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Review Article

# Cassava: Nutrient composition and nutritive value in poultry diets

Natalie K. Morgan*, Mingan Choct

*School of Environmental & Rural Science, University of New England, Armidale 2351, Australia*

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ABSTRACT

Insufficient supply, high prices and competition with the human food and biofuel industries means there is a continuous demand for alternative energy sources for poultry. As a result, cassava is becoming an increasingly important ingredient in poultry diets, largely due to its high availability. Efficient use of cassava products has been shown to reduce feed costs of poultry production. The utilisation of cassava is, however, limited by a number of factors, including its high fibre and low energy content and the presence of anti-nutritional factors, primarily hydrocyanic acid (HCN). With correct processing the inclusion level of cassava in poultry diets could be increased. Extensive research has been conducted on cassava products for poultry, but there is still a lack of consistency amongst the measured nutritive values for cassava and its products, hence variation exists in results from poultry studies. This paper reviews the nutrient composition of cassava products and its value as an alternative energy source in poultry diets.



## 1. Introduction

In recent years, the cost of maize has increased considerably due to competition with the human food industry, increased production of biofuel and droughts in some parts of Africa; from September 2005 to September 2015 maize price increased by 71.16% (USDA, 2015). There have been large increases in the prices of some vegetable protein sources as well. Such increases in the cost of conventional raw materials have accelerated the demand to find alternative feed resources that can replace a proportion of these products in poultry diets at a lower cost of production. Cassava is the highest supplier of carbohydrates among staple crops and can potentially completely replace maize as an energy source in poultry diets.

World annual cassava production has increased by approximately 100 million tonnes (1 tonne = 1,000 kg) since 2000. This is driven by demand for cassava food products in Africa and for dried cassava and starch for use in livestock feed in Asia. Cassava is believed to represent the future of food security in some developing countries. Approximately 500 million people currently depend on it as a major carbohydrate source (Montagnac et al., 2009), making it the third largest source of carbohydrate for human food in the world (Fauquet and Fargette, 1990). The reason is that it is tolerant to poor soils, diseases and drought (Chauynarong et al., 2009). Under tropical conditions it is the most productive crop in terms of energy yield per unit land area, with a yield of between 25 and 60 tonnes/ha (1 ha = 10,000 $m^2$) (Garcia and Dale, 1999).

World cassava output increased by 4.6% between 2013 and 2014 (FAO, 2014). The majority (70%) of the world's cassava is produced in Nigeria, Brazil, Indonesia, Democratic Republic of Congo and Thailand (FAO, 2014). Approximately 70% of the estimated total 13 million hectares of cultivated area in Africa and Asia has cassava growing on it (El-Sharkawy, 2003). The current world average yield of cassava is 12.8 tonnes per hectare (world output of approximately 290 million tonnes), but there is potential to produce an average of 23.2 tonnes of cassava roots per hectare. This would equate to more than 500 million tonnes a year on the current harvested area, and yield could reach 80 tonnes per hectare under optimal conditions (FAO, 2014).

High export prices from the European Economic Community in the 1970s and 1980s caused a boost in cassava production in Thailand, resulting in it becoming the largest cassava exporter. Production in Thailand increased from 3.4 million tonnes of roots in

* Corresponding author.
*E-mail address:* nmorga20@une.edu.au (N.K. Morgan).

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1970 to 24.3 million tonnes in 1989 and 19.1 million tonnes in 1995 (Garcia and Dale, 1999). The expansion of the cassava industry is driven primarily by rising food demands in the African continent (Okudoh et al., 2014) and increasing industrial applications of cassava in East and Southeast Asia (notably for ethanol and starch production) (Nguyen et al., 2007). Cassava is a strategic crop for alleviating poverty and for food security, but its continued success, particularly in Asia, is dependent on how it fares compared with other substitutes.

## 2. Cassava products

The composition of cassava depends on the specific tissues (roots or leaves), geographic location, variety, age of the plant and environmental conditions (Garcia and Dale, 1999). Cassava roots can be left in the ground for over a year, requiring very little input, and harvested when there are food shortages or prices of alternative ingredients become prohibitive. Cassava, unlike other crops, can be grown in areas with poor soil fertility and soil problems, such as high phosphorus fixation, erosion, low exchangeable base content and high aluminium content (Alves and Setter, 2000; Howeler, 1991), leaving better soils available for more profitable crops. It is resistant to adverse environments and tolerates a range of rainfalls. Its mature roots can maintain nutritional value for a long time without water (El-Sharkawy, 2003; Montagnac et al., 2009) and can grow in areas that receive just 400 mm of average annual rainfall (FAO, 2014).

Compared with other cereal grains, cassava is low in protein and the protein it has is of poor quality with very low essential amino acid contents (Olugbemi et al., 2010). As a result, cassava-based diets must be supplied with protein sources that provide an adequate supply of methionine and lysine, which can be costly. Adegbola (1977) stated high cassava based diets need to be supplemented with 0.2% to 0.3% methionine. Options for overcoming this problem include incorporating cassava leaves, seeds or cakes, which are richer in protein, into the diet (Ngiki et al., 2014) or supplementing the diet with synthetic amino acids. Cassava must also be subjected to biofortification of micronutrients, such as vitamin A, iron and zinc, because it is grown in areas where mineral and vitamin deficiencies are widespread (Montagnac et al., 2009; Nnadi et al., 2010).

### 2.1. Roots

Cassava root production has been increasing steadily since the 1960s but between 1997 and 2007 its production increased by over 40% (from 161 to 224 million tonnes), and its use in animal feed increased by 76 million tonnes (FAO, 2014). The root is composed almost exclusively of carbohydrate, as well as approximately 1% to 3% crude protein (Stupak et al., 2006). The metabolizable energy (ME) levels of cassava root have been presented by various authors, with values ranging from 3,000 to 3,200 kcal/kg (Buitrago et al., 2002), 3,200 kcal/kg (Egena, 2006), 3145 kcal/kg (Khajarern and Khajarern, 2007) and 3,279 kcal/kg (Olugbemi et al., 2010).

Root chips and pellets are the most common types of poultry feedstuff produced from cassava roots and are produced widely in Thailand, Malaysia, Indonesia and some parts of Africa (Chayunarong et al., 2009). Chips are the dried shredded root, usually produced from fresh roots that are sun-dried on a concrete floor for 2 to 3 days until the moisture content is reduced to 14% (Oguntimein, 1988). The chips can then be ground and used in either mash or pellet diets. The specification for export cassava chips are a maximum of 5% fibre, 3% soil contaminants, 14% moisture and a minimum of 65% starch (Balagopalan, 2002). The chips vary substantially in size, shape and quality depending on drying rate and contamination during processing. The advantage of turning the chips into pellets for animal feed is improved performance and lower transportation costs (as they are less bulky than chips). The powdered residue resulting from processing the chips and roots is called cassava meal. In Africa cassava meal is used frequently, but in Europe other cassava products are favoured over cassava meal because of its low starch content and presence of soil contaminants (Chauynarong et al., 2009).

Cassava roots are usually peeled to rid them of the thin skin and leathery parenchymatous covering, which constitutes approximately 15% to 20% of the tuber (Obadina et al., 2006; Onyimonyi and Ugwu, 2007). The waste peel produced currently poses a disposal problem, but it has the potential to be an important resource if exploited properly by biotechnological systems (Obadina et al., 2006). Cassava peel meal is low in both energy and protein and contains higher levels of cyanogenic glucosides than root meal (Ngiki et al., 2014). Tewe (1991) found cyanide levels were approximately 650 and 310 mg/kg for the peel and pulp respectively in bitter tasting varieties of cassava, and 200 and 38 mg/kg for the peel and pulp respectively in sweeter varieties. The protein content of peel meal is approximately 46 to 55 g/kg, so lower than that of most cereal grains, meaning that if it is used as a replacement for cereals it is necessary to balance for protein deficiencies. Cassava root products are also deficient in carotene and carotenoids, so supplements must be added to diets containing these products to maintain normal egg yolk and broiler skin pigmentation (Khajarern and Khajarern, 2007). Supplementing diets containing cassava root with cassava leaf meal could potentially mitigate this issue.

Cassava pulp, the solid, moist by-product of cassava starch manufacture, represents approximately 10% to 15% of the root (Thongkratok et al., 2010). Cassava pulp has a moisture content of approximately 60% to 70% and contains 50% carbohydrates on a dry weight basis. Dried cassava pulp is low in protein (approximately 2%), deficient in carotene and has high levels of fibre (in the form of insoluble fibre) making it difficult to use successfully in poultry diets (Aro et al., 2008).

### 2.2. Leaves

Approximately 10 tonnes of dry cassava foliage is produced per hectare. Cassava leaves are highly nutritious. They have high protein, ranging from 16.6% to 39.9% (Khieu et al., 2005), and mineral levels, as well as being a valuable source of vitamin $B_1$, $B_2$ and C and carotenes (Adewusi and Bradbury, 1993). Additionally, the amino acid concentration of cassava leaves is very similar to that of alfalfa (Ravindran, 1991) and the ME ranges from approximately 1590 kcal/kg (Khajarern and Khajarern, 2007) to 1,800 kcal/kg (Ravindran, 1991). Dry cassava leaves can therefore be ground into meal to be fed to poultry as a source of protein and carotene (Khajarern and Khajarern, 1992). The leaves can be harvested within 4 to 5 months of planting, without having any adverse effect on the root. As the leaf ages, crude protein and amino acid levels decrease, but crude fibre, hemicellulose and cellulose levels increase (Ravindran and Ravindran, 1988). Cassava leaves have a significant level of the antinutrient hydrocyanic acid (HCN), low digestible energy and high tannin and phytin content which limits their use in poultry feed (Ravindran et al., 1986).

## 3. Nutrient composition

The proximate nutrient composition of cassava products as reported by a number of researchers is presented in Table 1.

**Table 1**
Proximate composition of cassava products.*

| Product | DM, g/kg | SEM | CP, g/kg | SEM | Crude fibre, g/kg | SEM | Ether extract, g/kg | SEM | Nitrogen free extracts, g/kg | SEM | Ash, g/kg | SEM | Ca, g/kg | SEM | P, g/kg | SEM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Peel[1] | 287.60 | 7.99 | 53.57 | 3.18 | 158.26 | 15.06 | 15.97 | 2.26 | 681.21 | 18.14 | 60.49 | 4.90 | 3.47 | 0.47 | 1.60 | 0.10 |
| Peel meal[2] | 875.93 | 11.58 | 53.31 | 2.52 | 142.29 | 9.85 | 18.14 | 3.30 | 703.83 | 10.94 | 55.09 | 4.30 | 6.48 | 1.17 | 2.48 | 0.29 |
| Root[3] | 392.44 | 34.88 | 26.20 | 2.27 | 35.78 | 5.49 | 9.00 | 0.92 | 825.50 | 43.26 | 29.78 | 3.71 | 2.00 | 0.33 | 2.30 | 0.48 |
| Root meal[4] | 894.24 | 6.90 | 31.00 | 3.67 | 37.26 | 3.87 | 9.85 | 1.67 | 827.73 | 18.67 | 38.84 | 4.86 | 1.60 | 0.15 | 3.70 | 1.53 |
| Leaf[5] | 430.54 | 72.96 | 198.22 | 23.71 | 128.91 | 13.97 | 79.24 | 8.37 | 449.58 | 12.59 | 74.05 | 11.30 | 20.96 | 2.55 | 8.43 | 2.09 |
| Leaf meal[6] | 920.60 | 2.71 | 237.88 | 8.48 | 176.96 | 9.47 | 68.29 | 5.75 | 405.78 | 8.69 | 80.75 | 3.33 | 12.44 | 1.22 | 6.01 | 1.53 |
| Starch[7] | 794.36 | 82.58 | 11.59 | 2.10 | 69.18 | 31.12 | 1.35 | 0.05 | 724.95 | 6.06 | 10.76 | 2.89 | 0.07 | 0.00 | 0.12 | 0.03 |
| Pulp[8] | 897.76 | 8.92 | 25.29 | 6.41 | 161.02 | 16.38 | 16.15 | 4.70 | 528.45 | 2.23 | 31.08 | 6.22 | 0.54 | 0.10 | 0.36 | 0.07 |
| Pellets[9] | 887.00 | 6.74 | 58.38 | 14.20 | 108.33 | 28.02 | 10.18 | 1.31 | 695.33 | 27.45 | 44.93 | 6.26 | 4.80 | 0.53 | 1.74 | 0.27 |
| Flour[10] | 853.49 | 17.46 | 17.92 | 2.67 | 19.26 | 5.12 | 6.58 | 2.16 | 787.75 | 21.11 | 16.24 | 4.92 | 0.40 | 0.05 | 3.58 | 0.68 |
| Chips[11] | 894.27 | 6.38 | 23.62 | 3.28 | 34.87 | 6.15 | 12.00 | 1.90 | 820.89 | 7.35 | 26.05 | 2.90 | 1.70 | 0.20 | 1.15 | 0.08 |

* Values represent the average and SEM of a minimum of 10 values, presented in the corresponding articles.

1 Adegbola (1980), Adegbola and Asaolu (1986), Devendra (1977), Heuzé and Tran (2012), Kortei et al. (2014), Lukuyu et al. (2014), Onyimonyi and Ugwu (2007), Smith (1992), and Sogunle et al. (2009).

2 Adesehinwa et al. (2008), Adeyemo et al. (2014), Khajern and Khajern (1992), Lekule and Sarwatt (1988), Mayaki et al. (2013), Oboh (2005), Ogbonna and Adebowale (1993), Oladunjoye et al. (2010, 2014), Olafadehan (2011), Onifade and Tewe (1993), Onyimonyi and Ugwu (2007), Smith (1992), Sogunle et al. (2009), and Udo and Umoren (2011).

3 Adegbola and Asaolu (1986), Buitrago (1990), Gil and Buitrago (2002), Heuzé and Tran (2012), Lukuyu et al. (2014), Oguntimein (1988), and Smith (1992).

4 Adeyemi et al. (2007), Buitrago et al. (2002), Diarra et al. (2014), Egena (2006), Khajarern et al. (1979), Khajarern and Khajarern (1992, 2007), Lim (1978), Limsila et al. (2002), Olugbemi et al. (2010), and Onifade and Tewe (1993).

5 Akinfala et al. (2002), Adegbola and Asaolu (1986), Buitrago (1990), Fasuyi (2005), Gil and Buitrago (2002), Iheukwumere et al. (2008), Khajarern and Khajarern (2007), Montagnac et al. (2009), Okigbo (1980), Ravindran (1991), Salvador et al. (2014), and Smith (1992).

6 Heuzé and Tran (2012), Kanto and Juttupornpong (2005), Lukuyu et al. (2014), Mayaki et al. (2013), Nwokoro and Ekhosuehi (2005), and Ravindran (1992).

7 Cereda and Takahashi (1996), Chinma et al. (2013), Fakir et al. (2012), Khempaka et al. (2009), Lola et al. (2012), Nwosu et al. (2014), Samuel et al. (2012), and Sriroth et al. (2000).

8 Chauynarong et al. (2015), Digbeu et al. (2013), Edama et al. (2014), Fakir et al. (2012), and Khempaka et al. (2009, 2014).

9 Bhuiyan and Iji (2015), Garcia and Dale (1999), Kanto and Juttupornpong (2002) Tang et al. (2012), Tesfaye et al. (2013), and Ukachukwu (2005).

10 Adepoju et al. (2010), Akubor and Ukwuru (2003), Bankole et al. (2013), Buitrago et al. (2002), Ciacco and D'Appolonia (1978), Egena (2006), Fakir et al. (2012), Ibanga and Oladele (2008), Igbabul et al. (2013), and Lim (1978).

11 Olugbemi et al. (2010), Bhuiyan and Iji (2015), Boonnop et al. (2009), Ekwu et al. (2012), Garcia and Dale (1999), Kanto and Juttupornpong (2002), Lim (1978), Oghenechavwuko et al. (2013), and Paul and Southgate (1978).

### 3.1. Protein and amino acids

Cassava tubers have low protein content (0.7% to 1.3% fresh weight (Ngiki et al., 2014)). The protein content of cassava flour, peels and leaves is also low at approximately 3.6%, 5.5% and 21% respectively (Iyayi and Losel, 2001). Cassava based diets must therefore be supplemented with methionine and lysine (Tewe and Egbunike, 1992). As reported by Nagib and Sousa (2007), the total amino acid content of cassava is approximately 0.254 g per 100 g and lysine content is approximately 0.010 g per 100 g. The protein in cassava has a high arginine content but low methionine, threonine, cysteine, phenylalanine, isoleucine and proline content (Onwueme, 1978).

The protein content of cassava could be improved by addition of protein sources into the diet, or alternatively fermenting the cassava prior to adding it into the diet. Antai and Mbongo (1994) found that fermenting cassava peels using pure cultures of *Saccharomyces cerevisiae* increased protein content from 2.4% in non-fermented cassava to 14.1% in fermented products. Oboh and Kindahunsi (2005) found that fermenting cassava flour with the same culture improved protein level from 3.3% to 10.9% and reduced the cyanide content. Fermenting cassava with rumen filtrate is believed to be the cheapest and most effective way of improving the protein content of cassava (Adeyemi and Sipe, 2004; Ubalua and Ezeronye, 2008); Adeyemi et al. (2004) observed a 237.8% increase in crude protein value of cassava root meal when fermented with rumen filtrate. Eruvbetine et al. (2003) found that grinding cassava roots and leaves together in equal amounts before sun-drying improved the crude protein content and texture and reduced the cyanide content of the material. Additionally, a high-protein variety of cassava, called ICB300, has recently been developed by interspecific hybridisation between cassava and *Manihot oligantha*. This product could potentially improve the value of cassava in feed, for example Nagib and Sousa (2007) found that ICB300 has 10 times more lysine and 3 times more methionine than common cassava.

### 3.2. Lipids

Cassava is very low in lipids. Gomes et al. (2005) found that cassava contains just 0.1% lipids, compared with maize which has approximately 6%. Hudson and Ogunsua (1974) found that flour from cassava roots contains approximately 2.5% lipids, but only half of this is extractable with conventional solvent systems, and the fatty acids in cassava are primarily saturated. The low level of lipids in cassava means it is also a poor source of fat soluble vitamins; Onwueme (1978) found it had low levels of vitamin A, $B_1$, $B_2$ and niacin but high levels of vitamin C.

### 3.3. Carbohydrates

Cassava contains highly digestible starch. Gomes et al. (2005) and Promthong et al. (2005) compared cassava starch to maize starch and found that cassava starch contains 17% amylose and 83% amylopectin, compared with maize starch which has 28% amylose and 72% amylopectin. The comparatively higher amylopectin level means that the digestible starch may be higher in cassava compared with other common starch sources fed to poultry. Resistant starch refers to starch and starch degradation products that escape digestion in the small intestine. Cassava chips contain approximately 40.91% resistant starch compared with maize which has 47.55% (Promthong et al., 2005), and raw cassava contains approximately 75.38% resistant starch (Onyango et al., 2006). Amylose becomes a resistant starch by crystallisation, as a result of chain elongation by double helical formation between amylose molecules. These elongated chains become folded and form tightly packed structures which are stabilised by hydrogen bonds

(Eerlingen and Delcour, 1995). Amylopectin can form resistant starch but it is a slower and less stable process. Kiatponglarp and Tongta (2007) reported that the high resistant starch levels in raw cassava was likely because it is composed of 82.85% amylopectin with branch linkage of 5.79% and 17.25% amylose with branch linkage of 0.48%. Another possible explanation is that the amylopectin in cassava has a comparatively longer chain length (Raphael et al., 2011).

## 4. Anti-nutritional factors

In order to replace maize with cassava on a large scale, technology needs to be developed that can reduce the high moisture and HCN content of cassava tubers. The cyanide levels in cassava range from 75 to 1,000 mg/kg, dependent on the variety and age of the plant, the soil conditions, presence of fertilizer and weather, among other factors (Ngiki et al., 2014). There are two types of cyanogenic glucosides in cassava; linamarin (93%) and either lotaustralin or ethyl linamarin (7%). They act as sources of aspartic acid, glutamic acids and glutamine, and are not harmful to the plant. Linamarin is chemically similar to glucose but is conjugated to cyanide ions. The levels of linamarin vary from 2 to 395 mg/100 g in fresh tuber, depending on the variety (Yeoh and Yruong, 1993). Linamarin is synthesised from valine and lotaustralin is synthesised from isoleucine (Andersen et al., 2000). When cassava roots are crushed or the sliced linamarin and lotaustralin are changed to HCN by linamarase enzymes present in the root (Cardoso et al., 2005; Santana et al., 2002). The cyanogenic glucoside content in the leaves are six times higher than that in the roots and decease as maturity of the leaf increases (Ngiki et al., 2014).

Hydrocyanic acid is liberated further in the bird by enzymes such as ß-glucosidase produced by the intestinal microflora (Fomunyam et al., 1984; Gonzales and Sabatini, 1989), glucosidases produced by the liver and other tissues (Padmaja and Panikkar, 1989) and acid hydrolysis in the intestine (Onabowale, 1988). In the liver HCN is changed into thiocyanate by the enzyme rhodanase, which is then excreted in the urine (Garcia and Dale, 1999). This process uses sulphur from methionine, and hence increases the requirement for this amino acid.

### 4.1. *Improving the nutritive value of cassava products through physical processes*

Drying is the most popular practice used to reduce cyanide content of cassava. Sun-drying is more effective at eradicating cyanide than oven-drying because with this method the cyanide is in contact with linamarase for a longer period (Ngiki et al., 2014). Ravindran (1991) stated that sun-drying alone can eliminate almost 90% of initial cyanide content. Tewe and Iyayi (1989) compared the HCN level in fresh, oven-dried and sun-dried cassava. The HCN levels in the root, pulp and peel were a maximum of approximately 416, 200 and 815 mg/kg, respectively in the fresh samples, 64, 31 and 1,250 mg/kg in the oven-dried samples and 42, 27 and 322 mg/kg in the sun-dried samples. Ravindran et al. (1987) found that fresh cassava leaves had an average HCN content of 1,436 mg/kg, but when they were sun-dried this was reduced to 173 mg/kg. Additionally, Khajarern et al. (1982) found HCN content was reduced from 111.83 to 22.97 mg/kg when cassava roots were sun-dried for 6 days. Gomez et al. (1984) found that more than 86% of HCN in cassava was lost by sun-drying due to evaporation of free cyanide at 28 °C.

Fermentation also reduces the cyanide content of cassava products. Fresh cassava root contains approximately 400 to 440 mg/kg HCN which can be reduced to 84 mg/kg by wet fermentation and 14 mg/kg by solid-state fermentation (Muzanila et al., 2000), and to 15 or 8 g/kg when turned into unfermented or fermented meal, respectively (Udedibie et al., 2004). Soaking of cassava roots preceding cooking and fermentation can enable heightened extraction of soluble cyanide by removing approximately 20% of free cyanide in the fresh root after 4 h (Tewe, 1991). Boiling cassava chips also removes some of the cyanide; approximately 90% of free cyanide is removed within 15 min of boiling and 55% of the bound cyanide is removed after 25 min of boiling (Cooke and Maduagwu, 1985). Okoli et al. (2012) found that there is great variation in the physiochemical and HCN contents of cassava processed by different methods. Samples that had been peeled, fermented and sun-dried had higher water holding capacity and digestible fibre compared with samples not exposed to these methods, and samples that has been oven toasted prior to milling had higher crude fibre and HCN values compared with samples that were not toasted (100 to 200 mg/kg compared with 5 to 15 mg/kg). In conclusion, there is not one optimum method for processing cassava, but rather a combination of different techniques is required based on the specific variety of the cassava.

## 5. Nutritive value of cassava for broilers

Wide variation has been observed between studies with regards to the success of feeding cassava meal to poultry. Early research, such as McMillan and Dudley (1941) and Vogt (1966), found that inclusion of cassava in poultry diets reduced performance. However later studies, such as Khajarern and Khajarern (1992), Aderemi et al. (2000) and Tewe and Egbunike (1992), found more encouraging results, likely due to increased awareness of how to balance the nutrients and the negative impact of HCN.

Feed intake of cassava products is limited in poultry by the palatability of cassava-based rations, due to its dustiness and bulkiness. This could be partially mitigated by processing the cassava-based diets further through pelleting or potentially addition of molasses or fat to improve texture and reduce dustiness, whilst simultaneously supplying essential fatty acids. Muller et al. (1974) and Oke (1978) reported that when cassava was fed in mash form, feed conversion and growth were lower compared with corn-based diets, but similar performance was observed between the two groups when the diets were pelleted. Ogbonna et al. (1996) found that pelleting cassava based diets significantly improved performance, and Adeyemi et al. (2008) found pelleting significantly improved nutrient retention and reduced abdominal fat pad weight, compared with feeding the same diets as mash. Pelleting does not however have any impact on HCN concentration (Panigrahi et al., 1992). The viscous nature of cassava, particularly at high temperatures, also causes reduced feed intake in birds fed cassava as the cassava material may create a gut-filling effect, reducing appetite.

The maximum recommended level of cassava meal that can be used in broiler diets varies greatly among studies. Osei and Duodu (1988) stated the recommended level should be 10% and Gomez et al. (1987) recommended 30%, but De Brum et al. (1990) suggested the level can be as high as 40% to 60%. Onjoro et al. (1998) found that when maize was completely replaced by fermented whole cassava meal there was a reduction in weight gain, but when 20% to 80% of the maize was substituted there was no effect on performance. Also, Kana et al. (2012) found that body weight (BW) was highest in birds fed diets in which 50% of the maize was replaced by cassava flour meal (with 3% palm oil and 1% cocoa husk), compared with birds fed diets of 100% or 75% maize or 100% cassava flour meal. Cassava meal can also potentially substitute other carbohydrate sources. For example, it was found that 15% cassava meal can substitute coconut meal in broiler diets with no negative effect on growth performance (Ravindran et al., 1986).

The high levels of cyanide and fibre and low energy in cassava leaves mean that its success as a substitute for maize is limited. Ironkwe and Ukanwoko (2012) found that final BW was significantly reduced and feed intake was increased when cassava leaves replaced over 50% of dietary maize. Also, Tang et al. (2012) found that substituting maize completely with cassava pellets or chips resulted in significantly reduced growth, non-starch polysaccharide and CP digestibility and ME utilisation in broilers. Lower levels of dietary cassava leaf can however potentially be used successfully in broiler diets. Montilla (1997) and Ravindran et al. (1986) found that cassava leaf meal can be included up to 15% to 20% in broiler diets without any negative impact on performance. Feeding a combination of cassava leaf meal with other cassava products has also been shown to result in no negative impact on broiler growth, feed conversion or carcass characteristics. Eruvbetine et al. (2003) found that broilers could be successfully fed a substitution of 10% half cassava root and half leaf meal. Abu et al. (2015) found that up to 20% inclusion of cassava leaf meal and 20% cassava peelings could be used as a replacement for maize and soybean meal. Body weight reduces significantly when broilers are fed whole cassava. Akinfala et al. (2002) observed that replacing maize with either 12.5% or 25% whole cassava plant resulted in reduced growth rate of 13% and 19% respectively in broilers. Ochetim (1991) also found completely replacing maize with sun-dried whole cassava resulted in a reduction in final average BW, from 1.91 to 1.72 kg. However feed efficiency in this study was not affected, and feeding sun-dried cassava reduced the cost of the feed by approximately 30%, and cost per kilogramme BW gain was lowered by approximately 26% (Ochetim, 1991). This suggests the focus should not be just on the effect of cassava on BW, but rather on the overall performance. It may be advantageous to use sun-dried cassava instead of maize due to the attractive economic return.

Onyimonyi and Ugwu (2007), Osei (1992) and Tewe and Egbunike (1992), among other researchers, state that cassava peel and peel meal can be successfully used in broiler diets up to a maximum inclusion level of 15%, although feed intake increases as the level of cassava increases. Other researchers have however found that levels higher than 15% can potentially be fed to broilers. Oyebimpe et al. (2006) found that 200 g/kg cassava peal meal could replace maize without any reduction in broiler performance. Additionally, Adeyemo et al. (2014) and Abubakar and Ohiaege (2011) concluded that the optimum level of cassava peels as a replacement for maize was 50%, based on observations of bird performance and the histology of broiler organs. It was found that there was a 20.6% reduction in the cost of production in birds fed the diets with 50% cassava peels compared with the birds fed 100% maize (Abubakar and Ohiaege, 2011). Dairo (2011) also found that cost of feed per kg and cost per kg flesh gained was lower and live weight, BW gain and protein efficiency were higher when broilers were fed diets containing 50% dried cassava peel and dried caged layers' manure, which was mixed at a ratio of 5:1 (wt/wt) and ensiled for 14 days, compared with birds fed diets of 100% maize.

Agwunobi and Okeke (2000) found in broiler chickens there was no significant difference in apparent metabolisable energy (AME) between 19 different cultivars of cassava. In poultry, the ME content of cassava root meal ranges from approximately 2.87 to 4.27 kcal ME/g DM (Khajarern and Khajarern, 2007). A number of studies, such as Eshiett and Ademosun (1980), Ekpenyong and Obi (1986) and Stevenson and Jackson (1983), have demonstrated that cassava root meal can be fed to broilers up to 50% without any negative effect on bird growth performance. Additionally, Gomez et al. (1983) found that performance of broilers fed 200 g/kg cassava root meal was similar to that of birds fed maize based diets, and Ezeh and Arene (1994) found that cassava root meal could replace up to 75% of dietary maize, resulting in a cost benefit ratio of 1.41:1 against maize. The opposite was however illustrated by Oso et al. (2014) in a study in which unpeeled cassava root meal was fed to broilers up to a level of 200 g/kg. It was found that live weight, weight gain, feed intake and crude protein digestibility decreased and serum glucose and cholesterol levels increased as the dietary cassava root meal level increased.

Efficiency of nutrient utilisation of cassava can be improved by using microbial enzyme supplements. Midau et al. (2011) found that a diet containing 50% cassava peel meal supplemented with a cocktail of enzymes (Maxigrain) resulted in performance values similar to that of a 100% maize diet. Also, Bhuyian et al. (2012) found that presence of carbohydrase and phytase significantly improved live weight and ME energy in birds fed diets containing cassava chips and pellets. The oil content of the cassava based diets may also influence efficiency. Kana et al. (2014) found that cost of feed consumed was reduced and bird growth was increased when diets containing cassava flour and fibre were supplemented with palm oil. Additionally, the efficacy of cassava in the bird likely varies with bird age. Mhone et al. (2008) observed a live weight of 2 kg and dressed carcass weight of 1.2 kg at week 7 when broilers were fed diets containing 20% cassava from either 2 or 6 weeks of age, but when birds were fed these diets from day old live weight and dressed carcass weight were lower.

## 6. Nutritive value of cassava for layers

Fewer studies have been conducted in layer chickens compared with broilers. As with broilers, the believed maximum level of cassava that can be used in layer diets varies greatly between studies, ranging from 30% to 50% of the diet (Eustace and Olumide, 1994; Garcia et al., 1994; Enyenihi et al., 2009; Tesfaye et al., 2014). Cassava toxicity in layers results in reduced egg production, egg quality, shell thickness and hatchability.

Production performance in birds at pullet and laying stage has been found to be similar, and in some cases better, when cassava meal is used as an energy source instead of maize (Khajerern and Khajarern, 1986). Maize and cassava have similar effects on laying rate and egg quality. Saparattananan et al. (2005) reported egg yolk colour score to be lower in eggs from birds fed diets containing cassava. Aderemi et al. (2012) found that birds fed diets containing over 25% cassava meal (dried and ground root, leaves and stems) showed reduced feed intake, feed efficiency and hen day production, but presence of cassava meal had no impact on gut morphology, shell thickness or albumen. Aina and Fanimo (1997) also found that layers fed cassava meal has reduced daily egg production, but the levels of cassava in the diet had no impact on egg weight, feed intake, shell thickness or feed efficiency. Potential positive effects of inclusion of cassava in layer diets are that it could possibly reduce cholesterol content of the plasma and egg (Idowu et al., 2005) and it has been shown to reduce abdominal fat content in layers after 40 weeks in lay (Eruvbetine, 1995).

Feeding cassava peelings to layers at a level up to 27% of the diet improves egg production and also increases feed per unit egg produced (Sonaiya and Omole, 1977; Tewe and Egbunike, 1992). Obioha et al. (1984) found that when layers were fed diets with cassava peel meal at 100 and 200 g/kg egg production, egg weight and feed conversion was similar to birds fed maize diets, but when birds were fed 300 or 400 g/kg cassava peel meal performance was comparatively lower. The method of processing cassava peel meal however has a significant impact on its success as a replacement for maize. Salami and Odunsi (2003) observed the response of layers to cassava peel meal that was either ensiled, parboiled, retted or sun-dried. It was found that retted cassava peel meal could replace up to 75% of the maize, but cassava peel meal processed by any other method could not replace maize beyond 50% without negative consequences on hen-day production or egg weight.

Cassava root products are deficient in carotene and most carotenoids, meaning supplementation of these ingredients is required in cassava-based diets for maintenance of normal egg yolk (Khajarern and Khajarern, 2007). This could potentially be overcome by adding cassava leaves in the diet. Anaeto and Adighibe (2011) found that average BW and hen-day production was significantly lower in birds fed 75% or 100% cassava root meal and egg weight was lower in birds fed 100% cassava root meal as a replacement for maize. Also, Raphaël et al. (2013) found that replacing maize with cassava root meal in pullet diets had no negative effect on feed consumption, egg production, production cost, egg weight or hen age at first laying, but BW reduced as level of cassava increased. The problems with feeding cassava root to layers could however potentially be overcome if it is fermented by *Aspergillus niger* prior to feeding. A study conducted by Panigrahi (1996) stated that low-cyanide cassava root meals are able to be incorporated into poultry diets between 500 and 600 g/kg without reduced weight gain or egg production. Cyanide levels of 100 mg/kg have a negative effect on broiler performance and as low as 25 mg/kg can have a negative effect on layer production, egg quality and hatchability of the eggs (Ezeala and Okoro, 1986; Fakir et al., 2012).

## 7. Nutritive value of cassava for ducks, geese and guinea fowl

A number of studies have been conducted to observe the responses of ducks, geese and guinea fowl to dietary cassava. Phith and Montha (2007) concluded from a study on Cambodian and Pekin ducks that cassava leaves can be included up to 15% in duck diets without affecting growth rate or feed conversion. It was also observed that nitrogen retention and digestibility coefficients of dry matter, organic matter and nitrogen were comparatively higher in diets containing cassava leaves compared with those without cassava leaves. Borin et al. (2006) also observed that weight of the small intestine, caeca, gizzard and pancreas in Cambodian ducks and White Pekin ducks increased with increasing dietary cassava leaf meal content.

Replacing maize with cassava appears to have a positive impact on duck performance. Saree et al. (2012) found that from 0 to 16 days of age Cherry Valley ducks fed cassava diets had improved BW and BW gain, average daily gain and feed conversion compared with those fed maize. Cost of feed per gain was also significantly reduced in birds fed the cassava diets. In older birds (17 to 47 days) feed intake and gizzard size were comparatively higher in the birds fed the cassava based diets. Sahoo et al. (2014) observed the performance in White Pekin ducklings when maize was replaced with differing levels of water soaked and untreated cassava tuber meals. Significantly higher growth rates and lower FCR was observed in birds fed the water-soaked cassava tuber meal diets compared with those fed the diets without cassava or with untreated cassava tuber meals. Additionally, significantly higher percentage of breast meat yield was also observed in this study in the birds fed the diets with 40% or 60% water soaked or 40% raw cassava tuber meal compared with those fed the control diet. No differences were seen between the treatments for apparent metabolisability of dry or organic matter or crude protein or energy.

Inclusion of cassava into diets for geese appears to have little effect on their performance. Sahle et al. (1992) found that inclusion of up to 450 g/kg cassava meal in geese diets had no significant effect on bird performance and carcass quality, although protein digestibility decreased with increasing levels of cassava meal. It was observed in this study that AME and nitrogen corrected true metabolisable energy (TMEn) of cassava meal were 12.48 and 12.59 MJ/kg respectively in growing geese at 9 weeks of age. Yang et al. (2010) observed no significant difference for nutrient digestibility, growth performance or serum parameters when geese were fed diets in which the maize was replaced with cassava meal at ratios up to 75%. The AME of cassava residue was shown to be 3.73 MJ/kg in Yangzhou geese (Li et al., 2015).

Feeding cassava leaves and chips to guinea fowl was shown to be profitable with regards to feed cost and production, particularly in the finishing period (Dahouda et al., 2009). In this study, it was observed that cassava chips and leaves had no negative influence on carcass quality or feed conversion, and feed cost per kg live weight gain was reduced by approximately 25% in the birds fed the cassava based diets compared with the control group.

## 8. Conclusion

There is a continuous demand for alternative energy sources for poultry due to insufficient supply, high prices and competition with the human food and biofuel industries. Cassava is already viewed as a valuable feed ingredient in pig and poultry diets in some parts of the world, namely South East Asia, and it is becoming increasingly more important worldwide because of its high availability and high digestible starch content. Cassava could potentially be substituted quantitatively up to 50% for maize in poultry diets without adverse effects on bird performance. It must however be processed first, by methods such as drying, boiling and fermentation, to reduce the HCN content to non-toxic levels. Also, diets containing cassava must be formulated with care, particularly with regards to the balance of limiting amino acids, vitamins and minerals and essential fatty acids. Extensive research has been conducted on cassava products for feeding poultry, but these products have not been fully adopted in the commercial poultry feed industry. This is likely due to a lack of consistency amongst the measured nutritive values of cassava and its products, hence variation exists in results from poultry studies. Future research should aim to improve its potential as an energy source by observing responses in birds fed cassava products in varying forms and feed formulations, grown and processed in different conditions, and in the presence of different enzyme combinations.

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