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Review article

Cassava chip (*Manihot esculenta* Crantz) as an energy source for ruminant feeding

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ABSTRACT

Cassava (*Manihot esculenta* Crantz) is widely grown in sub-tropical and tropical areas, producing roots as an energy source while the top biomass including leaves and immature stems can be sun-dried and used as cassava hay. Cassava roots can be processed as dried chip or pellet. It is rich in soluble carbohydrate (75 to 85%) but low in crude protein (2 to 3%). Its energy value is comparable to corn meal but has a relatively higher rate of rumen degradation. Higher levels of non-protein nitrogen especially urea (1 to 4%) can be successfully incorporated in concentrates containing cassava chip as an energy source. Cassava chip can also be processed with urea and other ingredients (tallow, sulfur, raw banana meal, cassava hay, and soybean meal) to make products such as cassarea, cassa-ban, and cassaya. Various studies have been conducted in ruminants using cassava chip to replace corn meal in the concentrate mixtures and have revealed satisfactory results in rumen fermentation efficiency and the subsequent production of meat and milk. In addition, it was advantageous when used in combination with rice bran in the concentrate supplement. Practical home-made-concentrate using cassava chip can be easily prepared for use on farms. A recent development has involved enriching protein in cassava chips, yielding yeast fermented cassava chip protein (YEFECAP) of up to 47.5% crude protein, which can be used to replace soybean meal. It is therefore, recommended to use cassava chip as an alternative source of energy to corn meal when the price is economical and it is locally available.

1. Introduction

Livestock production in tropical areas plays a crucial role, which extends beyond its traditional supply of meat and milk. Livestock are used for multiple purposes as draft power, means of transportation, capital, credit, meat, milk, social value, hides, and provide a source of organic fertilizer for seasonal cropping. Ruminants can utilise agricultural crop residues and farm by-products that are abundantly available (Wanapat and Kang, 2013a; Jetana and Bintbihok, 2013). Cassava (*Manihot esculenta* Crantz) is an annual crop grown widely in the tropical and subtropical regions. It thrives well in sandy-loam soils with low organic matter, and in climates with low rainfall and high temperature. Cassava roots have high levels of energy (75 to 85% of soluble carbohydrate) and minimal levels of crude protein (2 to 3% CP); they have been used as a source of readily-fermentable energy (Kang et al., 2015; Polyorach et al., 2013; Wanapat et al., 2013a, 2013b), while the top growth could be harvested at four months initially and at 2 to 3 month intervals subsequently. The leaves and green stems are chopped and sun-dried to reduce their moisture and hydrocyanic acid (HCN) content to produce cassava hay (CH), which has been used as a ruminant feedings successfully (Wanapat, 2000, 2003; Lunsin et al., 2012). Harvesting of cassava leaves at an early growth stage (3 months) to make hay could reduce the condensed tannin (CT) content and increase the protein content (25% of DM) resulting in a higher nutritive value (Wanapat et al., 1997). Root yield is about 50 t/h and when processed into dried

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chip, it will be about 15 to 20 t/h. If the whole plant is harvested for hay making after 4 months after planting, it can be harvested when reaching one year, in this case the root yield will be reduced about 15% from the original yield.

Furthermore, establishment and development of food-feed-systems (FFS) under small-holder livestock farming systems have also been developed (Wanapat et al., 1997, 2013c). The FFS has been developed as an integrated livestock-crop production system where crops are grown on farms and the product is harvested for human consumption and the crop-residues or by-products of such crops are used as feeds for livestock. The use of legumes in such a system used can enrich soil fertility and enhance the crop productivity. A good example of such a system can be seen in the integrated dairy-cassava system with cowpea or *Phaseolus calcaratus* where CH can be produced as dairy feed (Wanapat, 1999; Wanapat et al., 2000a, 2006; Chanthakhoun et al., 2008). The expansion and intensification of these systems is a realistic objective, given the extent of farmer experience, the periodic collapse of world prices for plantation commodities and the projected demands for animal products in the future (Devendra, 2002).

2. Planting, cultivation and cutting of cassava

Studies by Wanapat et al. (1997; 2000a; 2000b; 2000c; 2000d) have revealed the details of planting cassava for hay making. This procedure is designed to increase the whole crop digestible biomass while roots were considered as a by-product. Earlier work by Wanapat et al. (1997) demonstrated that planting cassava at 60 × 40 cm and intercropping between the rows with cowpea or *Leucaena* could enrich soil fertility and the leaves could be used as food and feed for human and livestock, respectively. The initial cutting of leaves three months after planting, followed by subsequent cuttings at two-month intervals involved hand breaking of the young stem about 20 to 30 cm above the ground (with 3 to 5 remaining branches). The fresh whole tops were either directly sun-dried or were chopped before sun-drying to obtain 80 to 90% dry matter content. This might take 2 to 3 days, but chopping helps to shorten the drying process. Sun-drying also eliminated more than 90% of HCN, enhanced the palatability and enabled long-term storage. Plant spacing and frequency of cuttings have been shown to affect the total yield of CH (Polthanee et al., 2001; Wanapat and Kang, 2013b).

3. Cassava chip (CC)

According to Wanapat and Kang (2013b), recent attempts have been made to develop new products using CC as an energy source with urea (U) as a non-protein nitrogen (NPN) source. Two new cassava based products have been developed, cassarea, cassaya and cass-ban. Different form of cassarea have been formulated to contain the following ingredients: 57.1% CC + 9.9% U and 3% tallow (Cassarea I, 30% CP); 83.6% CC + 13.4% U and 3% tallow (Cassarea II, 40% CP); 80.2% CC + 16.8% U and 3% tallow (Cassarea III, 50% CP). Cassareas were tested for rumen degradability using a nylon bag technique and were found to have 46.2 to 56.7% effective DM degradability. Further investigations with cassarea II (40% CP) showed that it could be used to replace soybean meal (SBM) in the rations of lactating cows, but supplementation with a rumen by-pass protein such as cottonseed meal would be recommended. Cassaya (30% CP) was a product formulated using chopped whole cassava crop hay (85%) + SBM (5%) + CC (5%) + U (2%) + tallow (2%) + sulfur (1%), mixed with water, pressed through a pelleting machine and sun-dried to at least 85% DM. The use of cassaya in lactating dairy cows as a protein source proved to be efficient in promoting rumen fermentation, improved milk yield and composition, and in providing an increased economic return. Cass-ban was formulated by using cassava chip (56.6%) + raw banana (37.7%) + urea (5.7%). Feed intake, end-products of ruminal fermentation, ruminal microorganisms, milk yield and quality and economical return were enhanced by supplementation of cass-ban (Lunsin et al., 2010).

Chanjula et al. (2007a) conducted a study to assess effect of levels of U and CC on feed intake, rumen ecology, blood metabolites and microbial populations in growing male goats. It was reported that higher levels of U (3%) could be used with high levels of CC as a concentrate without altering feed intake, rumen ecology, blood metabolites or animal performance when compared with control diets. Increasing levels of U in the diet was associated with higher ruminal NH_3−N but did not affect physiology and was adequate for microbial growth. It is a potential approach to exploiting the use of local feed resources. Moreover, Chanjula et al. (2007b) also reported that cassava was a good source of ruminal degradable starch in replacing corn grain and had the potential to improve goat performance. The optimal inclusion of cassava in replacing corn is suggested to be between 25 and 75% of CC (12.5 to 37.50 kg) in concentrate. There was no evidence of any adverse effects on feed intake, digestibility, rumen fermentation patterns, blood metabolites, rumen microbes and nitrogen balance or animal health when fed fresh elephant grass. Based on this data, it would be desirable to conduct further research on the use of CC in practical rations for small ruminant feeding systems (Table 1).

Based on Chanjula et al. (2004) reported that providing a non-structural carbohydrate (NSC) source from cassava-based diets did not affect feed intake, rumen ecology, rumen microorganisms, milk production and composition, and animal performance compared with corn-based diets, but tended to improve milk fat (Table 2). These results indicated that feeding diets containing up to or more than 75% of DM, with NPN supplied by U>3% DM (3.3 to 4.5% DM) can be used in dairy rations without altering rumen ecology or animal performance compared with corn-based diets.

The results of the study of Chanjula et al. (2003) demonstrated that the ruminal disappearance characteristics of seven feeds differed among feeds and that CC had the greatest retention time (Table 3). The content of DM and OM disappearance ranked from the highest to the lowest of rate of degradation (c) were as follows: CC, yellow sweet potato, purple sweet potato, white sweet potato, cassava waste, corn meal and rice bran, respectively. These values could potentially be used in synchronizing degradation with the availability of NPN in the rumen to optimize ruminal availability of energy : protein to maximize microbial protein synthesis.

4. Yeast fermented cassava chip protein (YEFECAP)

Cassava chip or other forms of cassava roots can be successfully fermented with yeast (*Saccharomyces cereviceae*) to obtain a final product with high CP and a relatively balanced profile of amino acids (Poungchompu et al., 2009; Polyorach et al., 2012; Wanapat et al., 2013c). The amino acid profile of the YEFECAP is presented in Table 4, with high levels of lysine, glutamic acid, leucine and phenylalanine. Supplementation of YEFECAP in replacement for SBM in concentrates for lactating dairy cows resulted in very good milk yields (15.7 kg/d) (Wanapat et al., 2011a).

Dietary yeast can be used as a ruminant feed especially *Saccharomyces cerevisiae* because the yeast cell contains nutrients that are rate limiting especially for ruminant production and the high lysine content is particularly important (7.6 ± 0.7 g/16 g N) (Polyorach et al., 2012; Nelson et al., 1959; Polyorach et al., 2013). Addition of yeast to ruminant diets can not only improve the rumen environment but also enhance microbial activity especially cellulolytic activities, which increases their total number, fiber digestion, reduces lactate accumulation and concentration of oxygen in rumen fluid and improves utilization of starch (Robinson, 1997; Lila et al., 2004). Moreover,

Table 1
Use of cassava chip as an energy source in the diet of goat.[1]

Item	Sources of data	
	Chanjula et al. (2007a)	Chanjula et al. (2007b)
	Cassava chip incorporated with urea	Cassava chip replacement for corn meal
DM intake	ns	ns
Rumen ecology		
pH	ns	ns
NH_3–N	↑	↓
Total VFA	–	ns
C_2	–	ns
C_3	–	ns
C_4	–	ns
BUN	ns	↑
Microbe		
Bacteria	ns	ns
Protozoa	ns	ns
Fungi	ns	ns
N balance		
Excretion	–	↓
Absorption	–	ns
Retention	–	↑

NH_3–N = ammonia nitrogen; VFA = volatile fatter acid; C_2 = acetic acid; C_3 = propionic acid; C_4 = butyric acid, BUN = blood urea nitrogen.
[1] ns = non-significant; ↓, decrease; ↑, increase.

Table 2
Use of cassava chip as an energy source in the diet of dairy cow.[1]

Item	Sources of data[2]
	Cassava chip incorporated with urea
DM intake	↑
Digestibility	↓
Rumen ecology	
pH	ns
NH_3–N	↑
BUN	ns
Microbe	
Bacteria	↑
Protozoa	ns
Fungi	ns
Milk production	
Milk yield	ns
Milk fat	ns
Lactose	ns
Milk protein	ns
Solids not-fat	ns
Total solids	ns

NH_3–N = ammonia nitrogen; BUN = blood urea nitrogen.
[1] ns = non-significant; ↓, decrease; ↑, increase.
[2] Source: Chanjula et al. (2004).

S. cerevisiae also stimulates DM intake and productivity in growing and lactating cattle (Robinson and Garrett, 1999), improved microbial protein synthesis and milk production of dairy cows (Strohlein, 2003; Hristove et al., 2010). However, Desnoyers et al. (2009) reported that highly variable effects of live *S. cerevisiae* cultures could be associated with changing in the ratio of forage and concentrate used. Cassava chip is an energy source with low CP, to which when fermented with yeast could increase CP from 1 to 3% CP to 30.4% CP (Boonnop et al., 2009). Recently, Polyorach et al. (2012, 2013; 2014) reported that YEFECAP could be prepared to increase CP levels up to 47%. The YEFECAP preparation process according to the method of Polyorach et al. (2013) is shown in Table 4 and Fig. 1.

The beneficial use of YEFECAP has been evaluated by Boonnop et al. (2010) and Wanapat et al. (2011a, 2011b). Boonnop et al. (2010) studied the effect of replacement of SBM by YEFECAP on rumen ecology and nutrient digestibility in dairy crossbred steers.

Table 4
Chemical composition of yeast fermented cassava chip protein (YEFECAP) detergent fiberyeast fermented cassava chip products.[1]

Item	YEFECAP	Cassava chip
Dry matter	90.6	90
Chemical composition, % of dry matter		
Organic matter	97.2	97.3
Crude protein	47.5	2.4
Ether extract	7.9	–
Neutral detergent fiber	6.1	10.0
Acid detergent fiber	4.3	5.0
Amino acid profile, mg/100 g of YEFECAP		
Alanine	70.5	
Arginine	5.0	
Aspartic acid	69.9	
Cystine	5.0	
Glutamic acid	189.4	
Glycine	52.7	
Histidine	55.4	
Hydroxylysine	5.0	
Hydroxyproline	5.0	
Isoleucine	130.8	
Leucine	201.5	
Lysine	481.1	
Methionine	16.3	
Phenylalanine	167.8	
Proline	47.9	
Serine	29.8	
Threonine	21.0	
Trytophan	15.1	
Tyrosine	87.2	
Valine	92.6	

[1] Source: Polyorach et al. (2012).

Table 3
Dry matter (DM) and organic matter (OM) disappearance in the rumen at various incubation times in crossbred beef steers.[1]

Item[2]	CC	YP	WP	PP	RB	CW	CM	CV, %
DM disappearance, %								
a	61.5^a	47.4^b	37.7^c	28.5^d	20.7^e	19.7^e	17.4^f	2.8
b	37.8^e	50.2^d	59.5^c	69.0^a	66.8^b	58.9^c	64.3^b	2.0
c	0.23^a	0.21^b	0.16^c	0.20^b	0.05^e	0.13^d	0.06^e	10.4
a + b	99.3^a	97.6^{ab}	97.5^{ab}	97.2^b	87.5^c	78.6^e	81.7^d	0.9
Effective degradability, %	92.5^a	87.9^b	87.9^b	87.8^c	63.6^c	63.0^c	59.3^d	1.6
OM disappearance, %								
a	65.0^a	60.4^b	45.3^c	39.8^d	25.0^e	18.4^f	24.1^e	2.3
b	34.4^e	38.4^b	53.1^c	58.7^b	67.4^a	66.6^a	59.5^b	1.6
c	0.26^a	0.24^a	0.18^b	0.22^a	0.05^c	0.13^c	0.07^d	12.6
a + b	99.4^a	98.8^a	98.5^a	98.4^a	92.4^c	85.1^c	83.6^d	1.0
Effective degradability, %	93.4^a	89.8^b	98.4^b	88.1^c	65.8^d	66.9^d	63.3^e	0.7

CC = cassava chip; YP = yellow sweet potato; WP = white sweet potato; PP = purple sweet potato; RB = rice bran; CW = cassava waste; CM = cornmeal; CV = coefficient of variation.
[a-f] Within rows values not sharing common superscripts are significantly different ($P < 0.05$).
[1] Source: Chanjula et al. (2003).
[2] a, the gas production from the immediately soluble fraction; b, the gas production from the insoluble fraction; c, the gas production rate constant for the insoluble fraction (b); a + b, the gas potential extent of gas production.

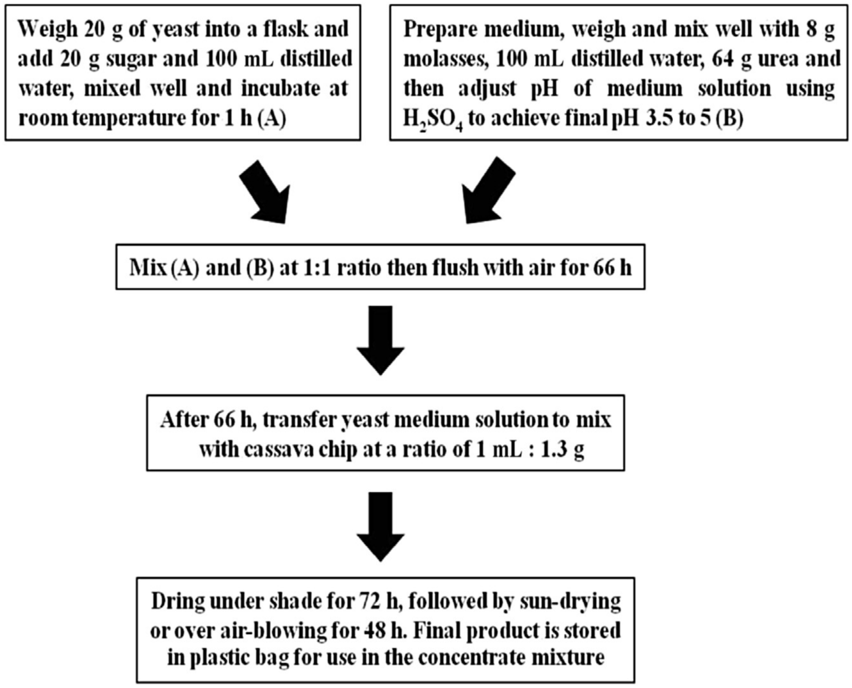

Fig. 1. Process chart for yeast fermented cassava chip products (YEFECAP) preparation. Source: Polyorach et al. (2013).

It was found that YEFECAP could completely replace SBM and was beneficial to cattle in terms of efficiency of rumen fermentation, microbial protein synthesis, nitrogen retention and nutrient digestibility. Khampa et al. (2010) reported that YEFECAP could replace 75% of concentrate and improved ruminal fermentation efficiency, average daily gain and reduced cost of production in daily heifers. Supplementation with YEFECAP also increased the population of bacteria and fungal zoospores, but decreased the population of Holotrich and Entodiniomorph protozoa in the rumen of dairy steers (Khampa et al., 2009). Polyorach et al. (2010) and Wanapat et al. (2011a, 2011b) revealed that replacing SBM with YEFECAP at rate of 0, 33, 67 and 100% enhanced milk yield, milk fat and milk protein and was the highest at 100% of replacement. Moreover, Wanapat et al. (2011b) compared from 4 sources of protein in concentrate diets, SBM, CH, *Leucaena leucocephala* (LL) and YEFECAP in lactating dairy cows and found that CP digestibility was the highest when supplementing with CH and YEFECAP. Propionic acid were found the highest in cows receiving CH and YEFECAP, while ruminal fungi, proteolytic and cellulolytic bacteria were the highest with YEFECAP supplement, milk fat and milk protein were significantly increased in cows offered CH and YEFECAP. Based on these studies, YEFECAP can practically prepared and used as an alternative protein source for ruminant feeding (Table 5).

Wanapat et al. (2011a, 2011b) and Promkot et al. (2013) reported on the study of using YEFECAP (in replacing SBM) in concentrate mixtures for early lactation cows. It was found that YEFECAP can fully replace SBM in concentrate mixtures while enhancing rumen fermentation, dry matter intake, nutrient digestibility, milk yield and composition. A summary of the above research data is shown in Table 6.

Table 6
Effect of yeast fermented cassava chip products (YEFECAP) as a protein source in concentrate mixtures for cow early lactation on milk production, milk composition and economic return.[1]

Item	Treatments[2]				SEM	Contrasts
	T1	T2	T3	T4		
Production, kg/d						
Milk yield	13.5	14.0	14.5	15.0	0.27	**
3.5% FCM	13.7	14.7	15.9	17.1	0.49	**
Milk composition, %						
Protein	4.0	4.1	4.5	4.7	0.17	**
Fat	3.2	3.3	3.4	3.5	0.06	**
Lactose	4.5	4.6	4.6	4.7	0.07	ns
Solids-not-fat	8.2	8.4	8.4	8.5	0.29	ns
Total solids	12.3	12.7	12.8	13.0	0.78	ns
Milk urea N, mg/dL	14.8	12.5	12.3	12.0	0.58	*
Economic return, $US/(cow·d)						
Feed cost	2.5	2.6	2.6	2.7	0.14	ns
Milk sale	9.5	9.8	10.2	10.5	0.19	**
Profit	7.0	7.2	7.6	7.8	0.16	**

SEM = standard error of means; FCM = fat corrected milk.
$^*P < 0.05$; $^{**}P < 0.01$; ns = non significant.
[1] Source: Wanapat et al. (2011a).
[2] Replacement levels of soybean meal by YEFECAP at 0, 33, 67 and 100% in concentrates T1, T2, T3, and T4, respectively.

Table 5
Effect of using yeast fermented cassava chip products (YEFECAP) as a protein source in ruminants.[1]

Animal	DMI	Dig.	TVFA	C_2	C_3	C_2:C_3	Bact.	Pro.	Fung	MSP	Milk			Reference[2]
											Yield	Fat	Protein	
Lactating dairy cows	↑	↑	↑	nc	↑	↓	↑	nc	↑	nd	↑	↑	↑	Wanapat et al. (2011a)
Dairy steers	↑	↑	↑	↓	↑	↓	↑	↓	↑	↑	nd	nd	nd	Boonnop et al. (2010)
Lactating dairy cows	ns	↑	↑	nc	↑	nd	↑	↓	↑	nd	nc	↑	↑	Wanapat et al. (2011b)

DMI = dry matter intake; Dig. = digestibility; TVFA = total volatile fatty acid; C_2 = acetate; C_3 = propionate; C_2:C_3 = proportion of acetate to propionate; Bact. = bacteria; Pro. = protozoa; MPS = microbial protein synthesis.
[1] ↑, increase; ↓, decrease from control group; nd = not determined; nc = no change.
[2] Yeast fermented cassava chip products replacement of soybean meal in concentrate diet.

5. Conclusions

Based on this review, it can be concluded that cassava chip, and its' processed products are useful as an energy source especially when used with urea to improve ruminant productivity. Its relied availability in the tropical and sub-tropical regions facilitates practical use in ruminant production systems.

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