



Factors Affecting the Utilisation of Cassava Products for Poultry Feeding [Review]

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SHORT supply and high cost of traditional ingredients affect efficient livestock production globally. This has driven interest in alternative cheap materials mostly products of agro-industrial processing to replace traditional feed ingredients. Products such as discarded roots, leaf, peel and pulp are wasted or dumped in landfills in many developing regions, which could replace part of the expensive feed ingredients in livestock feeding. Cassava (*Manihot esculenta Crantz*) processing emits several products such as peel, pulp and leaves. The beneficial cassava products are underutilised and more investigation is warranted to improve its utilisation, reduce feed cost and environment sustainability. Cassava peel, pulp and leaves are potential cheap feed ingredients for poultry feeding. However, these products may contain anti-nutritional factors such as cyanogenic glucosides which affect their maximum utilisation in poultry feeding. Several factors such as cultivar, stage of maturity, cyanide levels and processing methods affect the utilisation of cassava products in poultry diets. Several processing techniques have been used to reduce cyanogenic glucosides concentration to safe levels and enhance the utilisation of the products in poultry diets. This paper discusses the anti-nutritional factors affecting cassava utilisation, processing methods to reduce cyanide levels and future of cassava products for poultry feeding.

Keywords: Cassava products, Cyanide, Poultry, Processing methods.

Introduction

High feed cost is a major factor affecting livestock production worldwide. The main energy and protein feed ingredients are expensive due to short supply [1,2]. The world wheat production in 2019 estimates show decline by 4.5% and in the next 5 years forecast to fall by 16.3% [3]. The high demand and low supply of grains has increased research interest in alternative cheap feed materials such as root crops and products to reduce livestock feed cost [2, 4].

Cassava (*Manihot esculenta Crantz*), a woody perennial and oldest agriculture crop is assumed to have been cultivated for 9,000 years [5]. Cassava has two major sweet and bitter cultivars [6, 7, 8] which are grown for food. Cassava is

the third major energy source and an important part of diet for over 800 million to half billion people globally [4, 5, 9-11]. Cassava is cultivated in 90 to 100 countries [5, 12] with the yield ranging from 23 to 80 tonnes per hectare [5, 6, 13]. Besides a cash and food security crop, cassava grows successfully in many regions due to its tolerance to drought, acidic soils and sporadic pest attacks. Cassava is best harvested between 8-10 months or anytime from 6 to 24 months as desired [5].

The world cassava production in 2016 was over 276 million tonnes of which, Africa produced over 155 million tonnes [3]. Nigeria was the world's leading cassava producing country in 2016 followed by Thailand, Brazil, Indonesia, Ghana and Democratic republic of Congo, contributing to over 15 million tonnes of

cassava annually [3]. Among the other countries of the Pacific region, Fiji produced over 63,000 tonnes of cassava in 2016 compared to more than 72,000 tonnes in 2018 [14]. The future production and consumption would be compromised due to competition for food and multiple uses such as ethanol, starch, flour, adhesive, textile, paper, plywood, cardboard and pharmaceutical industries [5, 12]. However, processing of cassava for food generates several useful products, which have potential as poultry feed ingredients. These products include roots, peel, pulp and leaves which could replace expensive conventional energy and protein sources [2].

Nutritional composition of cassava products

Cassava root or tubers contributes 50% of mature plant and is the main nutritional food source [15]. Cassava root has 12.56-13.72 MJ/kg metabolisable energy [16, 17], 14.5-37 g/kg crude protein, 5.8-28.4 g/kg ether extract, 94-103 g/kg crude fibre, 21.2-68.5 g/kg Ash and 886-948 g/kg dry matter [8, 18, 19]. Cassava root has high carbohydrate content (32 to 35% fresh and 80-90% dry matter) [20]. Starch is produced from 80% carbohydrates [21] of which amylose is 83% and amylopectin is 17% [22]. Lower quantities of glucose, fructose, maltose and sucrose are found in cassava root [15]. Sweet cassava variety consists of up to 17% sucrose with lesser amounts of fructose and dextrose [23].

Cassava peel, the outer layer of tuber, contributes to 8 to 13% of root weight [24, 25]. The peels of cassava including small rejected tubers are potential poultry feed ingredients after processing. Cassava peel meal (CPM) contains 11-14.2 MJ/Kg metabolisable energy (ME), 880.9-881 g/kg dry matter (DM), 28.8-42 g/kg crude protein (CP), 41.8-127 g/kg crude fibre (CF), 59.9-152 g/kg acid detergent fibre (ADF), 65.5-481 g/kg neutral detergent fibre (NDF), 9.4-14 g/kg ether extract (EE) and 57-87g/kg ash [11, 26]. Fresh cassava peels deteriorate rapidly and needs immediate processing for preservation commonly by sun or oven drying methods [11].

Cassava pulp, a solid moist product of starch production, contributes about 20 to 30% of root weight [28, 29]. The pulp contains 16-20 g/kg CP, 136-278 g/kg CF, 1.4-2.5g/kg EE, 17-28 g/kg ash, 8.6 MJ/Kg ME and 540-700 g/kg starch [27, 29]. Further processing by enzymatic fermentation improves protein content of pulp [27] and used as potential feed for animals [28]. Khempaka et al. [27] observed enhanced protein content from

more than 2 to 118 g/kg when cassava pulp was fermented with *Aspergillus oryza*. Sengxayalth and Preston [30] reported increased protein content of pulp when fermented with 2% yeast, 4% urea and 1% di-ammonium phosphate.

Cassava leaves makes up 6% of mature plant [15] and contribute to 30% of waste at harvest and remain unused but is good plant protein [31]. Older cassava leaf contributes to 21% crude protein in meal form [32]. Nearly 85% of cassava leaf protein exists as true protein [31, 33]. Cassava leaf meal (CLM) nutrient content ranges from 167-399 g/kg CP, 48-290 g/kg CF, 36-105 g/kg EE, 57-125 g/kg ash, 314.7-450 g/kg NFE and 6.7-10.2 MJ/kg ME [2, 32, 34]. Cassava leaves could be either sundried or oven-dried for meal preparation. Table 1 summarises cassava products and its nutritional compositions.

Antinutritional factor (ANF) content

The major ANF in cassava are Cyanogenic Glucosides (CG), which naturally occurs in plants for self-defence against predation and damages [43]. Cyanogenic glucosides are originated from amino acids namely isoleucine, leucine, valine, tyrosine and phenylalanine [44]. Cassava contains CG in the form of Linamarin 93-95% and Lotaustralin 5-7% [7, 45] in the leaves, stem, tuber and peels. According to [46] CG especially Linamarin is synthesised in leaves and transported to root. Lotaustralin are found in vacuoles of cassava cell while the cell wall contains Linamarase enzyme and this is released once the root is damaged [47]. The enzyme, β -glucosidase hydrolysis CG to produce cyanohydrins, which decomposes to release HCN [48]. Cyanogenic glucosides are synthesised to form HCN through cyanohydrin intermediate by the process of cyanogenesis [49, 50]. Cyanide content of cassava leaves and peel ranges from 10 to 2000 mg/kg HCN [51-53] in sweet and bitter varieties. Bitter cassava variety has higher cyanide content compared to sweet varieties thus needs proper processing before consumption and better utilisation of cassava products [6]. Poorly processed bitter cassava have been found to cause several health problems such as cyanide toxicity both acute and chronic, neurological disorders, stunted growth, goitre and cretinism in humans [10, 44]. The FAO/WHO [54] recommend safe limit of 10 mg HCN/ kg dry weight as safe for consumption. Efforts have been directed towards removal of anti-nutritional factors using appropriate technologies to safe levels.

TABLE 1. Proximate composition of cassava root, peel pulp and leaf meals.

Products	Root		Peel		Pulp		Leaf		
	Sun Dried	Ensiled	Sun/oven dried	Fermented (<i>Aspergillus niger</i>)	Dried	Fermented (<i>Aspergillus oryzae</i>)	Dried	Ensiled	
ME (MJ/kg)	-	1.26	1.11-1.12	-	1.16	0.86	1.06	1.08	4.29
Moisture	-	-	9.46	9.06	-	-	-	-	-
DM	88.6-94.8	97.5	87.9-88.8	90.94	89.5-93.1	94.39	93.0-93.7	-	-
CP	3.1-3.7	2.0	3.8-5.49	4.15	2.02-2.68	11.82	21.0-29.9	24.2	47.0
CF	9.4	2.9	10.5-23.0	3.35	14.38-14.6	10.6	13.9-20.0	14.3	21.6
EE	0.58-2.84	0.5	1.19-3.97	0.84	0.14-0.25	0.15	5.5-11.4	7.0	2.0
Ash	4.33-6.85	-	5.16-8.7	4.37	3.1-4.92	1.58	8.5-9.62	-	-
Source	[8, 19]	[35]	[11, 24, 36, 37]	[38]	[27, 39]	[27]	[8, 32, 40]	[35]	[41]

ME: Metabolisable Energy; DM: Dry Matter; CP: Crude Protein; EE: Ether Extract; CF: Crude Fibre

TABLE 2. Amino acid composition of soybean meal and cassava leaf.

Amino acids (g/16gN)	Soybean meal		Sun dried leaf		Ensiled leaf		Concentrated leaf pulp		Leaf meal
	2.39	0.7	4.4 (2.9-5.9)	1.4	5.6	-	-	-	5.3
Arginine	2.39	0.7	4.4 (2.9-5.9)	1.4	5.6	-	-	-	5.3
Cysteine	2.2	2.2	3.47 (1.04-5.9)	1.4	-	6.8	6.8	6.8	1.2
Lysine	0.56	1.26	1.12 (0.34-1.9)	1.26	1.2	2.48	2.48	2.48	5.9
Methionine	1.26	0.94	1.82 (0.34-3.3)	0.94	1.2	2.48	2.48	2.48	1.5
Total SAA	0.94	1.6	2.1 (1.9-2.3)	1.6	1.7	-	-	-	2.7
Histidine	1.6	2.58	2.81 (1.12-4.5)	2.58	4.2	-	-	-	2.0
Isoleucine	1.69	1.69	5.65 (3.1-8.2)	1.69	8.3	9.65	9.65	9.65	4.5
Leucine	-	-	4.15 (2.6-5.7)	-	5.6	-	-	-	8.2
Phenylalanine	1.29	1.48	2.0	1.29	-	2.31	2.31	2.31	5.4
Tryptophan	1.48	1.77	4	1.48	4.4	-	-	-	2.0
Tyrosine	1.55	1.55	3.55 (2.7-4.4)	1.55	3.9	-	-	-	5.4
Valine	1.55	1.55	4.4 (3.2-5.6)	1.55	5.3	6.3	6.3	6.3	4.4
Glycine	1.55	1.55	4.1	1.55	4.1	-	-	-	5.6
Alanine	1.55	1.55	5.7	1.55	6.4	-	-	-	7.0
References	[1]	[1]	[8, 33, 42]	[42]	[42]	[41]	[41]	are	[32]
SAA:	amino acids;	amino acids;	Values in brackets	in	in	brackets	brackets	are	ranges

Moreover, presence of cyanide at high level in cassava products (leaves, peel and pulp) affects its utilisation but appropriate processing would enable maximum inclusion levels in poultry diets [6, 55]. Cassava root enzyme and HCN in monogastric stomach and glucosidic intestinal enzymes hydrolyse glucosides. The detoxification process uses sulphur from methionine to convert cyanate to thiocyanate causing increased requirement for methionine in poultry. The high fibre, low energy, low mineral content and anti-nutritional factors CG of cassava root may limit the utilisation of cassava in poultry [13]. However, the anti-nutritive effect could be removed by fermentation, sun drying, ensiling, and cooking [6, 13]. Cassava leaves have about 84 mg/kg cyanide [56] levels and sun drying easily eliminates to lower levels. The cyanide of leaves are higher in younger leaves (30%) compared to matured leaves [56]. Ngudi et al. [57] found high CG in raw pounded leaves and cooking removed 96 to 99% cyanogens. The difference in cyanide levels could be attributed to several factors such as varietal differences, age of plant, soil type, environment and fertiliser application [7]. The cyanide content of cassava products, processing and cooking is summarised in the table below.

Factors affecting the hcn content

Stage of maturity

The stage of maturity and age of leaf or root harvest has different cyanide levels. Ravindran et al. [62] reported that younger cassava leaves have higher cyanide levels compared to matured leaves. The authors also found that fresh leaves have lower cyanide levels compared to the dry leaves irrespective of stage of leaf. The dried whole leaves, blades and petioles have higher cyanide compared to fresh [62]. Cyanide levels of fresh cassava leaves range between 200 to 800 mg/kg are higher in early stage of maturity compared to later stage and could be due to genetic, physical, chemical factors and climatic conditions [31]. Wobeto et al. [63] found that cassava leaves of 12 months old contained lower levels of cyanide, oxalates, polyphenols, saponins and trypsin inhibitors compared to 15 and 17 months old leaves. Several factors such as drying time, drying method, age at harvest affect HCN of cassava. Hue et al. [64] found lower HCN level in leaves of Vietnamese cassava varieties (K94-very bitter, K98-7-medium bitter and local-sweet) at first harvest 3 months compared to increase in successive harvests at 6 and 9 months. Cyanide levels of leaves decrease but increases in the tubers as it matures.

TABLE 3. Cyanide content (mg/kg) of processed cassava root, pulp, peel and leaf.

Cassava product	Processing method	Cyanide content mg/kg	Reference
Root meal	Sun dried	12	[8]
	Fermented (<i>S. cerevisiae</i>)	32.52	[19]
	Ensiled	<0.0005	[58]
	Fresh peeled	25	[35]
Leaf meal	Fresh peeled	23-70	[59, 60]
	Sun dried	15.03	[8]
	Sun dried	84	[61]
	Ensiled	160	[35]
Peel meal	Ensiled	198	[35]
	Fermented (<i>Aspergillus niger</i>)	0.74	[38]
	Sun dried	50	[24]
Pulp	Lye treated	30	[24]
	Fermented	0.92	[27]
	Sun dried	3-3.26	[27,39]

S.: *Saccharomyces*

Cultivar

Cassava cultivars have different levels of HCN in leaves and roots in different countries. Several studies have proved that there is range of bitterness in cultivars. Ubi et al. [65] found that HCN contents of fresh leaves range from 122 to 1,040 mg/kg in 17 different Nigerian cassava varieties. Dufour [66] reported higher HCN levels in bitter compared to sweet cassava cultivars. The author also found that HCN levels of 13 bitter cultivars in the study were even higher than the reported literature values. The authors also observed that K94 variety produced more leaves and developing leaves had lower HCN content. Hang and Preston [67] observed HCN range of 610 to 1,840 mg/kg of leaves in 20 Vietnamese cassava varieties at root harvest. The genotype and age at harvest could influence HCN content of cassava roots and leaves between cultivars.

Agronomic practices

Agronomic practices carried out during cassava cultivation have effect on the HCN content of the cassava root and leaves. Imakumbili et al. [68] found that agronomic practices of Konzo farmers influence bitterness in cassava root. Obigbesan [69] observed lower HCN content of peeled tubers in improved Nigerian cassava (60506 and 60447) compared to local 53101 cultivar. Obigbesan [69] found that fertiliser application had no effect on HCN content of cassava roots. The authors observed that harvesting at 15 months showed increased HCN levels compared to harvesting at 9 months. Obigbesan [69] recommended appropriate processing of tubers at 15 months harvest before consumption. Srihawong et al. [70] found high tuber HCN content of Thailand cassava varieties (Hanatee and Kasetsart) harvested within 6 months after planting under drought condition. Several factors including soil characteristics, poor weeding, branch pruning, age at harvest and fractional harvesting could be contribute to increased HCN levels in cassava [68].

Technologies for cyanide reduction

Several methods including heat processing, soaking, fermentation and ensiling have been reported to reduce cyanide in cassava. After processing, cassava roots starts deteriorating fast and for this reason need managed immediately to retain its nutritive value. The processing technologies have been reported to improve the quality and reduce the toxicity of cyanide of cassava products enabling its palatability and storage.

Heat processing

Heat processing includes sun-drying, oven drying, earth oven, steaming, boiling and roasting which reduce cyanide content of cassava products. In tropical countries, the most common and cheapest method is sun drying.

Sun drying

Sun drying reduces HCN to safer levels efficiently, removes moisture and makes it pathogen free without affecting the nutritional value [13]. Sun drying cassava leaves reduces cyanide by 90% [27, 71] reported cyanide level reduction of cassava pulp with sun drying. Tewe and Iyayi [72] also reported lower cyanide content of sun dried cassava peel, pulp and root from 815, 200 and 416 mg/kg to 322, 27 and 42 mg/kg respectively compared to oven drying 1,250, 31 and 64 mg/kg respectively. Ravindran et al. [62] found that wilting full and chopped leaves for 3 days under sun drying reduced cyanide levels from 1,436 to 173 mg/kg without affecting the crude protein content of cassava leaves. Sun-drying process lowers cyanide retention of cassava peel, pulp, root and leaves [27, 62, 71, 72].

Oven drying

Oven drying is the process of increasing drying temperature for cyanide reduction. Temperatures above 55°C inhibits Linamarase enzyme and causes accumulation of Linamarin during drying [45]. At higher temperatures (80-100 °C), cyanide is reduced to 10-15% in comparison with drying at 47-60 °C which eliminates 80-100% cyanide levels [52]. Cooke and Maduagwu [73] found that cyanide reduced from 29 to 10% when temperature increased from 46 to 80°C respectively. Nambisan [74] found at 50 and 70°C cyanide reduced from 45-50% and 53-60% respectively. The author observed that cyanide reduction depend on size of cassava during oven drying. Nambisan [74] reported that 10mm sized cassava chips reduced 50-55% CG whereas 3mm thickness reduced 40-45%. Oven drying temperature and cassava thickness affects level of cyanide reduction [45, 52, 73, 74].

Earth oven

Earth oven removes 37% cyanide in whole cassava [59]. Grated cassava alone reduces cyanide level almost 60% cyanide [59]. When cassava tissues are reduced in size, this enables enzymes and substrate (Linamarin and Lotaustralin) interaction to break cyanohydrin to HCN gas, which is heat labile and dispel in the air.

Boiling

Water based processing such as boiling, cooking and steaming have been found to reduce cyanide of cassava tuber. Hidayat et al. [75] found boiling cassava leaves for 20 minutes reduced cyanogenic glucosides up to 75%. Boiling removes about 90% free HCN within 15 minutes and 55% bound cyanide in 25 minutes [73]. Aalbersberg and Limalevu [59] found that boiling reduces 50-60% of cyanide in cassava roots. The authors further found that combined process of grating and boiling eliminates cyanide up to 80%. During boiling process the Linamarase enzyme perish at 100 °C so Linamarin is unable to be hydrolysed to cyanohydrins. For this reason, boiling is better suited for sweet cassava but is not an effective method of cyanide removal of bitter varieties [45]. Ngudi et al. [57] observed that cooking leaves lowered cyanide content ranging from 0.3-1.9 mg/kg compared to uncooked leaves (35.9 to 107.5 mg/kg).

Fermentation

Solid-state fermentation have been reported to reduce fibre, cyanide and increases protein content of cassava products. The fermentation microbes assist positively in preservation of products, anti-nutrient reduction, biosynthesis of amino acids, vitamins and flavour enhancement[45, 76]. Muzanila et al. [77] reported lower cassava root HCN with solid state fermentation from 400-440 to 14 mg/kg compared to 84 mg/kg with wet fermentation. The reduced particle size of cassava products allows interaction of Linamarin and Linamarase with the particles to break down HCN to soluble form, which is removed after the fermentation period[45].

In cassava pulp and *gari*, HCN is reduced due to microbial activity in hydrolysis of cyanogenic glucosides using non-starch polysaccharides to bacterial protein. Akindhuni et al.[76] found fermentation of cassava flour and *gari* with *Rhizopus oryzae* reduced cyanide content from 213 to 172 and 149 to 135 g/kg respectively. The authors attributed low cyanide levels to the ability of microbial activity on cyanogenic glucosides hydrolysis. Akindhuni et al.[76] also reported increased protein content of flour and *gari* from 44 to 87 and 36 to 56 g/kg. The authors found reduced fibre content of cassava flour from 38 to 35 g/kg in the same study.

Fermenting cassava peel, pulp and leaves with *Aspergillus niger*[78] and *Saccharomyces cerevisiae* [79] reduced HCN and improve crude

protein from 44 to 109 g/kg. Yafetto [80] observed that fermentation of cassava pulp with *Aspergillus niger* and ammonium nitrate increased crude protein by 22.1%. Sengxayalath and Preston [30] reported increase in crude protein and true protein from 95 to 184 and 20 to 120 g/kg respectively in fermented cassava pulp within 9 days. However, steaming of pulp before fermentation had no additional effect on crude and true protein content of fermented cassava pulp. Ofuya and Obilor [81] observed higher protein content (54 to 169 g/kg) and amino acid composition (804 g/kg) in fermented peels with *Rhizopus sp.* compared to unfermented peels (326 g/kg). Sugiharto et al. [82] fermented cassava pulp with *Rhizopus oryzae* and *Acremonium charticola* with urea and observed higher crude protein and lower crude fibre content. However, fermentation of pulp without urea had no effect on crude protein but reduced crude fibre content [82]. Several factors including scale of processing, type of substrate and microorganism used affect the fermentation of cassava products.

Ensiling

Ensiling leaves with lactic acid bacteria reduced HCN content and increased the utilisation of carbohydrates [40]. Nguyen et al. [40] observed that ensiling cassava leaves for 90 days reduced up to 80.6% HCN. The authors also reported a gradual reduction in cyanide and improvement in crude protein content of cassava leaves. Phuc et al. [42] reported reduction of cyanide of ensiled cassava leaves by 62%. Ensiling is an efficient method in reducing HCN and improves the utilisation of cassava products by poultry.

Soaking

Soaking has been found to reduce cyanide of cassava tuber. Soaking causes some of the water soluble cyanohydrins to be leached during the process and this lowers the HCN content of cassava[83]. Nebiyu and Getachew [84] observed that soaking cassava root chips for 24 hours followed by 3-4 days sun drying effectively reduced cyanide from 108.4 to 10.4 mg/kg. Cyanide concentration of less than 50mg/kg fresh and 10mg/kg processed are safe for consumption [85].

Storage temperature and drying period

Cyanide contents of roots and leaves are affected by storage temperature and duration of drying. Ravindran et al. [62] found rapid cyanide reduction within the first 4 months of storage

of cassava leaves thereafter the rate gradually decreased. Aalbersberg and Limalevu [59] assessed cyanide levels with storage temperature and found 39% cyanide reduced at 23 °C for a period of 6 days. The longer storage time with lower temperature reduces cyanide in cassava leaves. Aalbersberg and Limalevu [59] compared fresh roots of 4 different Fijian cassava varieties Ro Tabuanakoro, Beqa, H.97 and Vula Tolu-Dalip Singh with cyanide content of 84, 121, 117 and 25 mg/kg and observed reduction of HCN to 40, 52, 59 and 12 mg/kg respectively. Aalbersberg and Limalevu [59] pit fermented cassava roots of Sokobale variety and found that in 15 days the cyanide level reduced from 25 to 3 mg/kg along with lower pH from 6.5 to 4.7. Ravindran et al. [62] established that cyanide levels of fresh whole (1436) and chopped (1045 mg HCN/ kg DM) cassava leaves condensed drastically upon sun (88) and oven (92 mg/kg) drying on the same day of harvest. However, the cyanide levels slightly increased when leaves were kept until 3 days. Okwonko et al. [86] found that at higher temperatures the rate of drying was faster, decreased moisture content and cyanide levels of cassava chips. Ravindran et al. [62] also evaluated the length of storage and temperature on cyanide content in cassava leaves. The authors observed that cassava leaf cyanide reduces when stored at lower temperature.

Utilisation of cassava products in poultry diets

Nigeria produces 90% cassava for food, 5-10% production is also for industrial and animal feed purposes [87]. Cassava products have been successfully included variably in poultry diets. Several factors such as cassava cultivar, stage of maturity, cyanide concentration and processing affect the inclusion level of cassava root meal (CRM) in poultry diets.

Cassava root meal (CRM) has high starch content but low protein of about 10 to 30 g/kg [88]. Feeding up to 500 g/kg CRM of 50mg cyanide/kg maintain broiler performance [52]. Inclusion of 250 g/kg cassava flour inclusion did not have detrimental effects on broiler performance [89]. Ferreira et al. [90] found that 119 to 200 g/kg cassava flour improves weight and feed conversion ratio of finishing broilers. Cassava root meal have been fed to poultry as a main energy source either in peeled or unpeeled form. Akapo et al. [78] fed 100 g/kg peeled CRM and observed higher final weight gain and lower HCN intake in broilers. In another study, the

authors found poor performance of broiler chicks fed 200 g/kg unpeeled CRM compared to 100 g/kg peeled root meal. Peeled CRM improved feed intake and best feed: gain compared to unpeeled root meal in broilers. Cassava root meal inclusion in poultry diet reduces feed cost and can replace some of the grains such as maize. Bhuiyan and Iji [91] found improved growth performance in broilers with 50% cassava root replacement of maize.

Cassava pulp (CP) has 50% carbohydrates, low protein of about 20 g/kg [92] and low cyanide, high insoluble fibre making its utilisation challenging in poultry diets. However, microbial fermentation have been found to improve its quality to be efficiently utilised in poultry diets. Khempaka et al. [29] reported that 40-80 g/kg dried CP could be included in broiler diets. In another study, [27] found that feeding 160 g/kg *Aspergillus oryzae* fermented CP had no effect on growth, carcass quality, nutrient digestibility and blood biochemistry of broilers. Khempaka et al. [39] observed improved performance in laying hens fed 200 g/kg sun-dried CP diet and found a further improvement following enzyme addition [93]. During microbial fermentation, the protein content of CP increases and the fibre is broken down and this enables its utilisation by poultry. This could explain the improved performance of broilers. Laying hens have lower energy requirement and for this reason are able to utilise higher levels of cassava products compared to broilers.

Cassava peel meal (CPM) is low in energy and protein but high HCN and have been used variably from 100-270 g/kg in poultry diets [2, 11, 94, 95, 96]. Ofuya and Obilor [81] observed improved mean body weight and low mortality of broilers fed 83.9g *Rhizopus sp.* fermented peel meal compared to unfermented. Dayal et al. [11] replaced 154 g/kg CPM with tallow and enzyme addition and found improved performance of finishing broilers. Babatunde [96] observed 100 g/kg CPM improved broiler performance and cost effectively. Tewe and Egbunike [94] and [95] recommended 200 and 270 g/kg CPM in laying birds diets. Inclusion of amino acid, enzyme and fats improve CPM utilisation in poultry diets. Oladunjoye et al. [24] found no effect on layer performance and blood parameters fed 50% sun-dried with 70% lye treated CPM. Dayal et al. [11] and [97] replaced 40 and 50% CPM replacement of maize in broiler diets.

Cassava leaf meal (CLM) is a good protein source, carotenoids and rich in vitamins and minerals but low in methionine and energy. The recommendation of CLM is variable from 50-200 g/kg in poultry diets [7, 13]. Ravindran et al. [61] reported that feeding up to 150 g/kg CLM maintained broiler performance. Iheukwumere et al. [98] found depressed growth of broilers fed 50 g/kg CLM. Diarra [43] observed that methionine supplementation with vegetable oil in cassava leaf based diets maintained pullet performance. According to Montilla [99], 200 g/kg pelleted CLM maintained broiler performance. This could have been possible by improved digestibility of fibre due to heating action which helped in breaking carbohydrate structures during pelleting.

Synthetic amino acids are readily available and is supplemented to fortify quality of nutrients of poultry diets. Methionine is reported to be deficient in cassava and this need to be supplemented in the diet of poultry. Methionine is a methyl donor, responsible for protein and polyamine synthesis. Ravindran [71] reported that methionine supplementation improves amino acid of the diet of monogastric livestock. Enzymes, acts as catalysts which speeds up chemical reactions but is unused in the process.

Enzymes naturally occur in salivary glands but in poultry enzymes are produced in lower quantity and need to be supplied in the diet [100]. Several studies have found that enzyme addition improve cassava utilisation in poultry. Bhuiyan and Iji [91] and [101] recommended 0.1g/kg Arizyme 1502 0.1 g/kg of Roxazyme G2G in cassava root respectively. Dayal et al. [11] recommended 0.35 g/kg challenzyme in cassava peel meal for improved finishing broiler performance.

Future of cassava products in poultry feeding

Cassava is an economic crop for climate change due to its tolerance to drought, poor soils, disease resistance, cost effective and better production with minimal effort especially for rural development. Although earlier known as a poor man's food, cassava is progressing in terms of production capacity better than cereal and serves as food security crops in urban areas [5]. Cassava has vast prospects for developing countries with multiple industrial utilisation such as renewable energy, climate change adaptation and import substitution. Crop intensification programmes of FAO focuses on over a billion smallholder cassava growers to intensify production in the tropics due to the growing demand for cassava [5]. In many

countries of the world, the programmes could be valuable means to assist policy makers attain poverty alleviation, food security and economic development. Cassava production and processing emit abundance of solid products and wastewater which has disposal problem globally [120] and needs to be managed well. These wastes can be further processed and earn value in the market [121]. Some technological advances have been made in areas such as cassava harvesting, processing and product diversification.

Harvesting

According to Agbetoye [122], cassava harvesting is the most difficult process and manual method has been the past and present practice in Nigeria. Some cassava harvesting machines used includes hand-operated levers, manually operated fork-lifters [123], Ritcher wide share harvester [124], Mark II harvesters [125], Peipp and Maechnett combined digger and harvesters [126] and commercial CEEMAG Arm '81 harvesters [121]. Several products from cassava needs processing technologies to focus on diversification [121]. Specialised machines are also used for soil loosening, uprooting and lifting cassava tubers after harvesting.

Processing

Cassava processing methods include peeling, dewatering, grating and roasting which are time consuming and laborious. Peeling is done with abrasive peeler machine with assistance of National Centre for Agricultural Mechanizations (NCAM) and Federal University of Technology, Akure, (FUTA), Nigeria, which has proven to be successful and awarded for its innovative design. This machine has enhanced cassava processing. Manual grating method has been mechanised using rotor grater, which saves time and protects from injury. Dewatering and pressing process mechanical press is now used including hydraulic jacks and screw press [121]. Raffia sieve, plastic sieve, grater and mechanical shakers are used for sieving *gari* [127]. Clay, *Agbada*, tray fryers [127] and automated *gari* fryer developed by Obafemi Awolowo University are used for frying [121]. According to Taiwo [127], Rural Agro-industrial Development Scheme (RAIDS), Product Development Agency (PRODA), Federal Institute of Industrial Research (FIIRO), International Institute for Tropical Agriculture (IITA), University Agricultural engineering departments have developed machines to ease domestic cassava processing in Nigeria.

TABLE 4. Recommendations of cassava products in poultry diets.

Products	Processing method	Class of birds	Inclusion rate in diet (g/kg)	References
Root meal	Peeled	Broiler chicks	100	
		Japanese quails	250	[78]
		Laying hens	200-300 + 80 g/kg dried distillers grain	[102]
		Broilers	30% of maize + oil, lysine and methionine	[19]
	Unpeeled	Broiler	100 + 6 g/kg charcoal	[103]
		Laying hens	300	[18]
		Pullets	150	[104]
Peel meal	Sun dried	Laying hens	270	[94]
		Finishing Broilers	100	[96]
			154 + tallow and enzyme	[11]
	Parboiled	Laying hens	200-300	[95, 106]
	Oven dried	Broilers	100	[24]
Leaf meal	Sun dried	Broilers	50	[98]
		Laying hens	200	[107]
		Goose	100	[89]
		Laying ducks	50	[108]
			100	[109]
	Hay	Quails	100	[110]
Pulp	Sun dried	Broilers	120	[111, 112]
			80	[29]
			110	[113]
		Laying hens	150	[114]
		200	[39]	
		300 + enzymes (Cellulase, glucanase and xylanase)	[93]	
	Fermented (<i>A. oryzae</i>)	Broilers	160	[27]
	Laying hens	240	[115]	
Sievate meal	Dried	Starter cockerel	200	[116]
			280	[117]
Residuemeal	Air dried	Laying quails	100	[118]
Root chips	Dried	Broilers	< 50% of maize	[119]

A.:Aspergillus

Industrial and secondary products of cassava

Cassava flour, native starch, crude ethanol and cassava chips and pellets are primary industrial cassava products which have high importance in Nigeria [87]. The secondary cassava products include cassava starch, neutral alcohol, glucose syrup, noodle, confectionary, bakery, meat and textile. Cassava flour is used as raw material in baking (bread with 60% wheat, 30% cassava and 10% soybean flour), pastry and biscuit industries substituting wheat. The demand for cassava flour is gaining momentum due to Federal governments legislation to include 10% cassava flour in baking bread [87, 128]. High quality cassava flour, high quality garri, sweeteners, cassava chips, tapioca, ethanol, adhesives, noodles and glucose syrup and cassava pellets for animal feed are growing industries and has strong future export market potential.

Sweet starch is produced from starch extraction and is used for paper, textiles and battery industries whereas sour starch is obtained from fermentation and is used in food industry [129]. The waste cassava slurry is sieved, dewatered and sun or mechanically dried at 50°C for 6 hours after which lumps are crushed, sieved and packed [130]. Modified, unmodified starch and glucose are used in food industries, largely consumed as cooked food (custard), thickeners (soups, sauce, gravies, baby food), fillers (tablets, pharmaceuticals), binders (sausages, processed meat), stabilisers (ice cream), biscuit (crispiness) and confectionaries (sweets, gums) [87]. The sweetener industry is strong and forecast to grow by 50% in the next decade [87]. Cassava based adhesives such as liquid starch, pre-gel starch and dextrin are produced, supplied to consumers and exported as liquid or dry forms [87]. There is growing demand of these adhesives as raw materials in American and European industrial companies increasing export markets.

Animal feed

Among all countries, Nigeria has well advanced in using cassava products in animal feeding due to its high production. Cassava flour, leaves, whole unpeeled cassava root, dried peels and minerals are mixed as feed for animals [127, 131]. Processed unpeeled cassava root is exported from Thailand [132] and cassava chips and pellets from Ghana [131] to European Union. According to Tewe and Bokanga [132], 4 parts whole unpeeled cassava root and 1 part cassava leaf meal is washed, shredded, sundried

and milled before pelleting for poultry. The authors observed that complete substitution of maize with cassava maintained egg performance, body weight and darker yolk colour in pelleted feed because of high carotenoids. Cassava flour, chips and pellets are processed instead of fresh for easier transportation and product quality. Cassava chips are used in animal feed processing due to high demand for livestock feed and is forecast to increase [87]. Tewe [131] reported strategic interventions of cassava-based feed formulations for livestock production in Central, Eastern, Southern and Western Africa. Utilisation of cassava has become crucial in animal feed industry as per Nigerian federal governments legislation to use locally available cheaper energy sources [127].

Cassava based feed formulations are cost effective, encourages farmers to adapt and reduce reliance on expensive commercial rations. Cassava chips and flour pellets are produced to replace maize and reduce cost of poultry feed up to 10% (Cassava Master Plan, 2006 cited in [87]). The formulation for supplementary feed for fish, ruminant and non-ruminant animals for every growth stage is available in the market such as stater, grower and layer diets for poultry. Further, hard soft and floating pellets are processed for poultry, ruminant and fish feeds respectively. In Ghana, large-scale cassava inclusion in animal feed is restricted to government agricultural research station and they have released cassava root formulations to the market. Cameroon and Madagascar used 10% cassava production in livestock feed between 1991 to 2000 [131]. Future perspectives of cassava including feed management systems, food security, processing and utilisation, marketing feed and livestock products, policy issues, capacity building, environment considerations and research and development need to be looked into for the diversification of cassava products in livestock feed to reduce cost and make the environment sustainable.

Conclusion

Cassava is an important multiple utilisation crop, an alternative cheap feed for livestock and has huge potential in future due to growing demand for cassava products and products. Cassava root is low in protein but good source of carbohydrates, which could be used as a supplement in poultry diets. The leaves are moderate in protein content, which can replace

part of conventional protein sources in the diet. Anti-nutritional factors, mainly cyanide, reduce the feeding value of cassava products but proper processing can reduce this and make the products safe for livestock feeding. Cassava products have entered the industrial market and have huge potential in the feed industry. More research into processing and diet formulations will reduce feed cost and add value to cassava products.

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Conflict of interest

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