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Exploration of Cocoa (*Theobroma cacao*) By-Products as Valuable Potential Resources in Livestock Feeds and Feeding Systems

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Abstract

High cost of feeds and feeding management remain unresolved challenges facing livestock production globally specifically in developing countries. More than half of the production cost is associated with feeds and feeding alone; hence, it becomes imperative for livestock production science to explore lesser known or poorly exploited resources for use in animal feeds and feeding systems to reduce cost and increase productivity. One of such strategies is the use of alternative or nonconventional feed resources. Cocoa by-products have been reported as one of such nonconventional feed resources that can replace expensive and competitive conventional feed resources in livestock diets. Cocoa bean meal, cocoa bean shells, and cocoa pod husks are all potential but unexploited nutritive resources that can be considered as animal feed materials. Although their use is severely restricted by antinutritional factor (ANF) theobromine, which is toxic to livestock, there exist modern nutritional technologies capable of being applied to improve application of these resources in livestock feeding systems. Therefore, this chapter presents cocoa by-products as potential tropical feed resources in animal feeds and feeding systems with a view to providing solution to waste management problems associated with cocoa processing factories while increasing animal productivity and reducing cost of animal production.

Keywords: cocoa by-products, environmental pollution, feeds, livestock, utilization

1. Introduction

With current rising costs of conventional feed ingredients, animal nutritionists have advocated for the use of agro-industrial by-products as unconventional feedstuffs because they are cheaper and available in large quantities in producing countries. Cocoa pod husk, cocoa bean shell and cocoa bean meal form over 70% (w/w) of a whole matured fruit of cocoa (*Theobroma cacao* L.), and these are the major agro-industrial by-products from cocoa processing industries [1]. These by-products have continued to gain interest of researchers toward converting them to valuable uses such as in production of animal feeds—a critical contribution to improved food security.

Feed materials	Protein (% DM)	Fiber (% DM)	Fat (% DM)	Nonfiber carbohydrate	Gross energy (MJ/kg DM)
Dried cocoa pod husk	6.8–10	24.00–35.40	1.60–2.40	46.60	10.70
Cocoa bean cake	15.1–28.6	5.80–10.30	5.50–16.50	42.10	7.60
Cocoa beans shell	14.5–21.6	17.40–20.90	3.10–5.20	40.60	5.10
Bermuda grass	6–9	31.50	2.10	—	8.70
Soybean hull	12	34.20	2.20	—	8.40

Table 1.
Comparative chemical compositions of selected cocoa by-products, Bermuda grass, and soybean hull [7–9].

World production in 2017/2018 was downwardly revised to 4.59 million from a previous forecast of 4.64 million and now 3.3% below the prior season’s 4.74 million [1]. Consequent upon this, large quantities of cocoa wastes or by-products are generated. Cocoa bean shell (CBS); a by-product of cocoa bean in chocolate, beverage and cocoa factories, which is crispy brown with pleasant smell is estimated at about 10,500 metric tons per annum and forms about 70% of the waste [2]. These wastes constitute environmental hazard to these factories and the immediate communities where they are sited. However, instead of this huge quantity of cocoa waste to constitute nuisance to the environment, they can be incorporated into ruminant feeding, thereby reducing the exorbitant cost of conventional feed ingredients.

One of the major qualities of alternative feed resources is their ability to provide adequate nutrients that meet up with nutrient requirement of the animal in question without compromising the animals’ performance, reproduction, health as well as availability, acceptable forms, environmental friendly and reduction in the cost of feeding the animals [3]. This may be in their raw state or improved forms. Adamafio [4] compared chemical compositions of cocoa pod husk and Bermuda grass and soybean hull and found a favorable similarity. Alemawor et al. [5] added that cocoa pod husk could supply a substantial amount of energy requirements for ruminants. Cocoa pod husk nutrient constituents are also very similar to that of soybean hulls, which are routinely included in animal diets in North America [4]. It is evident from **Table 1** that both cocoa bean shell and bean cake are furnished with high crude protein (14–29% DM), a vital component of animal feed. Ruminant animals need 10% DM crude protein for maintenance [4] and 16% DM for growing ruminant animals [6].

Ozung et al. [10] reported that acid detergent fiber (ADF) and neutral detergent fiber (NDF) values were highest in the fermented cocoa pod hull meal (CPHM) (73.09 and 79.45%, respectively), followed by the raw CPHM (68.64 and 75.08%, respectively) and least in the hot-water treated CPHM (64.60 and 71.09%, respectively). Cocoa pod husk could be included at 20% DM as reported by researchers.

2. Cocoa by-products used in ruminant feeding

There are many by products obtainable from cocoa processing such as the husk of cocoa pod and the pulp, sweating surrounding the beans and the cocoa shells [11].

2.1 Cocoa pod husk

When the beans are removed from the pod after harvest, they are covered by the mucilage pulp. The parts of the cocoa pod left over, the cocoa husk, represents

between 2/3 and 3/4 of the total weight of the fruit (average fruit weight about 400 g) and is usually discarded by local farmers after harvest during cocoa bean processing after harvest.

Ashun [12] presents a calculation by Dittmar that cocoa plantations would produce around 4650 kg of dry cocoa pod per hectare. Typical values for the composition of cocoa husks are given in **Table 1**. More detailed information on protein quality is given by [13, 14]. The ash composition has been investigated in more detail by [15, 16], and the fatty acid composition by [12]. Vadiveloo and Fadel [17] freeze dried and milled the cocoa husk and analyzed the milled material for nutrient composition. These studies showed that cocoa husk in addition to the nutrients shown above contain high amounts of soluble phenolics and condensed tannins, and a high content of uronic acids. The theobromine level has been reported to be around 1.5–4.0 g/kg dry weight [18–20]. These data indicate that cocoa husk is rich in fiber but, poor in metabolizable energy and crude protein, in particular for non-ruminants.

2.2 Cocoa bean shell

Cocoa shell comprises of seed coat and embryo. The shell is a dry, crisp, slightly fibrous brown husk with a pleasant odor resembling that of chocolate. When the shell is removed, it may contain 2–3% of an unseparated cocoa nib. Cocoa shell is a good source of energy and minerals, P and Mg for ruminants [21]. Typical values for the composition of cocoa bean shells are given in **Table 1**. The fiber content is equivalent to medium quality grass hay in feeding value. More detailed information on protein and fatty acid quality is given by [22]. The phytase activity of cocoa shell has been reported to be low [23].

The chemical composition of cocoa bean shell indicates it might be a useful ingredient for ruminant feeding. Meffeja et al. [24] presented crude protein values of 5.9% and crude fiber of 21.3% which is comparable to the results reported by [25], while [14, 15] obtained much lower values of 32.5 and 45.9% respectively. Marcel et al. [26] asserted that cocoa bean shell contains 17.6% crude protein, 4.6% fat, 0.36% Ca, 0.61% P, 0.06% Na, U 61% Mg and 1.6% theobromine. [12] concluded in their feeding studies up to the 1960s that cocoa shell proved to be a useful ingredient in cattle feeding (for meat or milk production).

Flachowsky [27] concluded that cacao bean shells may be used as roughages in ruminant diets up to 5% of dry matter intake. The factor limiting the use of cocoa bean shell in feed is the theobromine level which is dependent on the way the cacao bean is prepared for the market. Originally the shell contains a limited amount of theobromine acquired from the nib during fermentation. The shell of most well-fermented commercial cacao beans contains over 1% theobromine—five samples contained between 0.80 and 1.69%. Abiola [18] reported a level of 1.9%. [28] presented a complete analysis of a commercial sample of roasted shells; the average theobromine content was 13 g/kg (8.0–16.9 g/kg), and the caffeine content around 1 g/kg. In another study [29] measured the theobromine and caffeine content of five different shell fractions collected over the whole growing season and observed 14.0 g/kg (7.5–21.0 g/kg) theobromine and 1.4 g/kg (0.8–2.3 g/kg) caffeine, respectively.

The nutritive value of cocoa shell was also studied in vitro and nylon bag technique and a feeding trial was carried out in growing cattle by [21]. The dry matter digestibility of cocoa shell was 63.5%. Approximately 30% of cocoa shell protein disappeared from the rumen after 12 h and there was a small increase after that time. Whereas for fat, there was an increasing amount that disappeared from the rumen after 12 h but reached the maximum value (73%) at 48 h.

2.3 Cocoa bean meal

Cocoa bean meal can be obtained from unsold cocoa beans or prepared from discarded cocoa beans, pressed cake of cocoa beans or residues from cocoa factories. The composition of the meal varies considerably depending on the amount of shell fragments incorporated in the meal and the degree of oil extraction. Reports of the proximate composition of the cocoa meal are summarized in **Table 1**. More detailed information on protein quality and mineral content is given by [22, 30], and the fiber and carbohydrates by [27]. The high fiber content and the content of the cell wall constituents (neutral and acidic detergent fiber and lignin) suggest that cacao bean shells are more suitable for ruminants than monogastrics [27]. A drawback of the cocoa meal is its high theobromine content, typically 20–33 g/kg. The caffeine content is lower, around 1–4 g/kg. Adegbola and Omole [31] studied the influence of treating ground cocoa meal with various concentrations of sodium hydroxide or warm water of various temperatures to improve the usefulness of cocoa meal as a grower-fattener ration for swine. Water treatments at a temperature slightly above 60°C for a few hours efficiently extracted theobromine. The hot water treatment retained nutritional quality of the product better than an alkali treatment.

3. Effects of cocoa by-products based diets on the performance of ruminant animals

Feeding lambs with cocoa shell at 9% inclusion level improved feed intake and growth. However, inclusion rates caused a reduction in feed intake and weight gain [32]. Others observed a reduction in body weight in sheep and goats when cocoa shell was included at 15% in the daily ration of sheep and goat. Alexander et al. [33] obtained a contrary result when they excluded cocoa shell from the diet of sheep. Tewe [34] when assessing the nutritive value of cocoa pod husk obtained increase in body weight of lambs when fed with 12–30% cocoa pod husk. Live weight gain was not affected by feeding <27% cocoa shell in the concentrate (or 11% in the ration). However, at 37% cocoa shell (or 15% the ration), live weight gain stated to decline. At this level, the ration contains approximately 0.24% theobromine which may be responsible for reduced utilization of metabolizable energy [21]. There was no evidence of toxicity in cattle when fed pod meal quantities of up to 7 kg per day [26]. Pod meal also has been reported to have similar nutritive value with corn-on-cob in dairy cattle ration. Rations containing cocoa pod meal have a somewhat lower feed efficiency for beef cattle, but this was compensated by the larger intake [2].

4. Effects on reproductive indices and health status of ruminant animals

Attempts to utilize cocoa waste materials as feed resources have shown that, often, when dietary concentrations exceed 10–15%, growth and reproductive indices are negatively affected [35, 36]. The consumption of organic mulch, composed of cocoa by-products, is reported to cause vomiting, central nervous system depression, restlessness, diarrhea, muscle tremor, ataxia, hematuria, tachycardia and seizures in animals [32, 37]. Cases of mortality have also been documented [33]. However, susceptibility to the detrimental effects induced by cocoa by-products appears to be species-dependent and age-dependent. Dried fresh CPH can be fed to cattle up to 7 kg per day without toxic effects and up to 2 kg per day to pigs without toxic symptoms. Up to 0.8 kg of cocoa shells (a good source of vitamin D)

is acceptable to cows. Cocoa products can only be safe for animal feeding when theobromine is drastically reduced or removed by cooking in water for 1½ h, filtering and drying. It should be noted that animals fed on a CPH diet tend to consume more water than normal due to high sodium (Na⁺) content and the fact that the adsorption of water in the small intestines is proportional to the rate of sodium chloride (NaCl) adsorption. Additionally, animals fed on a CPH diet tend to have a leaner body for marketing.

5. Improvement of nutritive value of cocoa by-products

Agricultural by-products are usually characterized by their low nutritional quality; they contain highly fibrous materials and low protein content. Such characteristics often lead the by-products to be treated, either physically, chemically and/or biologically prior to feeding to animals [38]. A main obstacle of utilizing cocoa pod as an animal feed is its high fiber and low protein contents [39]. He further explained it contains a considerable amount of lignin, i.e., between 12 and 19% dry matter (DM), and such value is 2–3 times higher than that of rice straw. Studies using high inclusion levels of untreated cocoa pod in diets have resulted in lower digestibility and animal performance [40], confirming its low nutritional quality. Two main nutritional strategies have been proposed to overcome such limitation of cocoa pod, i.e., either by mixing with a more fermentable or digestible feedstuff [15] or by treating the pod with certain chemical or biological agents to improve its digestibility [5, 41]. Several methods have been adopted in the treatment and processing of cocoa pod husk meal for the purpose of animal feed formulation. Some of these methods include hot-water treatment [31]; alkali treatment [42]; enzyme (mannanase) treatment [43]; urea treatment [25]; fungal treatment [44] and microbial detheobromination [45]. These treatment procedures are somehow expensive and complex for the local farmers to adopt, hence the need to devise cheaper and less cumbersome methods like fermentation and hot-water treatment of cocoa pod husk meal and further ascertaining their nutrient/chemical compositions vis-a-vis their suitability for in animal feeding trials.

6. Cocoa by-products and its application in monogastric nutrition

In the developing countries where cocoa is a major cash crop, there are huge quantities of by-products that are discarded, causing enormous economic problems by polluting the environment. These by-products are usually considered as “waste” and left to rot on the cocoa plantation, which can cause environmental problems, such as producing foul odors or propagate diseases, e.g., pod rot, because they are not composted [46]. Considering the growing world population and disappearing raw materials, and a real threat of reduced food sources, it is not surprising that awareness about the needs of preservation and re-usage of materials that are treated as a waste is rising [47]. The main raw material for the production of all kinds of cocoa products is dried and fermented cocoa beans, and cocoa shells are one of the by-products of cocoa beans obtained in the chocolate industry. When cocoa is processed, there are three types of co-products: cocoa pod husk, cocoa bean shells, and cocoa mucilage. It is possible to use milled cocoa shells, without any modifications, as well as to alkalize cocoa shells, and then use them as food additive [48]. However, the most common use is still for feedstuff. A number of studies explored the potential of cocoa shells to replace a part of a usual animal diet and investigated their influence on animals, because it contains theobromine, which may have a negative

effect on some species [49]. Specifically, cocoa beans contain approximately 2–3% of theobromine, which crosses from seed into shell during fermentation [50]. The toxicity of a cocoa shell meal to broilers was examined by [51], and the authors added cocoa shell in amounts of 1, 2, 4, and 6% to the meal and concluded that 4 and 6% had a significant influence on the decrease of body weight of broilers.

In a subsequent experiment, they added exactly the same amount of pure theobromine as there was in cocoa shells that were in the previous meals, but the broilers' weight was drastically decreased. Pure theobromine was more toxic than that furnished by the cocoa shell meal. [52] confirmed that increasing the intake of sun-dried cocoa shells from 0 to 30% resulted in decreasing average daily feed intake and egg production, together with decreased weight of spleen, kidney, and ovary in hens fed with a diet containing 25 and 30% cocoa shell, because of increased theobromine intake. Olubamiwa et al. [53] however, claimed that cocoa shells that were boiled for 15 min could be used in laying hen feeds up to 20% without an influence on egg production and feed conversion. Recent studies were oriented on growing pigs. Magistrelli et al. [54] have shown that the use of cocoa shells in pig nutrition may have a positive effect on the balance of intestinal microbial ecosystem. Cocoa shell feeding for 3 weeks increased microbial populations of the Bacteroides-Prevotella group and *Faecalibacterium prausnitzii*, which produce short chain fatty acids, in particular butyrate, which positively influences growth and differentiation of enterocytes, and exerts anti-inflammatory effects, thereby reducing the incidence of a wide range of intestinal inflammatory diseases. Despite a reduction of *Lactobacilli*, cocoa shell feeding improved the proportion between the main phyla of the intestinal ecosystem, which may help to reduce the risk of excessive fattening, which is considered to be detrimental to the quality of the end products [55]. Ogunsipe et al. [56] also examined the addition of cocoa shells into pigs' meals and found that 20% was the optimal biological level of cocoa shells as an energy substitute for maize in a pig diet.

A number of researchers have reported poor performance following the ingestion of cocoa materials by chickens. Egg production was adversely affected by the consumption of cocoa bean shell in a study conducted by [53]. Teguia et al. [57] also observed detrimental effects on growth when the level of cocoa pod husk incorporated in the diet of broiler chickens exceeded 10%. According to [58], broiler chickens fed 15% untreated cocoa bean meal exhibited negative effects including an increase in creatinine levels and a reduction in feed intake, weight gain and hemoglobin level.

These adverse effects were absent in chickens fed a similar amount of cocoa bean meal which had been treated with alkali or hot water to reduce theobromine content. However, detrimental effects were observed at an inclusion rate 30% of alkali-treated or hot water-treated cocoa bean meal. These observations are in conformity with the findings of earlier studies, in which [59, 60] observed depressed weight gain and feed intake as well as increased mortality when chickens were fed 10–30% cocoa bean meal. Similar observations have been made following the inclusion of cocoa shell meal in the diets of broiler chickens [51].

The effect of replacement of maize by cocoa husks in a grower-finisher ration was determined in 180 broiler chickens. Cocoa husks were substituted for the maize component in the ration (65 g maize/100 g of diet) at levels of either 0, 10, 20 or 30% of the maize. The birds fed the diet with the 10% substitution level showed significantly faster growth than the control animals whose growth rates were not significantly different from the birds fed the diet with 20% maize replacement. When compared with the control birds, low body weight and poor efficiency of feed utilization were observed for the birds fed the diet with 30% maize replacement [57]. It was concluded that cocoa husk might be used as an ingredient for

poultry grower finisher diets [57]. A series of studies was conducted by [53] with the aim of finding commercial usage for cocoa bean shell in poultry (layer) diets. The results of this experiment indicated very strongly that the 15-minutes boiling duration is the best for optimal and profitable utilization of cocoa bean shell in layers mash [53]. Hamzat et al. [61] concluded that cocoa bean shell can be included up to 15% in the diet of rabbit. In their work, five experimental diets were formulated such that diet 1(control) was maize based while diets 2, 3, 4 and 5 had 5, 10, 15 and 20% cocoa bean shell respectively. Measurements taken were live weight gain, final live weight, feed intake, feed conversion ratio and cost per kg weight gain. Results showed that cocoa bean shell was useful in feeding weaned rabbits. Rabbit fed 15% cocoa bean shell were significantly ($p > 0.05$) different from the 20% cocoa bean shell diet in final live weight and daily weight gain, feed conversion ratio and cost per kg gain in weight [61].

Besides the nutritional interest, economic analysis of using cocoa bean shell as feed supplement in rabbit production was studied by [62]. Data used for this study was collected from an experimental study of performance of rabbits fed graded levels of various treatments of cocoa bean shell as feed supplement. Gross margin and dominance analysis were used to analyze the data. The study showed that untreated cocoa bean shell can be used economically at 100 g/kg inclusion in rabbit feed while hot-water treated cocoa bean shell can be included up to 200 g/kg in rabbit feed. The study recommends the use of hot water treatment of cocoa bean shell at 200 g/kg inclusion for optimum profitability of rabbit production [62].

Hot-water treated cocoa bean shell based diet was evaluated in respect of performance and physiological response of weaned rabbits. The treatment reduced the theobromine content of cocoa bean shell [36]. Feed intake and weight gain were significantly ($p < 0.05$) high in rabbits fed hot-water treated cocoa bean shell up to 200 g/kg. Water intake was highest in rabbits fed 400 g hot-water treated cocoa bean shell/kg. Rectal temperature and pulse rate also increased with increase in hot-water treated cocoa bean shell inclusion [36].

7. Enzyme addition improves utilization of cocoa by-products in poultry feed

Addition of enzyme has been reported to improve utilization of cocoa by-products in poultry feed. This is due to the fact that studies have shown that cocoa by-products contained high fiber. Alemawor et al. [5] reported that cocoa pod husk has high levels of lignin (14%), non-starch polysaccharides (NSP)-like hemicelluloses (11%), cellulose (35%), and pectin (6%). It is important to note that these nutrients are not readily available to monogastrics (poultry and pigs) because this class of animals lack fiber-degrading enzymes needed to hydrolyze NSP [63]. Undigested NSP can influence intestinal transit time and increase digesta viscosity. All these result in inefficient nutrient absorption which ultimately affects growth performance of animals. A good example is phosphorus (P) in plants and plant products such as cocoa pod husk which is available as phytate-phosphorus [64] and is not readily available to monogastric because they lack the enzyme phytase which is responsible for phytate hydrolysis. Even if they do, the quantities are insufficient [65].

Hence, for efficient use of CPH in monogastric diets, it is important to include exogenous fiber-degrading and phytase enzymes in such diets. These enzymes are able to hydrolyze fiber and phytate, improve nutrient utilization, and improve performance [66–68]. Phytase has also been shown to improve amino acid and energy utilization [69]. In order to determine the effect of enzyme

supplementation on poultry utilization of cocoa pod husk, an *in vitro* enzyme treatment study was conducted by [70] to test the effect of various combinations of selected exogenous fibrolytic enzymes on the digestibility of CPH feedstuff. Concentrations of 0.8, 0.6 and 0.8% w/w respectively for Pentopan®MonoBG, Viscozyme®L and Pectinex®5XL were observed as appropriate levels for supplementing CPH feedstuff. Among the enzyme combinations tested, the Pentopan®MonoBG + Viscozyme®L, Viscozyme®L + Pectinex®5XL and Pentopan®MonoBG + Viscozyme®L + Pectinex®5XL formulae were most effective in maximizing sugar release from CPH feedstuff by 42–53% increase with a corresponding reduction (7–14%) in crude fiber and non-starch polysaccharide fractions ($p < 0.05$). The authors concluded that supplementation with multi-enzymes or blends of exogenous NSP-degrading enzymes may enhance the capacity of poultry to efficiently digest and utilize dietary CPH.

Similarly, [71] carried out a study to determine if inclusion of cocoa pod husks (CPH) in layer diets will affect laying performance and egg characteristics. Two hundred and sixteen (216) Bovan Brown (BB) layers (92 weeks old) were randomly assigned to 12 experimental diets for 12 weeks in a completely randomized design. There were three levels of CPH inclusion: 0, 10 and 15%. For each level of CPH, diets were further sub-divided into four and each portion treated with, (i) no enzyme, (ii) phytase only, (iii) a commercial enzyme cocktail only and (iv) a combination of both phytase and cocktail. The enzyme cocktail was added at a rate of 200 g per ton of complete feed. The phytase was added at the rate of 250 g per ton of complete feed to give a phytase activity of 500 FTU (Phytase Units)/kg of complete feed. The authors reported that adding CPH did not affect average daily feed intake (ADFI). Hen day egg production for layers on diets with 0, 10 and 15% CPH, with a combination of phytase plus an enzyme cocktail (76.19, 73.81 and 66.34 respectively), was better than that of hens on diets without enzymes. Adding phytase, a cocktail enzyme, or a combination of the two improved egg weight. There were no effects of CPH or enzyme addition on egg quality characteristics. The authors concluded that cocoa pod husk (up to 15%) plus exogenous enzymes can effectively be used in layer diets without adversely affecting production performance or egg quality characteristics.

8. Conclusion

There is an increasing demand on food and feed resources by man due to rising global population. In order to prevent future food crisis and loss of animal protein, animal nutritionists have continued to explore alternative feed resources to meet the needs of both man and farm animals. Several crops and their by-products have potential as possible alternatives for livestock feed industry. One such crop is cocoa, a very abundant crop in tropical regions of Africa. Its by-products have been successfully used as alternative feedstuff in livestock production. Cocoa by-products show great potential as an alternative feed resource that can replace conventional feed ingredients used in animal nutrition.

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