livestock feeds [3,15-18].

3. THE NUTRITIVE COMPOSITION OF JACK BEAN SEEDS

Jack bean has a good nutritional value [19-21]. The crude protein content of dry ripe jack bean seed ranges from 26 – 32%. Udedibie [22] reported about 30% crude protein and 60% nitrogen free extract in raw jack bean seed. The gross energy content of 4.26 kcal/g was reported by [11] for raw jack bean seed. Jack bean contains significant amounts of niacin, thiamine, phosphorus, calcium and iron [6,20,23,24].

The macro-mineral that was most concentrated in raw jack bean seeds was potassium with the value of 9.9 g/kg while the lowest was sodium with the content of 0.07 g/kg. On the other hand, among the micro-mineral iron was the most abundant with the value of 48.7 g/kg whereas manganese recorded the lowest value of 15.6 g/kg in the raw seed [25].

Jack bean seed is relatively low in sulphur amino acids, but high in lysine. The most limiting amino acid in untreated jack bean seeds was methionine with the value of 0.46 while the lysine content of raw jack bean seeds was found to be 4.42g16gN [19]. Apata and Olohogbo [25] reported that jack bean contained 1.47 and 6.56g16gN methionine and lysine respectively. Some factors of variation in the composition of jack bean may be attributed to differences in geographical location, soil condition, handling and storage conditions.

Generally, processing has been well documented to improve the nutritional quality of jack beans. It is however, of paramount importance that future research should be specifically directed towards evaluating the effect of various processing methods on the nutritive composition of jack beans.

3.1 Proximate Composition of Jack Bean (*Canavalia ensiformis*) Seeds

The proximate composition of jack bean seed as shown in Table 1 reveals its potential value for future use in livestock feeding. Bressani and Sosa [6] reported the proximate content of jack bean as; 1.8 ether extract, 8.5 crude fibre, 3.2 ash, 13.5 moisture, 26 crude protein and 46.1% carbohydrate. D'Mello et al. [20] reported 2.12, 2.8 and 9.24% for ether extract, ash and crude fibre, respectively. Studies by [11] showed that jack bean contains about 3.16 ether extract, 3.73 ash and 7.8% crude fibre. The ether extract and ash contents of jack bean seeds are quite low while the crude fibre is slightly high. Akande [19] presented the proximate composition of jack bean as containing 28.38 crude protein, 3.10 crude fat and nitrogen free extract as 53.62%.

4. ANTI-NUTRITIVE CONSTITUENTS OF JACK BEAN

The use of legumes for livestock nutrition is impeded by the presence anti-nutritional substances in their raw seeds and foliage. Anti-nutritional factors are substances that are found in feedstuff which reduce their nutritional value and also affect the animals adversely in several ways. The adverse influence of the dietary raw legumes is associated with the effect of anti-nutritional factors. These adverse effect includes; alteration of gut permeability, growth retardation, reduction in feed intake, impairment of nutrient digestion and nutrient absorption, hyper-activity of the pancreas, interference and disruptions of cellular metabolic processes, impediment of hormonal and enzyme activities etc. [26-36]

The anti-nutritive substances found in jack bean (*Canavalia ensiformis*) seeds are predominantly: concanavalin A, trypsin inhibitors, the toxic non-protein amino acids (canavanine and canaline), saponins, cyanogenic glycosides and polyphenols. Akande et al. [37,38] reported that the occurrence and dietary effect of anti-nutritional factors present in unprocessed plant protein feed ingredients are major constraints to their optimum utilization as livestock feeds.

4.1 Concanavalin A

Concanavalin A, a lectin found in jack bean seeds was first described by [39]. Concanavalin A is a potent haemagglutinin and it is capable of agglutinating the red blood cells of several livestock animals and can also react with the sugar components of the intestinal cells causing a disruption in cell structure which consequently produces abnormalities in nutrient absorption. Jayne-Williams [15] postulated that lectin-induced disruption of the intestinal cell structure permits invasion of lymph, blood, and liver by

Table 1. Proximate composition of jack bean seeds

Content %	Jack bean seed and sources			
Dry matter	93.10 [19],	89.40 [25],	86.50 [6],	94.27 [9]
Crude protein	28.38 [19],	27.90 [25],	26.00 [6],	24.32 [9]
Crude fat	3.10 [19],	2.60 [25],	1.80 [6],	3.17 [9]
Crude fibre	5.20 [19],	9.70 [25],	8.50 [6],	6.13 [9]
Ash	2.80 [19],	2.80 [25],	3.20 [6],	2.11 [9]
Nitrogen free extract	53.62[19],	57.00 [25],	4.61 [6],	41.26 [9]

bacteria normally confined within the lumen of the gut. Consequently, the animal succumbs to otherwise innocuous organisms. Concanavalin A adversely affects nutrient absorption and metabolic processes in the gut [15]. Concanavalin A also reduces feed intake in non-ruminants [40].

4.2 Trypsin Inhibitors

Trypsin inhibitors are widely distributed within the plant kingdom, including the seeds of most cultivated legumes. They are protease inhibitors occurring in raw legumes seeds and they are the most commonly encountered group of anti-nutritive constituents of plant origin. These anti-nutritional substances inhibits the activity of the proteolytic enzyme (trypsin) in the gut [5,41, -43,1]. Trypsin inhibitors have been documented to be partially responsible for the growth-retarding property of raw legumes. The growth retardation has been associated with the inhibition of protein digestion, but there is evidence of pancreatic hyper-activity, resulting in increased production of trypsin with resultant loss of cystine and methionine [41,43]. Antitrypsin factors found in jack bean seeds are heat-labile [44]. Babar et al. [45] confirmed this in their experiment by achieving a total inactivation of antitrypsin activity in jack bean seed after soaking in water for 24 hours before 20 minutes cooking. Trypsin inhibitors are inactivated by heat especially moist heat, because of uniform heat distribution [46,47].

4.3 Toxic Non-protein Amino Acids of Jack Beans Seeds

According to [48] the toxic non-protein amino acids found in jack beans seeds are canavanine and canaline (the product of degradation of canavanine).

4.3.1 Canavanine

Canavanine is found in most legumes plant *Papilionoideae* [49] and abundantly in jack bean

(*Canavalia ensiformis*) (L.) (DC.), constituting up to 63 g/kg dry weight of seed [50]. Canavanine toxicity in higher animals is not completely understood [27]. Canavanine is structurally similar to arginine an essential amino acid, for this reason, it antagonizes arginine and impedes nuclear and cellular metabolic activities, consequently producing a toxic effect. Additionally, its toxicity to insects [51] and other organisms [52] is well documented and established and the function and role of this non-protein amino acid in plant defence mechanisms was reported by [49]. The deleterious effects of unprocessed *Canavalia ensiformis* have partly been attributed to the presence of canavanine [20]. Rosenthal [53] posited the interference of the metabolic activity of ribonucleic acid (RNA) by canavanine. This phytochemical may also antagonize arginine.

Researchers [54-56] have reported the reduction in feed intake of monogastric animals when the feeding of pure canavanine was done. Notwithstanding, this probably might not be the case when canavanine is present in the seed or meal fed to non-ruminant animals, due to the fact that the release of this factor in the gastro-intestinal tract varies when compared to the situation in which canavanine is purely fed to monogastric animals. Canavanine is soluble in water, it is however, heat stable and this presents a great challenge in terms of the inactivation of this anti-nutritive factor.

4.3.2 Canaline

The hydrolytic cleavage of canavanine by arginase results in the production of canaline and urea. Canaline is a structural analogue of ornithine which is a derivative of arginine. This non-protein amino acid is also found in jack bean seeds. It is heat-stable but solubilises in water. The derivative of canavanine, canaline, inhibits the activity of transaminases [53].

The structural similarity of canaline to ornithine allows canaline to react with the pyridoxal phosphate moiety of BG-containing enzymes to form a covalently bonded stable Schiff base. Therefore, canaline has been shown to be a potent inhibitor of pyridoxal phosphate enzymes [57,58]. However, canaline toxicity in animals has been suggested to occur in the following ways: By inhibition of enzymes, by competition with ornithine in the arginine urea cycle; or by forming a complex with pyridoxal phosphate cofactor in a manner similar to mimosine [59].

4.4 Saponins

Saponins are considered as one of largest classes of natural plant components, however, their phytochemistry and bio-functionality is not completely understood and known in plants [32]. Saponins are naturally occurring substances that are vastly distributed in all cells of most legumes. The have the ability to form stable, soap like foams in aqueous solutions, make up a complex

and chemically diverse set of compounds [32,60]. Saponins contain a carbohydrate moiety attached to a triterpenoid or steroids. Saponins possess both adverse and beneficial properties [60].

Saponins are known to be temperature sensitive. During processing such as washing, soaking and blanching saponins are dissolved and lost in water [61]. Saponins form complexes that are capable of causing damage to the intestinal mucosa and also affects protein digestion in the gut [30] and the absorption of nutrients across the intestinal wall [28,62]. It is also known to interfere with the uptake of vitamins and minerals and negatively affects membrane and cell wall permeability [27,63,32]. Saponins have been implicated in the retardation of growth rate, decrease in feed intake, prevention of the activity of smooth muscle [28]. Saponins have been reported to detectable in jack beans [59,64]. Udedibie et al. [64] found that saponins were not detected after boiling jack beans for the hour. Generally, saponins and its metabolites can produce several properties that can have either positive or negative effects in different animals [65,66].

4.5 Cyanogenic Glycosides

Cyanogenic glycosides are anti-nutritive compounds that are widely distributed in the plant kingdom. Cyanogenic glycosides are products of secondary metabolism. Cyanogenic glycosides are majorly vital natural plant components used in the defence mechanism in plant kingdom against herbivores owing to their bitter taste and the release of toxic hydrogen cyanide upon tissue damage or disruption [67]. Hydrogen cyanide production is generally dependent upon the cyanogenic glycoside synthesis and the presence or absence of its degradation enzyme. The main toxic substance producing toxicity is hydrogen cyanide (HCN) [68].

According to the reports of [69] hydrogen cyanide causes disruption in the metabolic processes of the pentose phosphate pathway, this consequently results in decrease in the rate of glycolysis and inhibiting the tricarboxylic acid cycle. Hydrogen cyanide has also been implicated in the inhibition of other vital metabolic activities such as metalloenzymes, many of which contain iron, copper or molybdenum [70].

Jack bean like some other raw legumes contains cyanogenic glycosides from which hydrogen cyanide (HCN) may be released by hydrolysis. Hydrogen cyanide is very toxic to animals even at low concentration. It can cause dysfunction of the central nervous system, respiratory failure and cardiac arrest [38]. It has been stated that there is 108 mg/kg hydrogen cyanide present in raw jack bean seeds [71]. According to the research reports of [64] the cyanogenic glycosides in *Canavalia ensiformis* were eliminated within thirty to sixty minutes of boiling.

4.6 Others

About 1.3% of polyphenols have been reported in jack bean and, like trypsin inhibitors, they are destroyed by moist heat (30 minutes) rather than dry heat [45].

5. LEVELS OF THE ANTI-NUTRITIONAL FACTORS PRESENT IN RAW JACK BEAN SEEDS

According to [45] about 1.3% of polyphenols is present in jack bean. Raw seeds of jack bean have been reported to contain 13,532 hemagglutinating units (HU) per g of seed, and also 1,682 trypsin inhibitor units (TIU) per g of seed [5]. Canavanine was found to constitute up to 6.3% dry weight of raw jack bean seeds [50]. Concanavalin A constitutes about 20% of the total protein of the seed [72]. Additionally, it has been reported that there is 108 mg/kg hydrogen cyanide present in raw jack bean seeds [71].

6. EFFECTS OF JACK BEAN SEEDS ON THE PERFORMANCE OF POULTRY

The proximate content of jack bean seeds has been reported to be suitable for poultry feeding. The amino acid composition of jack bean protein is very similar to that of roasted soybean meal with jack bean containing slightly less lysine than soybean and both having respectively low levels of methionine and cystine [19,16].

Jayne-Williams [15] reported 100% mortality in Japanese quails (*Coturnix coturnix japonica*) with diets containing 50% raw *Canavalia ensiformis* seed. However, autoclaving the seed overcame this effect. Laviada [73] included raw *Canavalia ensiformis* in chick diets at levels of 10, 20 and 30% and observed that mortality increased as the inclusion level increased and reached 50% at the 30% level. In a study conducted by [74],

Table 2. Recommended dietary inclusion level of processed jack bean in poultry diets

Poultry type	Recommended level %	Processing method used	Source
Japanese (Quails)	5	Autoclaving	[15]
Broilers (Chicken)	30	Autoclaving	[16]
Layers (Chicken)	20	Ensiling in Urea + Boiling	[80]
Broilers (Chicken)	20	Dry Urea Ensiling + Toasting	[17]
Broilers (Chicken)	30	Cracking + Soaking in Water + Cooking	[18]
Layers (Chicken)	10	Boiling	[80] [11]
Broilers (Chicken)	20	Soaking in Wood Ash Solution + Cooking	[3]
Broilers (Chicken)	25	Soaking in Urea + Cooking	[81]

autoclaved jack bean seeds included at levels of 10 and 15% in chick diet led to growth rate increases of 76% in comparison with that of the raw seeds. Udedibie and Madubuike [11] in their experiment showed that dietary inclusion of unprocessed and processed jack bean (*Canavalia ensiformis*) seeds at 20% level in the feed, depressed feed intake and hen-day egg production with the raw jack bean meal causing greater depression in animal performance.

Kessler et al. [16] in their study examined the effect of duration of feeding autoclaved jack bean seed (from one to eight weeks of age and from five to eight weeks of age) on the performance of broilers. Jack bean was included at 30% in diets of broilers. These researchers observed faster growth rates in those birds fed autoclaved *Canavalia ensiformis* for five to eight weeks of age, compared with those that received the same treatment from one to eight weeks of age. This suggests that the older birds were less sensitive to the anti-nutritive effect of *Canavalia ensiformis* than the young birds. Practical experiment on laying hens and broilers showed a significant decrease in feed intake, feed conversion and growth rate for dietary levels as low 10% raw jack bean seeds [75-77].

Research studies carried out by [78] on the effects of raw jack bean meal on performance of broilers, showed that both feed intake and body weight gain were reduced as the dietary level of raw meal increased, but the reduction became significant only at levels above 10% in the diet. According to the research reports of [79], laying birds were observed to be more tolerant, although even in these birds, egg production was significantly reduced by the inclusion of 20% in the diet.

Ensiling with ammonia or urea also seems to be successful in decreasing the toxicity of jack beans for chicks. The combination of autoclaving and ensiling gave better results than simple ensiling [76]. This is probably because of the solubilisation of the toxic factor in the alkaline (urea) solution [33]. Dry urea ensiling before toasting is effective, it has been shown that up to 20% dietary jack beans treated with dry urea and toasted did not have deleterious effect of broiler performance [17].

Udedibie et al. [18] showed that cracking and cooking of jack bean alone is not a good method of processing because dietary inclusion above 20% for broilers resulted in declined performance. Soaking the cracked seeds in urea solution for 24 hours prior to cooking could not appreciably improve its nutritive value when included in broiler diets above 20%. Soaking the cracked jack bean seed in water for 24 hours before cooking for an hour produced the best results, allowing dietary inclusion level of up to 30%. Probably, increasing the period of soaking in water could result in better performance [18]. Fabiyi [3] reported that detoxified jack bean meal can be included at levels up to 20% in broilers rations without adverse effect on performance and physiological parameters of the broilers.

Detoxified jack bean *(Canavalia ensiformis)* has high potentials for poultry feeding [3]. Table 2 presents the recommended dietary inclusion levels of processed jack bean in poultry diets.

7. CONCLUSION

Canavalia ensiformis has a protein quality similar to that of most edible food legumes. Jack bean has a great capability as an unconventional plant protein source for livestock feeding, however, the thermal-labile and non-thermal-labile anti-nutritive substances pose some restrictions in its usage for non-ruminant nutrition. Detoxification of the anti-nutritional factors is necessary for the improvement in the nutritional quality of the

legume and to effectively utilize their potential as livestock feed ingredients. An interesting fact is that heat treatment can lead to the improvement of jack bean's nutritive quality. This makes the use of processed seeds in animal nutrition a possibility, especially for monogastric animals. Many research authors have reported several processing methods such as; soaking, cooking, toasting, autoclaving, fermentation, extrusion cooking, sprouting, cracking and chemical treatment to improve the quality of the legume, by of the removal or inactivation of anti-nutritional factors. In many instances, for effective and complete detoxification process, a combination of two or more methods may be required. Further research should be geared towards examining the effect of processing methods on the nutritive quality of jack bean and in addition, effort should be intensified on devising ways of improving the palatability of jack bean for poultry feeding, in order` to enhance feed intake.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Udedibie ABI. Detoxifying Canavalia seeds. Spore. 1997;72:9.
2. Akande KE. Dietary effects of increasing levels of pigeon pea meal on rabbit performance. Journal of Agricultural Sciences. 2015;7(7):156-162. DOI: 10.5539/jas.v7n7p156.
3. Fabiyi KE. Utilization of jack bean (*Canavalia ensiformis* (L). DC) meal as Replacement for Soybean meal in Broiler Diets. M. Sc Thesis, Abubakar Tafawa Balewa University, Bauchi State, Nigeria; 1999.
4. Perez MM. *Canavalia ensiformis* en la alimentaction de pollos de engorda. EQ Thesis, F.M.V.Z – U.A.D.Y; 1984.
5. Carlini CR, Udedibie ABI. Comparative effects of processing methods on haemagglutinating and antitryptic activities of *Canavalia ensiformis* and *Canavalia braziliensis* seeds. Journal of Agricultural and Food Chemistry. 1997;45(11):4372-4377.
6. Bressani R, Sosa JL. Effects of processing on the nutritive value of Canavalia jack beans (*Canavalia ensiformis* (L.). Plant Foods for Human Nutrition. 1990;40:207-214.
7. Thompson, LV, Tenebaum AV, Hui H. Effects of lectins and the mixing of proteins on rate of protein digestibility. Journal of Food Science. 1986;51(1):150-152.
8. Sauer T, Kaplan L. Canavalia beans in American prehistory. American Antiquity. 1969;34:417-424.
9. Marimuthu M, Gurumoorthi P. Physiochemical and functional properties of starches from Indian jack bean (*Canavalia ensiformis*), an underutilized wild food legume. Journal of Chemical and Pharmaceutical Research. 2013;5(1):221-225.
10. Mittre V. Wild plants in Indian folk life- a historical perspective. In SK Jain (Ed.), Contribution to ethnobotany of India, Jodhpur, India. Scientific Publishers. 1991; 37-58.
11. Udedibie ABI, Madubuike FN. Effects of dietary raw and cooked jack bean (*Canavalia ensiformis*) on the performance of laying hens. Journal of Arid Agriculture. 1988;1:47-54.
12. Purseglove JW. Tropical crops – Dicotyledons. Longman, Harlow Eseex, UK.1982;244-245.
13. Rachie, KO. Relative agronomic merits of various food legumes for the low and tropics. In: Potential of Field beans and other food legumes in Latin America, 26 February – 1 March, 1973, Series seminar No. 2E, CIAT, Cali Colombia. 1973;123-139.
14. Cousidine DM. Foods and food production. Encyclopaedia; John Wiley Inc: New York. 1892;142.
15. Jayne-Williams DJ. The influence of dietary jack beans (*Canavalia ensiformis*) and concanavalin A on the growth of conventional and gnotobiotic Japanese quail. (*Coturnix coturnix japonica*), Nature. 1973;243:150-151.
16. Kessler M, Belmar R, Ellis N. Effects of autoclaving on the nutritive value of seed *Canavalia ensiformis* (jack beans) for chicks. Tropical Agriculture (Trindad). 1990;67:116-120.
17. Udedibie ABI, Esonu BO, Obaji CN, Drunna CS. Dry urea treatment prior to toasting as method of improving the nutritive value of jack bean (*Canavalia ensiformis*) for broilers. Animal Feed

Science and Technology. 1994;48:335-345.
18. Udedibie ABI, Esonu BO, Agbabiaka LA. Comparative performance of broilers fed diets containing differently processed jack bean meals at finisher phase. Nigeria Poultry Science Journal. 2000;1:32-41.
19. Akande KE. Proximate composition and amino acid profile of raw and processed seeds of jack bean (*Canavalia ensiformis*) (L) (DC). African Journal of Natural Sciences. 2004;7:50-51.
20. D'Mello JPF, Acamovic T, Walker AG. Nutritive value of jack bean (*Canavalia ensiformis*) for young chicks. Tropical Agriculture (Trinidad). 1985;62:145-150.
21. Pound B, Dona F, Peratta G. Effect of cutting frequency on seed and forage yield of *Canavalia ensiformis* (jack bean). Tropical Animal Production. 1982;7:262-266.
22. Udedibie, ABI. Nutritional evaluation of jack bean (*Canavalia ensiformis*) for the Nigerian poultry industry. Ambio. 1990;19: 361-365.
23. Leon AL, Angulo M, Pichard B, Carre L, Deronet JP, Harscoat JP. Amino acids and starch digestibility and true metabolizable energy contentof raw and extruded jack bean (*Canavalia ensiformis*) in adult cockrels. Annale Zootechnology. 1990;39: 53-61.
24. Udedibie ABI, Nwaiwu J. The potential of jack bean (*Canavalia ensiformis*) as animal feed. Nigerian Agricultural Journal. 1988; 23:130-143.
25. Apata DF, Ologhobo AD. Biochemical evaluation of some Nigerian legume seeds. Food Chemistry. 1994;49:333-338. DOI: http://dx.doi.org /10.1016/0308-8146 (94)90001-9
26. Aletor VA, Fetuga BI. Influence of raw and cooked lima beans on some liver enzyme activity in the rat. Nutrition Reports International; 1984.
27. Belmar R, Nava-Montero R, Sandoval-Castro C, McNab JM. Jack bean (*Canavalia ensiformis* (L). DC) in poultry diets: Anti-nutritional factors and detoxification studies – a review. World Poultry Science Journal. 1999;55(1):37-59.
28. Cheeke PR. Nutritional and Physiological implications Saponins: A review. Canadian Journal of Animal Sciences. 1971;51:621-623.
29. D'Mello JPF. Toxic amino acids. In: Anti-nutritional factors, Potentially Toxic Substances in Plants, (eds. JPF D'Mello and CM Duffus). (Warwick, Association of Applied Biologists). 1989;29-50.
30. Lásztitya R, Hidvégia M, Batab A. Saponins in food. Food Reviews International. 1998;14(4):371-390.
31. Liener IE. Soyin, a toxic protein from the soybean. 1. Inhibition of rat growth. Journal of Nutrition. 1953;49:527-539.
32. Moses T, Papadopoulou KK, Osbourn K. Metabolic and functional diversity of saponins, biosynthetic intermediates and semi-synthetic derivatives. Critical Reviews in Biochemistry and Molecular Biology. 2014;49(6):439-462.
33. Ologhobo AD, Apata DF, Oyejide A. Utilization of raw jack bean (*Canavalia ensiformis*) and jack bean fraction in diets for broiler chicks. British Poultry Science. 1993;34:323-337.
34. Pusztai A. Biological effects of dietary lectins. In: Recent Advances of Research in Anti-nutritional Factors in Legume seeds; (ed. Huismay) Wageningen, The Netherlands. 1989;17-29.
35. Roebuck BD. Enhancement of pancreatic carcinogenesis of raw soy protein isolate. In: Nutritional and Toxicological Significance of Enzyme Inhibitors in Foods. (ed. Friedman, M.). New York, Plenum Press. 1986;91.
36. Santidrian S, Reig G, Miralles M. Growth rate, muscle protein composition, intestinal absorption of D-galactose and L-leucine and nitrogen balance in rats fed the raw legume *Chamaecyutisus proliferus*. Plants Foods for Human Nutrition. 1988;38:135-143.
37. Akande KE, Doma UD, Agu HO, Adamu HM. Major anti-nutrients found in plant protein sources: Their effect on nutrition. Pakistan Journal of Nutrition. 2010;9(8): 827-832.
38. D'Mello, JPF. Anti-nutritional factors and mycotoxins. In: Farm animal metabolism and nutrition. CAB International Wallingford, U.K. 2000;383–403.
39. Sumner JB, Howell ST. Identification of the haemagglutinin of jack bean with concanavalin A. Journal of Bacteriology. 1936;32:227-237.
40. Larue-Achagiotis C, Pichard M, Louis-Sylvestre J. Feeding behaviour in rats on a complete diet containing concanavalin A. Reproduction and Nutrition Development. 1992;32:343-350.

41. Liener IE. Legume toxins in relation to protein digestibility – a review. Journal of Food Science. 1976;41:1076-1081.
42. Liener IE, Kakade ML. Protease inhibitors. In: Toxic constituents of plant food stuffs (Editor: I.E. Liener). Academic Press, New York. 1980;7-71.
43. McDonald P, Edwards RA, Greenhalgh JFD, Morgan CA. Animal nutrition. Fifth edition. Longman group Ltd, U. K. 1995; 607.
44. Borchers R, Ackerson CW. The nutritive value of legume seeds. X. Effects of autoclaving and trypsin inhibitor test for 17 species. Journal of Nutrition. 1950;41:339-345.
45. Babar VS, Chava JK, Kadam SS. Effects of heat treatment and germination on trypsin inhibitor activity and polyphenols in jack bean (*Canavalia ensiformis*). Plant Food for Human Nutrition. 1988;38:319-324.
46. Bressani R, Brenes RG, Gracia A, Elias LG. Chemical composition, amino acid contents and protein quality of Canavalia species seeds. Journal of the Science of Food and Agriculture. 1987;40:19-23.
47. Liener IE. Possible adverse effects of soyabean anticarcinogens. American Institute of Nutrition. 1995;125:7445-7505.
48. Duke, JA. Handbook of Legumes of World Economic Importance; Plenum Press; New York and London. 1981;39-42.
49. Bell EA, Lackey JA, Polhill RM. Systematic significance of canavanine in the Papilionoideae (Faboideae). Biochemistry of Systems Ecology. 1978;6:201-212.
50. Kitagawa M, Tomiyama T. A new amino acid compound in the jack bean and a corresponding new ferment. Journal of Biochemistry (Tokyo). 1929;11:265-271.
51. Rosenthal GA. The biological effects and mode of action of L-canavanine, a structural analogue of L-arginine. Quarterly Review of Biology. 1977;52:155-178.
52. Walker JB. Canavanine and homoarginine as anti-metabolites of arginine and lysine in yeast and algae. Journal of Biological Chemistry. 1955;212:207-215.
53. Rosenthal GA. Plant non-protein amino and imino acids: Biological, biochemical and toxicological properties. New York and London, Academic Press. 1982;95-113.
54. Enneking D, Giles LC, Tate ME, Davies RL. L-canavanine: A natural feed-intake inhibitor for pigs (Isolation, identification and significance). Journal of the Science of Food and Agriculture. 1993;61:315-325.
55. Michelangeli C, Vargas RE. L-canavanine influence feed intake, plasma basic amino acid concentrations and kidney arginase activity in chicks. Journal of Nutrition. 1994;124:1081-1087.
56. Tschiersch B. Uber das vorkommen von Canavanin. Flora. 1962;150:87-94.
57. Rahiala E. Canaline. Characterization of enzyme pyridoxal phosphate complex. Acta Chemica. Scandinavia. 1973;27: 3861-3867.
58. Rosenthal GA. A mechanism of L-canaline toxicity. European Journal of Biochemistry. 1981;114:301-304.
59. Acamovic T. Analysis and nutritional evaluation for young chicks of some toxic factors in three novel legumes. PhD Thesis. University of Edinburgh; 1987.
60. Shi J, Arunasalam K, Yeung D, Kakuda Y, Mittal G, Jiang Y. Saponins from edible legumes: Chemistry, processing and health benefits. J Med Food. 2004; 7(1):67-78.
61. Price KR, Johnson IT, Fenwick GR, Malinow MR. The chemistry and biological significance of saponins in foods and feeding-stuffs. Critical Reviews in Food Science and Nutrition. 1987;26(1):27-135.
62. Johnson LT, Gee JM, Price K, Curl C, Fenwick GR. Influence of saponins in gut permeability and active nutrient transport in vitro. Journal of Nutrition. 1986;116:2270-2272.
63. Jenkins KJ, Atwal AS. Effects of dietary saponins on faecal bile acids and neutral sterols and availability of vitamins A and E in the chick. Journal of Nutritional Biochemistry. 1994;5:134-137.
64. Udedibie ABI, Nwaiwu J, Madubuike F, Nkwocha CO, Immo IO. Jack bean (*Canavalia ensiformis*): Poison turned to good protein feed. Federal University of Technology Owerri, Nigeria; 1988.
65. Francis G, Kerem Z, Makkar HP, Becker K. The biological action of saponins in animal systems: A review. British Journal Nutrition. 2002;88:587-605.
66. Sparg SG, Light ME, Van Staden J. Biological activities and distribution of plant saponins. J Ethnopharmacol. 2004;94:219-243.
67. Zagrobelny M, Møller BL. Cyanogenic glucosides in the biological warfare between plants and insects: The Burnet moth-Birdsfoot trefoil model system.

Phytochemistry. 2011;72(13):1585-1592. DOI: 10.1016/j.phytochem.2011.02.023
68. Vetter J. Plant cyanogenic glycosides. Toxicon. 2000;38(1):11–36. DOI:10.1016/S0041-0101(99)00128-2
69. EPA. Summary review of health effects associated with hydrogen cyanide, health issue assessment environmental criteria and assessment office, Office of Health and Environmental Assessment Office of Research and Development, US Environmental Protection Agency Research Triangle Park, North Carolina, USA; 1990.
70. Solomonson LP. Cyanide as a metabolic inhibitor. In Cyanide in Biology, Vennesland B, Conn EE, Knowles CJ, Westley J, Wissing F. Academic Press, London, New York, Toronto. 1981;11-18.
71. SECAB. Haba criolla *Canavalia ensiformis* (L.) DC, (Fabaceae - Fabiodeae). Monografia No. 2. Programma de Recursos vegetates del Convenio Andres Bello (PREVECAB). Secretaria Ejecutiva del, Convenio Andres Bello, SECAB, B ogota; Colombia. 1990;177-192.
72. Dalkin K, Bowles DJ. Analysis of inter-relationship of jack bean seed components by two-dimensional mapping of iodinated tryptic peptides. Planta. 1983;157:536-539.
73. Laviada E. Estudios preliminaries del efecto de differentes tratamientos detoxificadore Sobre la semilla *Canavalia ensiformis* y su utilizacion en la alimentacion de aves, M.Sc. Thesis, Universidad Autonoma de ucatan, Mexico. 1983;24-31.
74. Dixon RM, Escobar A, Montilla J, Viera J, Carabano JM, Mora M, Risso J, Parra R, Preston TR. *Canavalia ensiformis*: A legume for the tropics, In: Recent Advances in Animal Nutrition in Australia (eds. Farrell DJ, Vohra P.) Armidale, University of New England Publishing Unit. 1983;129-140.
75. Carabano JM, Armas A, Madrigal J, Montilla J. Posibilitad de incorporar harina de grano de haba de burro (*Canavalia ensiformis*) en raciones para ponedoras. XXXV Convencion Annual AsoVAC, Merida, Venezuela. 1985;96.
76. Montilla JJ, Ferrero M, Cupul S, Gutierrez M, Preston T. Preliminary observations: The effects of ensilage and heat treatment on *Canavalia ensiformis* seeds in diets of poultry. Tropical Animal Production. 1981; 6:376-377.
77. Vierma C. Effecto de varios tratemientos sobre los factores antinutricionales de *Canavalia ensiformis* incluida eb dietas para pollos en crecimiento. (Trabajo de ascenso). Falcultad de Ciencias Veterinarias U.C.V Maracay, Venezuela. 1984;215.
78. Oyawoye EO, Ogunkunle M. Physiological and biochemical effects of raw jack beans on broilers In: Proceedings of the Silver Anniversary Conference of the Nigeria Society for Animal Production (NSAP). Abeokuta, Nigeria. 1998;71-72.
79. Herrera F, Gutierrez M, Cupul S, Ferriovo M, Carabano JM, Montilla JJ. The effect of incorporation of *Canavalia ensiformis* seed into a ration for laying hens at 10 and 20%. Tropical Animal Production. 1981;6:775-776.
80. Udedibie ABI. Relative effects of heat and urea-treated jackbean (*Canavalia ensiformis*) and swordbean (*Canavalia gladiata*) on the performance of laying hens. Livestock Research for Rural Development. 1991;3(3):68-76.
81. Udedibie ABI, Nkwocha CO. Comparative study of jack bean *(Canavalia ensiformis)* and sword bean (*Canavalia gladiata*) as protein supplements for young broiler chicks. Nigerian Agricultural Journal. 1990;24:7-14.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/12549