Egypt. J. Vet. Sci. **Vol. 52,** No. 3, pp. 387-403 (2021)

Egyptian Journal of Veterinary Sciences
https://ejvs.journals.ekb.eg/

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

Ashika Devi and Siaka Seriba Diarra
University of the South Pacific, School of Agriculture and Food Technology,P. M. Bag Alafua, Apia WS1343, Samoa .

SHORT supply and high cost of traditional ingredients affect efficientlivestock 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 emitsseveral products such as peel, pulp and leaves. The sebeneficial 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 productsmay 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 toreduce 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 proteinfeed 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 productsto reduce livestock feed cost[2, 4].

Cassava (*Manihot esculentaCrantz*), 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. Cassavais the third major energy source and animportant part of diet for over 800 million to half billion people globally[4, 5,9-11]. Cassava is cultivated in90 to 100countries [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 worlds' leading cassava producing country in 2016 followed by Thailand, Brazil, Indonesia, Ghana and Democratic republic of Congo, contributing to over 15 million tonnes of

Corresponding author: Ashika Devi, E.mail: ash03.d@gmail.com, Tel. +6798373397
(*Received* 18/11/2020; *accepted* 10/08/2021)
DOI. 10.21608/ejvs.2021.50090.1204

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 tuberscontributes 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 whichamyl pectin is 83% and amylose 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] andcontribute 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, leusine, 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 Linmarin 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		
Nutrient composition %	Sun Dried	Ensiled	Sun/oven dried	Fermented (*Aspergillus niger*)	Dried	Fermented (*Aspergillus oryzae*)	Dried	Ensiled	Leaf Pulp concentrate
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
Arginine	2.39	4.4 (2.9-5.9)	5.6	-	5.3
Cysteine	0.7	1.4	-	-	1.2
Lysine	2.2	3.47 (1.04-5.9)	5.4	6.8	5.9
Methionine	0.56	1.12 (0.34-1.9)	1.2	2.48	1.5
Total SAA	1.26	1.82 (0.34-3.3)	1.2	2.48	2.7
Histidine	0.94	2.1 (1.9-2.3)	1.7	-	2.0
Isoleucine	1.6	2.81 (1.12-4.5)	4.2	-	4.5
Leucine	2.58	5.65 (3.1-8.2)	8.3	9.65	8.2
Phenylalanine	1.69	4.15 (2.6-5.7)	5.6	-	5.4
Tryptophan	-	2.0	-	2.31	2.0
Tyrosine	1.29	4	4.4	-	5.4
Threonine	1.48	3.55 (2.7-4.4)	3.9	-	4.4
Valine	1.77	4.4 (3.2-5.6)	5.3	6.3	5.6
Glysine	1.55	4.1	4.1	-	7.0
Alanine	1.55	5.7	6.4	-	-
References	[1]	[8, 33, 42]	[42]	[41]	[32]

SAA: Sulphur amino acids; Values in 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]
		32.52	[19]
	Fermented (*S. cerevisiae*)	<0.0005	[58]
	Ensiled	25	[35]
	Fresh peeled	23-70	[59, 60]
Leaf meal	Sun dried	15.03	[8]
		84	[61]
	Sun dried	160	[35]
	Ensiled	198	[35]
Peel meal	Fermented (*Aspergillus niger*)	0.74	[38]
	Sun dried	50	[24]
	Lye treated	30	[24]
Pulp	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 itspalatability and storage.

Heat processing

Heat processing includes sun-drying, oven drying, earth oven, steaming, boiling and roasting which reduce cyanide content ofcassava 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^{o}C inhibits Linamarase enzyme and causes accumulation of Linamarin during drying[45]. At higher temperatures (80-100 ^{o}C), cyanide is reduced to 10-15% in comparison with drying at 47-60 ^{o}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^{o}C respectively. Nambisan [74] found at 50 and 70^{o}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 ^{o}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 productsallows interaction of Linamarin and Linamarase with the particles to break down HCN to soluble form, which isremoved 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. Akindhunsi 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. Akindhunsi 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 *Aspegillus niger*[78] and *Saccharomye cerevisiae* [79] reduced HCN and improve crude proteinfrom44 to 109 g/kg. Yafetto [80] observed that fermentation of cassava pulp with *Aspergillus niger*and ammonium nitrate increased crude protein by 22.1%. Sengxayalth 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 ^{o}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/kgcassava 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 proteinbut high HCNand 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/kgCPM with tallow and enzyme addition and found improved performance of finishing broilers. Babatunde [96] observed 100 g/kgCPM 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. Cropinten sification 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 emitabundance of solid products and wastewater which has disposal problem globally [120] and needs to be managed well. Theses 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. Somecassava 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		100	
		Broiler chicks	250	[78]
		Japanese quails	200-300 + 80 g/kg dried distillers grain	[102]
		Laying hens		[19]
		Broilers	30% of maize + oil, lysine and methionine	[103]
	Unpeeled	Broiler	100 + 6 g/kg charcoal	[18]
		Laying hens	300	[104]
		Pullets	150	[105]
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]
			200	[107]
		Laying hens	100	[89]
		Goose	50	[108]
		Laying ducks	100	[109]
	Hay	Quails	100	[110]
			120	[111, 112]
Pulp	Sun dried	Broilers	80	[29]
			110	[113]
		Laying hens	150	[114]
			200	[39]
			300 + enzymes (Cellulase, glucanase and xylanase)	[93]
	Fermented (*A. oryzae*)	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 andis 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^{o}Cfor 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 potentialin future due to growing demand for cassava products and products. Cassava rootis 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 processingcan reduce this and make the products safe for livestock feeding. Cassava productshave 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.

Acknowledgement

This review article did not have any substantial contributions from non-contributors.

Conflict of interest

The authors declare no conflict of interest

Funding statement

There was no funding provided for this article.

References

1. Diarra, S.S., Poultry industries in the South Pacific region: issues and future direction. *World's Poult. Sci. J.,* **73** (2), 293-300 (2017).
2. Devi, A. and Diarra, S.S., Maximum utilisation of available resources for efficient poultry feeding in the South Pacific: major issues and prospects. *Worlds Poult. Sci. J.,* **75**, 219-234 (2019).
3. FAO Food Outlook, Biennial Report on Global Food Markets 2018 Rome, (2018).
4. Omede, A.A., Ahiwe, E.U., Zhu, Z.Y., Fru-Nji, F. and Iji, P.A., Improving Cassava Quality for Poultry Feeding Through Application of Biotechnology. Chapter 14 Open access books Web of Science, pp 241-263 (2018).
5. FAO. 2013., Save and Grow: Cassava. A guide to sustainable production intensification. Food and Agriculture Organisation of the United Nations, Rome. ISBN: 978-92-5-107641-5.
6. Chauynarong, N., Elangovan, A. V. and Iji, P. A., The potential of cassava products in diets for poultry. *World's Poult. Sci. J*., **65**, 23-35 (2009).
7. Morgan, N.K. and Choct, M. Cassava: Nutrient composition and nutritive value in poultry diets. *Anim. Nutr.*, **2**, 253-261(2016).
8. Diarra, S.S., Koroilagilagi, M., Tamani, S., Maluhola, L., Isitolo, S., Batibasila, J., Vaea, T., Rota, V. and Lupea, U. Evaluation of cassava leaf meal protein in fish and soybean meal-based diets for young pigs. *J. Agr. Rural Dev. Trop*., **118** (1), 105–112 (2017).
9. Aryee, F.N.A., Oduro, I., Ellis, W.O. and Afuakwa, J.J. The physicochemical properties of flour samples from the roots of 31 varieties of cassava. *Food Contr.*, **17** (11), 916-922 (2006).
10. Adamolekun, B., "Neurological Disorders associated with Cyanogenic Glycosides in Cassava: A Review of Putative Etiologic Mechanisms". In: C.M. Pace (Ed.), Cassava:Farming, Uses, and Economic Impact. Nova Science Publishers, Inc. New York, pp. 165-180 (2012).
11. Dayal, A.D., Diarra, S.S., Lameta, S., Devi, A. and Amosa, F., High cassava peel meal-based diets with animal fat and enzyme for broilers. *Livestock Res. Rural. Dev*., **30** (99), 1-12 (2018).
12. Global Newswire, Global Cassava Processing Market Report 2019: Industry Trends, Share, Size, Growth, Opportunity and Forecasts 2011-2018 & 2019-2024 Global Newswire Inc. (2019). www.researchandmarkets.com. Accessed 20th February, 2020.
13. Diarra, S.S. and Devi, A. Feeding value of some cassava by-products meal for poultry: A review. *Pak. J. Nutr*., **14** (10), 735-741 (2015).
14. FAOSTAT. Food and Agriculture organisation of the United Nations. Statistical Database, statistics (2019). Updated 6th February 2020. www.fao.org/faostat/en/#data/Qc/visualise Accessed 28th February 2020.
15. Tewe, O.O. and Lutaladio, N. Cassava for livestock feed in sub-Saharan Africa. Rome, Italy: FAO. (2004).
16. Buitrago, J.A, Ospina, B., Gil, J.L and Aparicio, H. Cassava root and leaf meals as the main ingredients in poultry feeding: some experiences in Columbia, pp. 523-541 (2002)
17. Olugbemi, T.S., Mutayoba, S.K. and Lekule, F.P. Effect of Moringa (*Moringa olifera*) inclusion in cassava based diets fed to broiler chickens, *Int. J. Poult. Sci*., **9** (4), 363-367 (2010).
18. Oso, A.O., Li, L., Zhang, B., Uo, R., Fan, J.X., Wang, S., Jiang, G., Lui, H., Rahoo, T., Tossou, M.C., Pirgozliev, V., Oduguwa, O.O. and Bamgbose, A.M. Effect of fungal fermentation with *Aspergillus niger* and enzyme supplementation on metabolizable energy values of unpeeled cassava root meal for meat-type cockerels. *Anim. Feed Sci. Technol*., **210**, 281-286 (2015).

19. Lei, X.J., Park, J.H., Hosseindoust, A. and Kim, I.H. Effects of Cassava (*Manihot esculenta* Crantz) Root Meal in Diets Containing Corn Dried Distillers Grains With Solubles on Production Performance, Egg Quality, and Excreta Noxious Gas Emission in Laying Hens. *Braz. J. Poult. Sci*., **19** (2), 239-246 (2017). https://doi.org/10.1590/1806-9061-2016-0386

20. Julie, A.M., Christopher, R.D. and Sherry, A.T., Nutritional value of cassava for use as a staple food and recent advances for improvement. Institute of food technologists. *Compr. Rev. Food Sci. Food Saf*., **8**, 181-192 (2009).

21. Gil, J.L. and Buitrago, A.J.A. Cassava in animal nutrition. In: Ospina B, Ceballos H, editors. Cassava in the third millennium: Modern systems of production, processing, use and marketing. Cali, Colombia. *Int. Center. Trop. Agr.* pp. 527–569, (2002). From: http://www.clayuca.org/PDF/libro_yuca/capitulo28.pdf. Accessed 20th September, 2020.

22. Rawel, H.M. and Kroll, J. The direction of Cassava (*Manihot esculenta*, Crantz) as the main crop in tropical landscapes. *Dtsch. Lebensm.-Rundsch*., **99**, 102-110 (2003).

23. Charles, A.L., Sriroth, K. and Huang, T.C., Proximate composition, mineral contents, hydrogen cyanide and phytic acid of 5 cassava genotypes. *Food Chem*., **92**, 615–620 (2005).

24. Oladunjoye, I.O., Ojebiyi, O. and Amao, O.A. Effect of feeding processed cassava (*Manihot esculenta* crantz) peel meal based diet on the performance characteristics, egg quality and blood profile of laying chicken. *J. Agric. Rural Dev. Trop*., **43**, 119-126 (2010).

25. Siddhartha, G.V, Costa, A.O., Nitschke, M. and Contiero, J. In: Cassava: Farming, Uses and Economic impact Chapter 4: Biotechnological potential of cassava residues: Peel, Bagasse and wastewater. Editor: Collen M Pace. Nova Science Publishers, Inc. ISBN: 978-1-61209-665-1. pp. 79-98 (2012).

26. NRC. Nutrient requirements of swine. 11th edition. National Academic Press, Washington, DC. (2012).

27. Khempaka, S., Thongkratok, R., Okrathok, S. and Molee, W. An evaluation of cassava pulp feedstuff fermented with A. oryzae, on growth performance, nutrient digestibility and carcass quality of broilers. *J. Poult. Sci*., **51**, 71-79 (2014).

28. Chauynarong, N., Bhuiyan, M. M., Kanto, U. and Iji, P. A. Variation in nutrient composition of cassava pulp and its effects on in vitro digestibility. *Asian J. Poult. Sci.*, **9**, 203–212 (2015).

29. Khempaka, S., Molee, W. and Guillaume, M. Dried cassava pulp as an alternative feedstuff for broilers: Effect on growth performance, carcass traits, digestive organs, and nutrient digestibility. *J. Appl. Poult Res.*, **18**, 487-493 (2009).

30. Sengxayalth, P. and Preston, T.R. Fermentation of cassava (*Manihot esculenta* Crantz) pulp with yeast, urea and diammonium phosphate (DAP). *Livestock Res. Rural Dev.*, **29**, (177) Retrieved August 1, 2021, fromhttp://www.lrrd.org/lrrd29/9/pom29177.html(2017).

31. Ravindran, V. Cassava leaves as animal feed: Potential and limitations. *J. Sci. Food Agri*., **61** (2), 141-150 (1993).

32. Ravindran, V. and Blair, R. Feed sources for poultry production in Asia and Pacific. II. Plant protein sources. *World's Poult. Sci. J.*, **48**, 205-231 (1992).

33. Eggum, O.L., The protein quality of cassava leaves. *Br. J. Nutr*., **24**, 761-769 (1970).

34. Diarra, S.S., Utilisation of cassava products-copra meal based diets supplemented with or without Allzyme SSF by growing pullets. *Mal. J. Anim. Sci*., **18**, 67-76 (2015).

35. Ly, N.T.H., Ngoan, L.D., Verstegen, W.M.A. and Hendriks, W.H. Ensiled and Dry Cassava Leaves, and Sweet Potato Vines as a Protein Source in Diets for Growing Vietnamese Large White×Mong Cai Pigs. *Asian-Australas. J. Anim. Sci.,***23** (9), 1205-1212 (2010).

36. Diarra, S.S., Peel meals as feed ingredients in poultry diets: Chemical composition, dietary recommendations and prospects. *J. Anim. Physiol. Anim. Nutr.*, **102**, 1284-1295 (2018).

37. Okechukwu, S. and Jiwuba, P.C. Effects of cassava and yam peel meals on carcass traits and economics of production of finishing broilers. *Sustainability, Agri. Food and Environmental Research*. **7**(3), 221-229 (2019).

38. Adeyemi, A.I., Sani, A., Aderibigbe, T.A., Abdurrasheed, M.O. and Agbolade, J.O., A study of *Aspergillus niger*- hydrolyzed cassava peel meal as a carbohydrate source on the histology of broiler chickens. *Springerplus*, **3** (31), 1-12 (2014).

39. Khempaka, S., Hokking, L. and Molee, W. Potential of dried cassava pulp as an alternative energy source for laying hens. *J. Appl. Poult. Res*., **25**, 359-369, (2016).

40. Nguyen, T.H.L., Ngoana, L.D., Boschb, G., Verstegenb, M.W.A. and Hendriks, W.H. Ileal and total tract apparent crude protein and amino acid digestibility of ensiled and dried cassava leaves and sweet potato vines in growing pigs. *Anim. Feed Sci. Tech*., **172**, 171–179 (2012).

41. Fasuyi, A.O. and Aletor, V.A., Varietal composition and functional properties of cassava (*Manihot esculenta* Crantz) leaf meal and leaf protein concentrates. *Pak. J. Nutr*., **4** (1), 43-49 (2005).

42. Phuc, B.H.N., Ogle, B. and Lindberg, J.E. Effect of replacing soybean protein with cassava leaf protein in cassava root meals based diets for growing pigs on digestibility and N retention. *Anim. Feed Sci. Technol.*, **83**, 223-235 (2000).

43. Wink M. Plant breeding importance of secondary metabolites for production against pathogens and herbivores. *Theoretical and Applied Genetics*, **75** (2), 225-233 (1988).

44. Nyirenda, K.K. Toxicity Potential of Cyanogenic Glycosides in Edible Plants. *Med. Toxicol*., pp 1-20, (2020).

45. Montagnac, J.A., Davis, C.R. and Tanumihardjo, S.A. Nutritional value of cassava for use as a staple food and recent advances for improvement. *Compr. Rev. Food Sci. Food Saf.*, **8** (3), 181-194 (2009).

46. Wheatley, C. and Chuzel, G. Cassava: The nature of the tuber and use as a raw material. In: Macrae R, Robinson RK, Sadler M, editors. Encyclopedia of Food Science, Food Technology and Nutrition. San Diego, California: Academic Press; pp. 964-970, (1993).

47. Gruhnert, C., Biehl, B. and Selmar, D. Compartmentation of cyanogenic glucosides and their degrading enzymes. *Planta*., **195** (1), 36-42 (1994).

48. Poulton, J.E. Cyanogenesis in plants. *Plant Physiol.*, **94** (2), 401-405, (1990).

49. Harborne, J.B., Recent advances in chemical ecology. *Natural Product Reports*, **3**, 323-344 (1986).

50. Harborne, J.B., Plant toxins and their effects on animals. In: Introduction to Ecological Biochemistry. London: Academic Press. pp. 71-103 (1993).

51. Cardoso, A., Mirone, E., Ernest, M., Massza, F., Cliff, J. and Haque, R., Modification of nutritional quality of cassava through plant nutrition. *J. Food Compos. Anal.,* **18**, 451-461 (2005).

52. Leeson, S. and Summers, J.D. Commercial Poultry Nutrition 3rd Edition Department of Animal and Poultry Science, University of Geulph, Ontario, Canada. ISBN: 978-1-904761-78-5, pp 99-101, (2008).

53. Chiwona-Karltun, L., Afoakwa, E. O., Nyirenda, D., Mwansa, C. N., Kongor, E. J. and Brimer, L. Varietal diversity and processing effects on the biochemical composition, cyanogenic glucoside potential (HCNp) and appearance of cassava flours from South-Eastern African region. *Int. Food Res. J.* [Internet], **22** (3), 973-980 (2015).

54. FAO. Roots, Tubers, Plantain and Bananas in Human Nutrition. Rome: FAO; 1991. ISBN: 92-5-103138-X

55. Westerberg, A., Zhang, J. and Sun, C. In: Cassava: Farming, Uses and Economic impact Chapter 7: Cassava: A multi-purpose crop for the future. Editor: Collen M Pace. Nova Science Publishers, Inc. ISBN: 978-1-61209-665-1, pp. 145-163, (2012).

56. Ravindran, G. and Ravindran, V. Changes in the nutritional composition of cassava (*Manihot esculenta* Crantz) leaves during maturity. *Food Chem*., **27**, 299–309 (1988).

57. Ngudi, D.D., Kuo, Y-H. and Lambein, F. Cassava cyanogens and free amino acids in raw and cooked leaves. *Food Chem. Toxicol*., **41**, 1193–1197 (2003).

58. Sandakabatu, D. and Diarra, S.S. *Canarium indicum* cake as a source of Lysine in fermented cassava-copra meal diets with challenzyme for broilers. *J. South Pacific Agr.,* **21**, 1-8 (2018).

59. Aalbersberg W.G.L. and Limalevu, L., Cyanide content in fresh and processed Fijian cassava (*Manihot esculenta*) cultivars. *Trop. Sci.*, **31**, 249–256 (1991).

60. Aalbersberg, W.G. and Dolodolotawake, U., Cyanide content of cassava and cassava products in some pacific island countries. University of the South Pacific, Suva, Fiji. pp 1-8, (2012).

61. Ravindran, V., Kornegay, E.T., Rajaguru, A.B.S., Potter, L.M. and Cherry, J.A. Cassava leaf meal as replacement for coconut oil in broiler diets. *Poult. Sci*., **65**, 1720-1727 (1986).

62. Ravindran, V., Kornegay, E.T. and Rajaguru, A.B.S. Influence of processing methods and storage time on the cyanide potential of cassava leaf meal. *Anim. Feed Sci. Technol.*, **17**, 227-234 (1987).

63. Wobeto, C., Angelita, D.C., de Abreu, C.M.P., dos Santos, C.D. and Pereira, H.V. Antinutrients in the cassava (*Manihot esculenta* Crantz) leaf powder at three ages of the plant. *Ciência Tecnol. Alim*., **26**, 865-869 (2007).

64. Hue, K.T., Van, D.T.T., Ledin, I., Wredle, E. and Sp Rndly, E., Effect of Harvesting Frequency, Variety and Leaf Maturity on Nutrient Composition, Hydrogen Cyanide Content and Cassava Foliage Yield. *Asian-Australas. J. Anim. Sci.*, **25**, 1691-1700 (2012).

65. Ubi, B.E, Ibiam, U.A., Effisue, A.A., Odu, E.M., Udehand, K.I. and Egesi, C.N. Varietal differences in leaf cyanide content of cassava (*Manihot esculentum* Crantz). *J. Agr. Biotechnol. Ecol*., **1**, 62-69 (2008).

66. Dufour, D.L., Cyanide content of cassava (*Manihot esculenta*, Euphorbiaceae) cultivars used by Tukanoan Indians in Northwest Amazonia. *Economic Botany*, **42**, 255–266 (1988).

67. Hang, D.T. and Preston, T.R. The effects of simple processing methods of cassava leaves on HCN content and intake by growing pigs. *Livestock Res. Rural Dev.*, **17**, (99). Retrieved August 1, 2021, from http://www.lrrd.org/lrrd17/9/hang17099.htm(2005).

68. Imakumbili, M.L.E., Semu, E., Semoka, J.M.R., Abass, A. and Mkamilo, G. Farmers' perceptions on the causes of cassava root bitterness: A case of konzo-affected Mtwara region, Tanzania. *PLoS ONE,* **14** (4), 215-527 (2019).

69. Obigbesan, G. Investigations on Nigerian root and tuber crops: Effect of potassium on starch yields, HCN content and nutrient uptake of cassava cultivars (*Manihot esculenta*). *J. Agric. Sci.*, **89** (1), 29-34 (1977).

70. Srihawong, W., Kongsil, P., Petchpoung, K. and Sarobol, E. Effect of Genotype, Age and Soil Moisture on Cyanogenic Glycosides Content and Root Yield in Cassava (*Manihot esculenta* Crantz). *Kasetsart J., Natural Sci*., **49**, 844 – 855 (2015).

71. Ravindran, V. Preparation of cassava leaf products and their use as animal feeds. In D. Machin & S. Nyvold (Eds.), Roots, Tubers, plantain and bananas in animal feeding, Rome, Italy: *Food and Agri. Org*., **95**, 111–125 (1991).

72. Tewe, O.O. and Iyayi, E.A. Cyanogenic glycosides. In P. R. Cheeke (Ed.), Toxicants of plant origin, Glycosides Boca Raton, FL: CRC Press. Vol. II, pp. 43–60, (1989).

73. Cooke, R.D. and Maduagwu, E.N., The effects of simple processing on the cyanide content of cassava chips. *Int. J. Food Sci. Tech*., **13** (4), 299-306 (1978).

74. Nambisan, B., Evaluation of the effect of various processing techniques on cyanogens reduction in cassava. *Acta Horticult*., **375**, 193–202 (1994).

75. Hidayat, A., Zuraida, N. and Hanarida, I. The cyanogenic potential of roots and leaves of ninety nine cassava cultivars. *Indonesian J. Agric*., **3** (1), 25-32 (2002).

76. Akindahunsi, A.A., Oboh, G., Oshodi, A.A., Effect of fermenting cassava with *Rhizopus oryzae* on the chemical composition of its flour and Gari products. *Riv. Ital. Sostanze Gr.,***76**, 437-440 (1999)

77. Muzanila, Y.C., Brennan, J.G. and King, R.D. Residual cyanogens, chemical composition and aflatoxins in cassava flour from Tanzanian villages. *Food Chemi*., **70**, 45-49 (2000).

78. Akapo, A.O., Oso, A.O. and Bamgbose, A.M, Effect of feeding cassava (*Manihot esculenta* Crantz) root meal on growth performance, hydrocyanide intake and haematological parameters of broiler chicks. *Trop. Anim. Health and Prod*., **46**, 1167–1172 (2014).

79. Oboh, G. and Akindahunsi, A.A. Nutritional and toxicological evaluation of *Saccharomyces cerevisiae* fermented cassava flour. *J. Food Compost Anal*., **18**, 731-738 (2005).

80. Yafetto, L. Protein enrichment of cassava pulp by solidstate fermentation using *Aspergillus niger*. *Studies in Fungi,* **3** (1), 7-18 (2018).

81. Ofuya, C.O. and Obilor, S.N. The suitability of fermented cassava peel as a poultry feedstuff. *Biores. Technol*., **44** (2), 101-104 (1993).

82. Sugiharto, S., Yudiarti, T. and Isroli, I. Haematological and biochemical parameters of broilers fed cassava pulp fermented with filamentous fungi isolated from the Indonesian fermented dried cassava. *Livestock Res. Rural Dev*., **28**, (53) Retrieved August 1, 2021, from http://www.lrrd.org/lrrd28/4/sugi28053.htm(2016).

83. Kasankala, L.M., Kitunda, M.E., Towo, E.E., Ngwasy, G.M., Kaitira, L., Cyprian, C. and Mushumbusi, D. Antinutritional Factors Reduction from Cassava (*Manihot esculenta* Crantz) Roots by Grating or Chipping Processing Technique in Mtwara Tanzania. *European J. Nutr. Food Saf*., **9** (2), 163-171 (2019).

84. Nebiyu, A. and Getachew, E. Soaking and drying of cassava roots reduced cyanogenic potential use of three cassava varieties at Jimma, Southwest Ethiopia. *African J. Biotech*., **10** (2), 13465-13469 (2011).

85. FAO/WHO. WHO Food Additive Series: 65. Safety evaluation of certain food additives and contaminants. Prepared by the 74th Meeting of the Joint FAO/WHO Expert Committee on Food Additives (JECFA). Geneva,(2012).

86. Okonkwo, U.C., Onokwai, A.O., Okeke, C.L., Osueke, C.O., Ezugwu, C.A., Diarah, R.S. and Aremu, C.O. Investigation of the effect of temperature on the rate of drying moisture and cyanide contents of cassava chips using oven drying process. *Int. J. Mech. Engineering and Technol*. (IJMET), **10** (1), 1507–1520 (2019).

87. Onyenwoke, C.A. and Simonyan, K.J. Cassava post-harvest processing and storage in Nigeria: A review. *Afri. J. Agri. Res.*, **9** (53), 3853-3863 (2014).

88. Stupak, M., Vanderschuren, H., Gruissem, W. and Zhang, P. Biotechnological approaches to cassava protein improvement. *Trends Food Sci. Technol*., **17** (12), 634-641 (2006).

89. Zanu, H.K. and Avukpor, C.M. Effects of enzyme (xzyme) supplementation on the performance of laying hens fed diets containing different levels of cassava (*Manihot esculenta* Crantz) leaf meal. *Online J. Anim. Feed Res*., **3**, 9-14 (2013).

90. Ferreira, A.H.C., Lopes, J.B., Abreu, M.L.T., Figgueirêdo, A.V., Ribeiro, M.N., Silva, F.E.S. and Merval, R.R. Integral cassava shavings for pullets from one to 42 days old. *Braz. J. Health and Prod. Anim*. [Online], **13** (1), 160-172 (2012).

91. Bhuiyan, M.M. and Iji, P.A., Energy value of cassava products in broiler chicken diets with or without enzyme supplementation. *Asian-Australas. J. Anim. Sci*., **28** (9), 1317–1326 (2015).

92. Aro, S.O., Aletor, V.A., Tewe, O.O., Fajemisin, A.N., Usifo, B. and Falowo, A.B. Proceedings of the 33rd Annual Conference of Nigerian Society of Animal Production (NSAP), Ayetoro, Ogun State, Nigeria. 21st May. Preliminary investigation on the nutrients, anti-nutrients and mineral composition of microbially fermented cassava starch residues, pp. 86–92, (2008).

93. Khempaka, S., Maliwan, P., Okrathok, S. and Molee, W. Digestibility, productive performance, and egg quality of laying hens as affected by dried cassava pulp replacement with corn and enzyme supplementation. *Trop. Anim. Health Pro.*,**50**, 1239-1247 (2018).

94. Tewe, O.O. and Egbunike, G.N. Utilisation of cassava in non-ruminant livestock feeds. Cassava as livestock feed in Africa. Proceedings of the IITA/ILCA/University of Ibadan workshop on the potential utilisation of cassava as livestock feed in Africa, Nigeria, pp. 28-38, (1992).

95. Salami, R.I. Preliminary studies on the use of parboiled cassava peel meal as a substitute for maize in layers' diets. *Trop. Agr*., **77**, 199-204 (2000)

96. Babatunde, B.B., Effect of feeding cassava wastes on the performance and meat quality of broiler chickens. *Mal. J. Anim. Sci*., **16**, 63-73 (2013).

97. Aguihe, P.C, Kehinde, K.S, Babatunde, T.O. and Iyayi, EA., Effect of supplementation of Cassava peel meal based diet with enzyme maxigrain on performance, apparent nutrient digestibility and economics indices of broiler finishers. *Nig. J. Anim. Product,* **41**, 100-109 (2015).

98. Iheukwumere, F.C., Ndubuisi, E.C., Mazi, E.A. and Onyekwere, M.U. Performance, nutrient utilization and organ characteristics of broilers fed cassava leaf meal (*Manihot esculenta* Crantz). *Pak. J. Nutr*., **7**, 13-16 (2008).

99. Montilla, J.J. Cassava in the nutrition of broilers. Cassava as Animal Feed, pp 43-50, (1977).

100. Khattak, F.M., Pasha, N.T., Hayat, Z. and Mahmud, A. Enzymes in Poultry Nutrition. *J. Anim. Plant Sci*., **16**, 1-4 (2006).

101. Ogunsipe, M.H., Adejumo, J.O., Agebede, J. and Asaniyan, E. Effect of roxyzyme G2G supplementation on cassava plant meal fed to broiler chickens. *Livestock Res. Rural Dev.*, **27**(240).Retrieved August 1, 2021, from http://www.lrrd.org/lrrd27/12/ogun27240.htm(2015).

102. Odo, B.I and Nnadi, A.E. Growth Response of Quails (*Coturnix coturnix* japonica) to Varying Levels of Cassava (*Manihot esculenta*) Tuber Meal as a Replacement for Maize (Zea mays). *American J. Experimental Agri.*, **4** (12), 1898-1903 (2014)

103. Tion, M.A. and Adeka, I. The evaluation of cassava root meal as a replacement for maize in broiler diet. Book of proceeding, 25th Annual NSAP Conference, pp.113-116, (2000).

104. Eruvbetine, D. and Oguntona, E.B., Unpeeled Cassava root meal in diets for laying hens. *Trop. Agr.*, **74** (4), 299-302 (1997).

105. Okiyi, P.C., Adagbo, A.P., Olaleru, I.F., Mbadiwe, M.N. and Okorie, K.C., Effects of yellow root cassava meal replacement of maize in diets of pullets up to point of lay. *J. Agri. Sci. Policy Res*.,**6** (1), 42-51 (2016).

106. Salami, R.I. and Odunsi, A. Evaluation of processed cassava peel meals as substitute for maize in the diets of layers. *International Journal of Poult. Sci*.,**2**, 112-116 (2003).

107. Abu A.O., Olaleru I.F. and Omojola A.B., Carcass characteristics and meat quality of broilers fed cassava peel and leaf meals as replacements for maize and soya bean meal. *J. Agric. Vet. Sci.*, **8**, 2319-2372 (2015).

108. Li, M., Zi, X., Tang, J., Xu, T., Gu, L. and Zhou, H. Effects of cassava foliage on feed digestion, meat quality, and antioxidative status of geese. *Poult. Sci.*,**99**, 423–429 (2020).

109. Sumiati, D.A. and Hermana, W. Performances and Egg Quality of Laying Ducks Fed Diets Containing Cassava (*Manihot esculenta* Crantz) Leaf Meal and Golden Snail (*Pomacea canaliculata*). *Trop. Anim. Sci. J.*, **43** (3), 227-232 (2020).

110. Silva Júnior, P.A.S., Lana, S.R.V., Lana, G.R.Q., Silva, L.C.L., Torres, E.C.and Ferreira, T.S. Cassava foliage in quail feeding. *Acta Vet. Bras*., **11**, 150-156 (2017).

111. Cunha, F.S.A., Evaluation of cassava (*Manihot esculenta* Crantz) and by-products in quail feeding (*Coturnix japonica*) 99 f. Monograph (Doctorate in Zootechnics) - Federal Rural University of Pernambuco, Recife. (2009).

112. Silva, J.H.V., Jordão F., José, Costa, Fernando G.P., Lacerda, Patrícia B.de., Vargas, Danilo G.Vieira, and Lima, M.R. Nutrient requirements of codornas. *Braz. J. Health Anim. Prod*., **13** (3), 775-790 (2012).

113. Ali-Mursyid, W.M., Bachruddin, Z., Zuprizal and Nur-Cahyanto, M., Corn substitution using fermented solid cassavawaste on broiler chicken. *J. Indones. Trop. Anim. Agric.*, **35** (1), 9-15 (2010).

114. Chauynarong, N., Iji, P.A. and Kanto, U., The optimum level of cassava pulp in diets for layers. Proceeding of 21st Australian Poultry Science Symposium, pp: 136-139 (2010).

115. Okrathok, S., Pasri, P., Thongkratok, R., Molee, W. and Khempaka, S. Effects of cassava pulp fermented with *Aspergillus oryzae* as a feed ingredient substitution in laying hen diets. *J. Appl. Poult. Res*., **27**, 188-197 (2018).

116. Okereke, C.O. Utilization of Cassava, Sweet Potato, and Cocoyam Meals as Dietary Sources for Poultry. *World J. Engineering and Pure and Appl. Sci.*, **2** (3), 63-68 (2012).

117. Nwokoro, S.O., Orheruata, A.M. and Paul, I.O., Replacement of maize with cassava sievates in cockerel starter diets; some blood metabolic. Proceeding of 25th Annual conference with NSAP, pp 234-236, (2000).

118. Almeida, A.Z., Eyng, C., Garcia, R.G., Nunes, R.V., Sangalli, G.G. and Nunes, K.C. Dried Cassava Residue in Laying Quail Feeding. *Braz. J. Poult. Sci*., **22** (1), 1-8 (2020).

119. Tesfaye, E., Animut, G., Urge, M. and Dessie, T. Cassava Root Chips as an Alternative Energy Feed Ingredient in Broiler Ration. *Int. J. Poult. Sci.*, **12** (5), 298 -306 (2013).

120. Omotosho, O.A. and Sangodoyin, A.Y. Production and utilization of cassava peel activated carbon in treatment of effluent from cassava processing industry. *Water Pract. Technol.*, **8** (2), 215-224 (2013).

121. Kolawole, P.O., Agbetoye, L. and Ogunlowo, S.A. Sustaining World Food Security with Improved Cassava Processing Technology: *The Nigeria ExperienceSustainability,* **2**, 3681-3694 (2010).

122. Agbetoye, L.A.S., *Engineering challenges in developing indigenous machinery for cassava production and processing.* In Proceedings of the Annual Conference of the Nigerian Society of Engineers (Lagelu 2003), Ibadan, Nigeria, 8–12 December, pp. 80-86 (2003).

123. Odigboh, E.U. A single-row model I Cassava harvester. *AMA. Agr. Mech Asia, Afr. Latin AMA.*, **22**, 63-66 (1991).

124. Kemp, D.C. Harvesting: A demonstration of two machines—Cassava harvesting and processing. In Proceedings of a Workshop Held in CIAT, Cali, Colombia, 24–28 April, (1978).

125. Johnson, I.M., Kemp, D.C. and Payne, P.C., Mechanisation of cassava production. In Proceedings of the International Workshop in Bangkok, Bangkok, Thailand, 6–9 December, (1989).

126. Peipp, L. The development of a technical solution to cassava harvesting problem. *Agri. Mech. Asia, Afr. Latin Ama.*, **23**, 33-36 (1992).

127. Taiwo, K.A. Utilization Potentials of Cassava in Nigeria: The Domestic and Industrial Products Cassava Use in Nigeria. *Food Rev. Int.*, **22**, 29–42 (2006).

128. Ajibola, O.O., New techniques in cassava processing. Paper presented at the seminar on Improvement in the quality of roots and tuber food project, Oct 10–13, 1988, FIIRO, Lagos. (1988)

129. Ene, L.S.O., *Prospects for processing and utilisation of root and tuber crops in Africa*. Proceedings 4th Triennial Symposium, International Society for Tropical Root Crops—Africa Branch (23–32). Kinshasa, Zaire, December 5–8, (1992).

130. Taiwo, K.A., Oladepo, W.O., Ilori, M.O. and Akanbi, C.T. A study on the Nigerian food industry and the impact of technological changes on the small-scale food enterprises. *Food Rev. Int.*, **18** (4), 243–262 (2002).

131. Tewe, O.O. Cassava for Livestock Feed in Sub-Saharan Africa. Rome: FAO. pp. 1-75, (2004)

132. Tewe, O.O. and Bokanga, M. Cost-effective cassava plant-based rations for poultry and pigs. Proceedings of the ISTRC, Africa Branch (IITA). 11- 10 November 2001, Ibadan, Nigeria. (2001).