# THE ROLE OF CASSAVA HAY AS ANIMAL FEED

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## ABSTRACT

Cassava (*Manihot esculenta* Crantz) has been nutritionally evaluated as a protein source for animal feeding. Planting cassava densely and harvesting the unlignified top portion of the plant about 20 cm above the ground at 3-4 months after planting, followed by subsequent harvests every two months for one year could produce high forage biomass. Moreover, intercropping cassava with leguminous crops such us cowpea, peanut or *Leucaena leucocephala* could enrich the soil and further increase cassava leaf biomass. After harvesting, the cassava leaf biomass could be sun-dried for 2-3 days to obtain dry (85% dry matter) cassava forage, also called "cassava hay". Sun drying reduces the hydrocyanic acid content by more than 90% and this results in good quality cassava hay. Cassava hay contains about 25% crude protein with a relatively good profile of amino acids as compared with soybean meal and alfalfa hay. Furthermore, cassava hay contains only 2-4% condensed tannins as compared to more than 6% in mature cassava leaves at time of root harvest. Producing cassava hay as a high-protein fodder is a means of increasing the protein to energy ratio of the whole cassava crop.

Feeding trials with cattle indicate the high levels of dry matter (DM) intake (3.2% of body weight) and high DM digestibility (71%). The hay contains tannin-protein complexes which could act as rumen by-pass protein for digestion in the small intestine. As cassava hay contains condensed tannins, it could have a subsequent impact by changing the rumen ecology, particularly the rumen microbial population. Therefore, supplementation with cassava hay at 1-2 kg/head/day to dairy cattle could markedly reduce the requirements of concentrate and improve the yield and composition of milk. Moreover, cassava hay supplementation in dairy cattle increases the milk thiocyanate content, which could possibly enhance milk quality and milk storage, especially in small-holder dairy farming. Condensed tannins contained in cassava hay have also been shown to reduce gastro-intestinal nematodes in ruminants and therefore could act as an anthelmintic agent. Cassava hay is therefore an excellent multi-nutrient feed resource for animals, and has the potential to increase the productivity and profitability of livestock production systems in the tropics.

## INTRODUCTION

Cassava (*Manihot esculenta* Crantz*)* is an annual root crop grown widely in tropical and sub-tropical areas. It can thrive in sandy-loam soil with low organic matter, receiving low rainfall and high temperatures. It is therefore a cash crop cultivated by small-holder farmers within the existing farming systems in many countries (Wanapat, 1999).

Cassava roots contain high levels of energy and minimal levels of crude protein, and have been used as readily fermentable energy in ruminant rations. Cassava leaves have been used as a protein source when collected at root harvesting time. However, the intake and digestibility was low due to the high level of condensed tannins (Reed *et al*., 1982; Onwuka, 1992). The role of tannins in tropical animal production has been currently presented (Brooker *et al*., 2000; Norton, 2000). Harvesting of cassava at an early growth stage (3 months) to make hay could reduce the condensed tannin content and increase the protein content (25% of DM) resulting in a higher nutritive value (Wanapat, 2003; Wanapat *et al*., 1997).

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## Production of Cassava Leaves and Cassava Hay

The studies by Wanapat *et al*. (1997, 2000a, 2000b, 2000c, 2000d) have revealed the details of planting and cassava hay making. Planting cassava for hay making was aimed to increase the whole crop digestible biomass and the roots as a by-product. Earlier work by Wanapat *et al*. (1997) demonstrated that planting cassava at 60x40 cm between rows and intercropping with cowpea or *Leucaena* could enrich soil fertility and the intercrops could be used as food and feed for humans and livestock, respectively. The initial cutting was made at three months and this was followed by subsequent cuttings at two month intervals by breaking of the stem by hand about 20-30 cm above the ground (with 3–5 remaining branches). The fresh tops were directly sun-dried or chopped before sun-drying until a DM content of 80-90%. This might take 2-3 days, but chopping helps to shorten the drying process. Sun-drying also eliminated more than 90% of hydro-cyanic acid (HCN) and enhanced the palatability and long-term storage. Intercropping cassava with leguminous crops such as cowpea could improve soil fertility and provide food for human consumption, while the residue could be used as supplemental feed, especially during the dry season (Polthanee *et al*., 2001). Plant spacing and frequency of cuttings have been shown to have a significant affect on the combined yield of cassava hay (Petlum *et al.*, 2001). Furthermore, planting pattern, either with or without ridging as well as manure fertilization, could affect cassava hay production (Puangchompoo *et al*., 2001) (**Table 1**). Protein yield of cassava hay has been reported to range from 1.5–1.7 t/ha from six collective harvests (Wanapat *et al*., 2002).

**Table 1. Effects of planting method and fertilization on cassava hay yield.**

| | With ridges | | Without ridges | | |
|---|---|---|---|---|---|
| Item | Without manure | With manure | Without Manure | With manure | SEM[1] |
| **Fresh leaf yield (t/ha)** | | | | | |
| First cutting | 3.7 | 4.0 | 3.8 | 3.5 | 0.26 |
| Second cutting | 3.1 | 3.1 | 3.1 | 3.3 | 0.31 |
| Third cutting | 6.0 | 7.7 | 5.7 | 7.8 | 0.54 |
| Fourth cutting | 5.6 | 4.7 | 5.6 | 4.6 | 0.27 |
| Fifth cutting | 2.7 | 3.0 | 2.8 | 3.5 | 0.19 |
| Sixth cutting | 0.7 | 0.8 | 0.4 | 0.9 | 0.11 |
| ***Total fresh yield*** | ***21.8*** | ***23.3*** | ***21.4*** | ***23.5*** | ***0.54*** |
| **Dry leaf yield (t/ha)** | | | | | |
| First cutting | 1.1 | 1.2 | 1.1 | 1.1 | 0.08 |
| Second cutting | 1.0 | 0.9 | 1.0 | 1.0 | 0.09 |
| Third cutting | 1.8 | 2.3 | 1.5 | 2.2 | 0.17 |
| Fourth cutting | 1.7 | 1.4 | 1.6 | 1.3 | 0.08 |
| Fifth cutting | 0.9 | 1.0 | 0.9 | 1.1 | 0.05 |
| Sixth cutting | 0.3 | 0.3 | 0.2 | 0.3 | 0.05 |
| ***Total dry yield*** | ***6.7*** | ***7.1*** | ***6.3*** | ***7.0*** | ***0.17*** |
| **Crude protein yield (t/ha)** | **1.5** | **1.7** | **1.5** | **1.7** | |

[1] SEM = standard error of the mean; there were no significant interactions

***Source:*** *Puangchompoo et al., 2001.*

**Table 2** shows the dry matter yield of leaf, petiole and stem when harvested at four months after planting. High levels of DM yield were obtained (Wanapat, 2002, unpublished data).

**Table 2. Fresh yield of cassava foliage of Rayong 72[1] harvested at 4 months after planting at Khon Kaen University, Khon Kaen, Thailand.**

| | | % DM | Fresh weight (g) | Dry weight (g) | % of total cut DM | Dry weight (kg/ha) |
|---|---|---|---|---|---|---|
| Leaf | P1 | 27.5 | 16.7 | 4.6 | 13.5 | 120 |
| | P2 | 30.5 | 41.9 | 12.8 | 37.4 | 336 |
| | P3 | 37.9 | 44.4 | 16.8 | 49.1 | 430 |
| | **Total** | | **103.0** | **34.2** | **61.6**[2] | **880** |
| Petiole | P1 | 14.1 | 7.7 | 1.1 | 9.9 | 32 |
| | P2 | 20.4 | 21.8 | 4.4 | 39.6 | 116 |
| | P3 | 22.1 | 25.5 | 5.6 | 50.5 | 142 |
| | **Total** | | **55.0** | **11.1** | **20.0**[2] | **290** |
| Stem | P1 | 10.5 | 4.5 | 0.5 | 4.9 | 14 |
| | P2 | 17.4 | 14.9 | 2.6 | 25.5 | 65 |
| | P3 | 20.1 | 35.1 | 7.1 | 69.6 | 185 |
| | **Total** | | **54.5** | **10.2** | **18.4**[2] | **264** |
| **Grand total** | | | **212.5** | **55.5** | | **1,434** |

1) Cassava tops harvested approximately 40 cm above the ground and separated into three portions:
P1 = light green and reddish colored young leaves, top part
P2 = green leaves, middle part
P3 = dark green leaves, lower part
2) Percentage of total biomas/cut
***Source:*** *Wanapat et al., 2002, unpublished data.*

The chemical composition of leaves and hay are presented in **Table 3**. It can be seen that cassava leaves/hay contain high levels of nutrients, especially high levels of protein. Harvesting of tops at an earlier stage, followed by subsequent cuttings at two month intervals resulted in a significantly higher protein to energy ratio (**Tables 3** and **4**).

## Nutritive Value of Cassava Hay

It has been found that cassava hay harvested at a younger stage of growth (three months) had a protein content up to 25% and with a good profile of amino acids. As presented in **Table 3** and **Figure 1**, cassava leaves and cassava hay have relatively high levels of nutrients particularly protein and certain amino acids. Comparing cassava leaves (CL) and cassava hay (CH) with soybean meal (SBM) and alfalfa hay (AH), the amino acid profiles were rather similar. Lysine, glutamine, asparagine and arginine were higher in SBM, but methionine and leucine were higher in CH. Condensed tannins and hydrocyanic acid (HCN) concentrations were low in both CL and CH. Sun-drying remarkably reduced the HCN content (Wanapat *et al.*, 2000a; Wanapat, 2002). Digestibility and intake studies in cattle resulted in relatively high values, which indicate that cassava hay is palatable and highly digestible. Levels of condensed tannins (CT) were generally higher in mature cassava leaves than in cassava hay harvested at a younger stage. Barry and Manley (1984) and Reed (1995) reported that if condensed tannins in the feed exceeded 6% of dry matter, it would reduce feed intake and digestibility. If the level of condensed tannins was between 2 and 4% of DM, it would help to protect protein from rumen digestion and thus increase by-pass protein.

**Table 3. Chemical compositions of dried cassava leaves and hay[1].**

| Item | Dried cassava leaves | Cassava hay |
|---|---|---|
| Dry matter, DM (%) | 90.0 | 86.3 |
| | ———% of DM——— | |
| Digestible protein, DP | 18.3 | 22.0 |
| Total digestible nutrient, TDN | 60.0 | 65.0 |
| Crude protein, CP | 20-30 | 25.0 |
| Neutral detergent fiber, NDF | 29.6 | 44.3 |
| Acid detergent fiber, ADF | 24.1 | 30.3 |
| Acid detergent lignin, ADL | 4.7 | 5.8 |
| Ether extract, EE | 5.9 | 6.2 |
| Nitrogen-free extract, NFE | 44.2 | 48.0 |
| Ash | 10.0 | 12.5 |
| Ca | 1.5 | 2.4 |
| P | 0.4 | 0.03 |
| | | |
| Secondary compounds: | | |
| -Condensed tannins (%) | 4.3 | 3.9 |
| -Hydrocyanic acid (mg/kg DM) | 46.0 | 38.0 |

[1] Leaves and whole tops harvested at 3-4 months after planting.

***Source:*** *Wanapat, 1999; Wanapat, 2001; Wanapat et al., 2000a.*

**Table 4. Comparison of energy and protein obtained from the traditional cassava cultivation and the new method of consecutive harvests of plant tops at two month intervals.**

| | Method of cultivation | |
|---|---|---|
| Item[1] | Traditional[2] | Consecutive harvests |
| Crude protein (CP), kg/ha | 550 | 3,125 |
| Total digestible nutrient (TDN), kg/ha | 21,250 | 18,125 (10,625+7,500) |
| CP/TDN | 0.026 | 0.172 |
| Efficiency CP/E, % | 10 | 90 |

[1] Includes roots and leaves harvested

[2] Harvest of remaining leaves at time of root harvest.

***Source:*** *Wanapat, 2001.*

Cassava hay contains condensed tannins (CT) and proanthocyanidin (PC) which are commonly found in tropical plants. CT are polyphenolics that are easily solubilized in water, which may result in precipitation of protein. Condensed tannins and protein could form a tannin-protein complex (TPC) by hydrogen bonding, especially under alkaline conditions. TPC is stable at pH 3.5-7, but the complex will dissociate at pH<3.0 and pH >8.0 (Jones and Mangan, 1977). Condensed tannins have been found to increase N-recycling in the rumen as well as salivation (Reed, 1995), and also improve rumen microbial protein synthesis (Makkar, 2000). McSweeney *et al*. (2000) found lower rumen cellulolytic bacteria in sheep that were fed tannin-containing diets, but microbial protein synthesis was not affected. However, the exact mode of action of CT on rumen fermentation is yet to be elucidated.

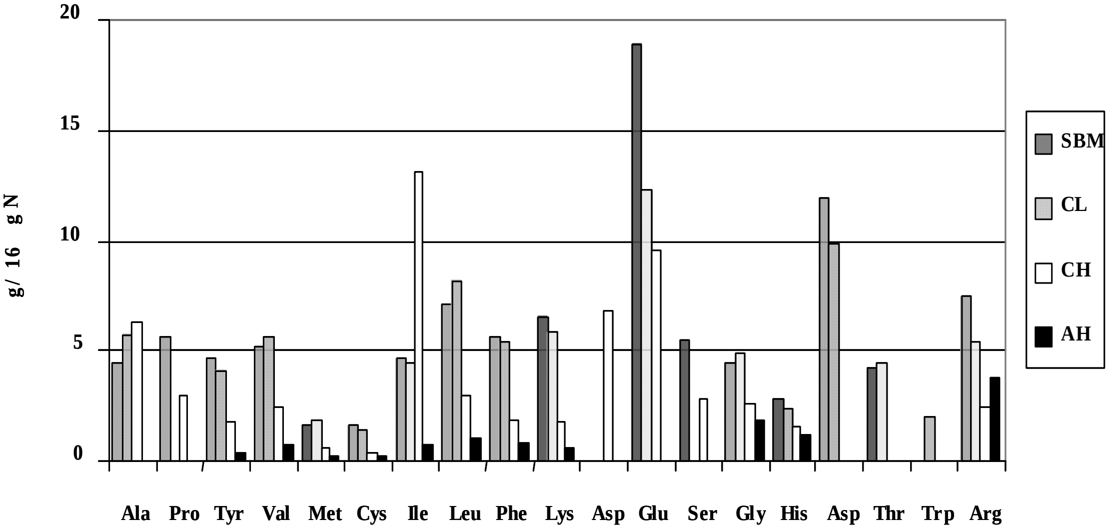

*Figure 1. Amino acid profiles in cassava leaves (CL), cassava hay (CH), soybean meal (SBM) and alfalfa hay (AH)*
***Source:*** *Wanapat, 2002.*

### Effect of Residual Hydrocyanic Acid (HCN) as Thiocyanate in Cassava Hay on Milk Preservation

Claesson (1994) reported that milk thiocyanate was required in the lactoperoxidase system in milk to help increase its shelf-life, and that the optimal range of milk thiocyanate should not exceed 20 ppm. Feeding dairy cows with cassava hay as a supplement resulted in a thiocyanate level of 19.5 ppm in the milk; however, more research is needed in order to pinpoint the role of residual HCN in cassava on milk thiocyanate.

### Effect of Condensed Tannins as a Gastrointestinal Anthelmintic Agent

Gastrointestinal (GI) parasites or nematodes are very common and result in poor performance of ruminants in the tropics. Common GI nematodes found include *Trichostrongylus colubriformis, Ostertagia circumcincta, Haemonchus centortus and T. vitrinus.* Nematode-infected animals had higher requirements of protein and minerals due to loss of endogenous nitrogen (blood, plasma, mucin and sloughed cells) and a lower P adsorption (Poppi *et al*., 1985; Kahn and Diaz-Hernandez, 2000). Research by Netpana *et al*., (2001) showed that the fecal parasitic egg counts in cattle and buffaloes were significantly lower when fed with cassava hay which contained condensed tannins, and were similar to the group of animals receiving a drenching treatment. Recent work by Granum *et al*. (2002) revealed that supplementation of CH at 1 kg/head/day significantly reduced the fecal egg counts in both buffaloes and cattle (**Table 5**). The reason may be that the animals received supplemental protein, and/or the CT could have a direct affect on the internal parasites. Possible mechanisms thorough which CT may reduce larval migration and development remain to be elucidated, but the process may involve interactions of CT with the external surface of larvae (Kahn and Diaz-Hernandez, 2000).

**Table 5. Effect of cassava hay supplementation on fecal egg counts (FEC).**

| | Buffaloes | | Cattle | | |
|---|---|---|---|---|---|
| Parasitic egg counts/g DM feces | C | S | C | S | SEM |
| Preliminary period (grazing only) | 1,552 | 1,243 | 1,189 | 1,462 | 82.2 |
| Experimental period | 918 $^{a}$ | 579 $^{b}$ | 951 $^{a}$ | 747 $^{c}$ | 77.4 |
| Reduction from preliminary period (%) | 31.7 $^{a}$ | 57.6 $^{b}$ | 24.7 $^{a}$ | 45.0 $^{c}$ | 6.2 |

Values in the same row with different superscripts are significantly different ($P<0.05$)
Values are the mean of six animals; C = control; S = cassava hay supplementation;
SEM = standard error of the mean
***Source:*** *Granum et al., 2002.*

### Feeding Trials Using Cassava Hay

Cassava hay has been used successfully as a source of high protein roughage in lactating dairy cows (Wanapat *et al*., 2000a; Wanapat *et al*., 2000b). **Table 6** shows that increasing levels of CH from 0.56 to 1.70 kg/head/day could reduce levels of concentrate from 0.1 to 1.6 kg/head/day, respectively, without affecting milk yield. Moreover, feeding CH at *ad libitum* basis resulted in similar results and could further reduce the need for concentrates. A study was conducted on supplementation levels of cassava hay (CH) in dairy cows. Six multiparous Holstein-Friesian crossbreds were paired and randomly assigned in a change-over design to receive three levels of CH supplement at 0, 0.8 and 1.7 kg DM/head/day. Concentrate was supplemented at the same level (concentrate:milk yield=1:2), while urea-treated (5%) rice straw was offered on *ad libitum* basis. **Table 7** shows that supplementation of CH could significantly reduce concentrate use resulting in similar milk yields, and significantly enhanced 3.5% fat-corrected milk (FCM). Moreover, CH supplementation significantly increased milk fat and milk protein percentages, especially when supplemented at 1.70 kg/head/day. Concentrate use could be significantly reduced by 27% at 1.7 kg/head/day CH supplementation.

In a later experiment (Wanapat *et al*., 2000b), supplementation of cassava hay to replace concentrate was studied using lactating Holstein-Friesian crossbreds grazed on Ruzi grass. Six multiparous cows in mid-lactating periods were paired and randomly assigned according to a change-over-design to receive three dietary treatments: $T_1$=0 kg cassava hay (CH) in 1:2 concentrate supplementation (CS) to milk yield (MY); $T_2$=1.0 kg DM CH/head/day in 1:3 CS to MY; $T_3$=1.7 kg DM CH/head/day in 1:4 CS to MY, respectively. **Table 8** shows that milk yields were similar among treatments while protein, lactose and solids-not-fat percentages were highest ($P<0.05$) in cows receiving CH at 1.0 kg/head/day. The most significant improvement from CH supplementation was the ability to reduce concentrate use by 42%, which could provide a higher income for small-holder dairy farmers. In addition, milk thiocyanate was enhanced from 5.3 in the control to 17.8 ppm ($P<0.05$) in the CH supplemented group (1.7 kg/head/day). Moreover, **Table 9** shows in more detail that CH supplementation significantly reduced the need for concentrate for dairy feeding, thus resulting in greater economic returns. These results are in agreement with those of Woodward *et al*. (1999), who reported that dairy cows fed with *Lotus corniculatus*, containing condensed tannins, had contributed to a 42% improvement in milk yield and 57% increase in protein percentage without changing feed intake.

**Table 6. Effects of cassava hay (CH) supplementation levels on ruminal pH, $NH_3$-N, milk yield and milk composition in late-lactating cows fed urea-treated rice straw (UTRS) as a roughage.**

| Item | T1[1] | T2 | T3 | T4 | T5 | SEM[2] |
|---|---|---|---|---|---|---|
| Cassava hay DM intake (kg/day) | - | 0.56 | 1.13 | 1.70 | 5.20 | 0.20 |
| Condensed tannin intake (g/head/day) | 0 | 1.44 | 2.90 | 4.37 | 13.36 | 5.26 |
| Concentrate saving (kg/head/day) | - | 0.10 | 1.30 | 1.60 | 3.10 | - |
| Urea-treated rice straw | | | | | | |
| DM intake | | | | | | |
| kg/day | 6.8 | 6.4 | 6.7 | 8.0 | - | 0.28 |
| $g/kgw^{.75}$ | 86 | 69 | 84 | 98 | - | 2.82 |
| % body weight | 2.0 | 1.8 | 2.0 | 2.3 | - | 0.06 |
| Ruminal pH | 7.2 | 7.0 | 7.0 | 7.0 | 6.8 | 0.13 |
| Ruminal $NH_3$-N (mg%) | 17 | 13 | 13 | 16 | 7.0 | 0.52 |
| Milk yield (kg/day) | 6.3 | 6.1 | 5.4 | 6.1 | 5.4 | 0.24 |
| 3.5% FCM (kg/day)[3] | $6.8^{ac}$ | $6.2^{ab}$ | $6.0^{b}$ | $7.1^{c}$ | $6.4^{ab}$ | 0.13 |
| Milk fat (%) | $4.0^{a}$ | $3.6^{b}$ | $4.2^{a}$ | $4.5^{c}$ | $4.6^{c}$ | 0.11 |
| Milk protein (%) | $4.4^{a}$ | $4.0^{a}$ | $3.8^{a}$ | $4.1^{a}$ | $5.3^{b}$ | 0.17 |
| Solids-not-fat (%) | 8.6 | 8.8 | 8.4 | 8.6 | 8.4 | 0.12 |
| Total solids (%) | 12.6 | 12.3 | 12.0 | 12.2 | 12.6 | 0.18 |

[1] T1 = Urea-treated rice straw (UTRS) *ad lib.* + Concentrate*: Milk yield (1:2) + 0 CH.
T2 = UTRS *ad lib.* + Concentrate : Milk (1:2) + CH at 0.56 kg DM/head/day
T3 = UTRS *ad lib.* + Concentrate : Milk (1:3) + CH at 1.13 kg DM/head/day
T4 = UTRS *ad lib.* + Concentrate : Milk (1:2) + CH at 1.70 kg DM/head/day
T5 = Cassava hay *ad lib.* + Cassava supplement (97% cassava chips + 3% urea) at 2 kg/head/day
*Concentrate mixture contained 95% cassava chips, 3% urea, 1% sulfur and 1% mineral mix in $T_1$ to $T_4$

[2] SEM = Standard error of the mean
Values with different superscipts within the some row are significantly different ($P<0.05$)

[3] FCM = fat corrected milk

***Source:*** *Wanapat et al., 2000b.*

In recent trials in Vietnam, Nguyen *et al*. (2002) obtained results that were similar to those earlier reported by Wanapat *et al*. (1997, 2000a, 2000b) that cassava hay could be produced from an initial harvest of plant tops at four months after planting and subsequent harvests at one month intervals. Supplementation of cassava hay could lower concentrate use and improve milk yield and milk composition (**Tables 10, 11** and **12**).

Koakhunthod *et al*. (2001) used CH as a major source of protein in high-quality feed blocks used as a supplement for lactating dairy cows. The results (**Table 13, 14, 15, 16, 17**) indicate that rumen ecology, milk yield and milk composition were significantly improved.

**Table 7. Effect of level of chopped cassava hay supplementation on milk yield and composition of Holstein-Friesian crossbreds fed urea-treated (5%) rice straw on *ad libium* basis.**

| | Chopped cassava hay (kg/head/day) | | | SEM[1)] |
|---|---|---|---|---|
| Item | 0 | 0.8 | 1.70 | |
| Concentrate DM intake (kg/day) | 5.53 | 5.00 | 4.03 | 0.25 |
| Concentrate saving (kg) | 0 | 0.53 | 1.50 | 0.30 |
| Milk yield (kg/day) | 12.50 | 12.12 | 12.62 | 0.57 |
| 3.5% FCM (kg/day)[2)] | $14.21^a$ | $15.70^c$ | $14.93^b$ | 0.67 |
| Milk composition: | | | | |
| Fat (%) | $4.06^a$ | $4.15^a$ | $4.61^b$ | 0.19 |
| Protein (%) | $3.40^a$ | $3.34^b$ | $3.50^c$ | 0.08 |
| Lactose (%) | $4.64^a$ | $4.82^b$ | $4.62^a$ | 0.05 |
| Solids-not-fat (%) | 8.74 | 8.80 | 8.81 | 0.09 |
| Total solids (%) | 13.56 | 13.18 | 13.76 | 0.32 |

[1)] SEM = Standard error of the mean

Values with different superscripts within the same row are significantly different ($P<0.05$)

[2)] FCM = fat corrected milk

***Source:** Wanapat et al., 2000a.*

**Table 8. Effect of cassava hay (CH) supplementation on concentrate use, milk yield and composition.**

| Concentrate : Milk yield ratio | 1:2 | 1:3 | 1:4 | SEM[1)] |
|---|---|---|---|---|
| CH supplementation (kg DM/day) | 0 | 1.0 | 1.7 | |
| Concentrate DM intake (kg/day) | $4.56^a$ | $3.20^b$ | $2.64^c$ | 0.25 |
| Concentrate saving (kg) | 0 | 1.36 | 1.92 | - |
| Milk yield (kg/day) | 10.72 | 10.19 | 10.42 | 0.58 |
| 3.5% FCM (kg/day)[2)] | 12.65 | 12.51 | 12.64 | 0.75 |
| Milk composition: | | | | |
| Fat (%) | $4.61^a$ | $4.98^b$ | $4.80^{ab}$ | 0.13 |
| Protein (%) | $3.36^a$ | $3.60^b$ | $3.45^{ab}$ | 0.10 |
| Lactose (%) | $4.47^a$ | $4.66^b$ | 4.53 | 0.07 |
| Solids-not-fat (%) | $8.80^a$ | $8.95^b$ | $8.68^c$ | 0.09 |
| Total solids (%) | 13.41 | 13.54 | 13.50 | 0.24 |
| Thiocyanate (ppm) | $5.3^a$ | $13.3^b$ | $17.8^b$ | 0.77 |

[1)] SEM = Standard error of the mean

Values with different superscripts within the same row are significantly different ($P<0.05$)

[2)] FCM = fat corrected milk

***Source:** Wanapat et al., 2000a.*

**Table 9. Effect of cassava hay supplementation on the economic return of milk yield per cow.**

| Concentrate : Milk ratio | 1:2 | 1:3 | 1:4 |
|---|---|---|---|
| CH Supplementation (kg DM/day) | 0 | 1.0 | 1.7 |
| 3.5% FCM (kg/day) | 12.65 | 12.51 | 12.64 |
| Milk sale (baht) | 141.68 | 140.11 | 141.57 |
| Concentrate intake (kg/day) | 5.15 | 3.62 | 2.97 |
| Concentrate cost (baht/day) | 30.90 | 21.72 | 17.82 |
| Cassava hay intake (kg/day) | 0 | 2.85 | 4.02 |
| Cassava hay cost (baht/day) | 0 | 1.92 | 2.01 |
| Total feed cost (baht/day) | 30.90 | 23.64 | 19.83 |
| Income over feed (baht/day) | 110.78 | 116.47 | 121.74 |
| Income over feed (baht/month) | 3,324 | 3,494 | 3,652 |
| Income over feed ($US/month) | 92.3 | 97.1 | 101.4 |

1 kg milk = 11.20 baht; 1 kg concentrate = 6.00 baht; 1 kg cassava hay = 0.50 baht; 1US$ = 36 baht

***Source:*** *Wanapat et al., 2000a.*

**Table 10. Fresh and dry fodder and protein yield of cassava (t/ha) with different cutting regimes.**

| | | | | | | Contrast[3)] | | |
|---|---|---|---|---|---|---|---|---|
| Item | T1[1)] | T2 | T3 | T4 | SEM[2)] | IC | SC | X |
| Fresh fodder yield (t/ha) | $27.89^a$ | $37.58^b$ | $33.51^b$ | $35.91^b$ | 1.14 | NS | * | * |
| Dry fodder yield (t/ha) | $4.25^a$ | $6.86^b$ | $6.49^b$ | $7.90^c$ | 0.35 | ** | ** | * |
| Protein yield (t/ha) | $1.16^a$ | $1.60^b$ | $1.55^b$ | $1.54^b$ | 0.06 | ** | NS | ** |

[1)] T1: IC = 2 months and SC = 1 month; total 11 cuts
T2: IC = 2 months and SC = 2 months; total 6 cuts
T3: IC = 4 months and SC = 1 month; total 9 cuts
T4: IC = 4 months and SC = 2 months; total 5 cuts

[2)] SEM = Standard eror of the mean
Values in the same row with different superscipts are significantly different ($P<0.05$)

[3)] IC = Initial cutting, SC = Subsequent cutting, X = Interaction between IC and SC.

*, ** = Significant at 0.05 and 0.001% probability level, respectively, NS = Non-significant.

***Source:*** *Nguyen et al., 2002.*

**Table 11. Effect of different cuttings regimes on chemical composition of cassava foliage.**

| Items | T1 | T2 | T3 | T4 | SEM |
|---|---|---|---|---|---|
| DM (%) | $16.41^{a}$ | $18.80^{b}$ | $18.89^{b}$ | $22.40^{c}$ | 0.60 |
| | | | % of DM | | |
| NDF | $42.70^{a}$ | $48.27^{b}$ | $49.16^{b}$ | $56.04^{c}$ | 1.26 |
| ADF | $25.93^{a}$ | $31.02^{b}$ | $32.06^{b}$ | $37.97^{c}$ | 0.14 |
| ADL | $10.44^{a}$ | $11.83^{b}$ | $12.59^{b}$ | $13.60^{c}$ | 0.32 |
| CP | $28.51^{a}$ | $24.23^{b}$ | $28.65^{a}$ | $20.79^{c}$ | 0.87 |
| Total Ash | $7.72^{a}$ | $6.66^{b}$ | $6.97^{b}$ | $5.21^{c}$ | 0.25 |
| Condensed tannins | 5.00 | 5.15 | 4.87 | 5.48 | 0.85 |

[1] T1: IC = 2 months and SC = 1 month; total 11 cuts
T2: IC = 2 months and SC = 2 months; total 6 cuts
T3: IC = 4 months and SC = 1 month; total 9 cuts
T4: IC = 4 months and SC = 2 months; total 5 cuts

[2] SEM = Standard error of the mean
Values in the same row with different superscripts are significantly different ($P<0.05$)

***Source:*** *Nguyen et al., 2002.*

**Table 12. Effect of cassava hay supplementation on milk yield and composition.**

| Item | T1[1] | T2 | T3 | T4 | T5 | SEM[2] |
|---|---|---|---|---|---|---|
| Milk yield (kg/day) | 7.48 | 8.42 | 7.70 | 8.00 | 7.90 | 0.12 |
| 4% FCM (kg/day)[3] | 7.79 | 9.53 | 8.76 | 9.10 | 8.87 | 0.16 |
| Milk DM (%) | 12.72 | 13.52 | 13.76 | 13.60 | 13.86 | 0.13 |
| Milk fat (%) | 4.32 | 4.90 | 4.90 | 5.04 | 4.90 | 0.09 |
| Milk CP (%) | $3.46^{a}$ | $3.76^{b}$ | $3.78^{b}$ | $3.94^{b}$ | $3.74^{b}$ | 0.03 |
| Milk SNF (%)[4] | 8.40 | 8.62 | 8.86 | 8.56 | 8.96 | 0.07 |

[1] T1: No cassava hay supplementation, supplementation of concentrate : milk yield at 1:2
T2: Supplementation of 1 kg DM of CH/h/d; supplementation of concentrate : milk yield at 1:2
T3: Supplementation of 1 kg DM of CH/h/d; supplementation of concentrate : milk yield at 1:3
T4: Supplementation of 2 kg DM of CH/h/d; supplementation of concentrate : milk yield at 1:2
T5: Supplementation of 2 kg DM of CH/h/d; supplementation of concentrate : milk yield at 1:2

[2] SEM = standard error of the mean
Values in the same row with different superscipts are significantly different ($P<0.05$)

[3] FCM = fat corrected milk, 4% FCM = 0.4 x(kg of milk)+15x(kg of fat); SNF = solids non-fat

**Table 13. Composition of high-quality feed block (HQFB).**

| Ingredients | HQFB1 | HQFB2 |
|---|---|---|
| | (% by weight) | |
| Molasses | 40 | 42 |
| Coarse rice bran | 30 | 0 |
| Cassava hay | 0 | 30 |
| Urea | 13 | 11 |
| Sulfur | 1 | 1 |
| Mineral mix | 1 | 1 |
| Salt | 1 | 1 |
| Tallow | 2 | 2 |
| Cement | 12 | 12 |

***Source:*** *Koakhunthod et al., 2001.*

**Table 14. Chemical composition of (as% of dry matter) urea-treated rice straw (UTRS), concentrate and high-quality feed block with (HQFB-CH) or without (HQFB) cassava hay (CH).**

| | Dry matter | Organic matter | Crude protein | NDF | ADF |
|---|---|---|---|---|---|
| UTRS | 55.2 | 83.6 | 6.8 | 83.0 | 58.1 |
| Concentrate | 85.0 | 92.2 | 13.6 | 24.3 | 10.7 |
| HQFB | 79.8 | 76.4 | 36.0 | 26.2 | 20.2 |
| HQFB-CH | 80.2 | 76.1 | 33.2 | 23.2 | 17.2 |

***Source:*** *Koakhunthod et al., 2001.*

**Table 15. Effect of cassava hay in a high-quality feed block on feed intake and dry matter digestibility in lactating dairy cows fed a basal diet of urea-treated rice straw(UTRS).**

| Item | Control | HQFB | HQFB-CH | SEM |
|---|---|---|---|---|
| UTRS DM intake | | | | |
| kg/day | 5.44 | 5.61 | 6.20 | 0.17 |
| % of body weight | 1.44 | 1.55 | 1.57 | 0.03 |
| HQFB DM intake | | | | |
| kg/day | | 0.65 | 0.79 | 0.03 |
| % of body weight | | 0.18 | 0.20 | 0.01 |
| Total DM intake | | | | |
| kg/day | $9.18^{a}$ | $10.1^{ab}$ | $11.1^{b}$ | 0.31 |
| % of body weight | 2.43 | 2.82 | 2.78 | 0.07 |
| Dry matter digestibility % | $48.4^{a}$ | $51.1^{ab}$ | $53.4^{b}$ | 0.76 |

[1] SEM = Standard error of the mean

Values in the same row with different superscripts are significantly different ($P<0.05$).

***Source:*** *Koakhunthod et al., 2001.*

**Table 16. Effect of cassava hay in the feed block on rumen pH, NH3-N and rumen microbes.**

| | Dietary treatments | | | |
|---|---|---|---|---|
| | Control | HQFB | HQFB-CH | SEM |
| pH | 6.64 | 6.50 | 6.59 | 0.07 |
| $NH_3$-N (mg %) | 7.95 | 8.61 | 9.14 | 0.71 |
| Bacteria (x $10^{9}$ cells/ml) | 6.56 | 6.74 | 7.25 | 3.05 |
| Protozoa (x$10^{5}$ cells/ml) | 6.30 | 6.20 | 6.10 | 0.34 |
| -holotrich (x$10^{5}$ cells/ml) | 2.30 | 2.30 | 2.40 | 0.52 |
| -entodiniomorp (x$10^{5}$ cells/ml) | 4.00 | 3.90 | 3.70 | 0.83 |
| Fungal zoospore (x$10^{7}$ cells/ml) | 3.02 | 3.75 | 4.16 | 3.87 |
| Total viable count (x$10^{10}$ CFU/ml) | 2.51 | 2.86 | 3.16 | 0.23 |
| Cellulolytic bacteria (x$10^{9}$ CFU/ml) | 3.04 | 3.21 | 3.48 | 0.27 |
| Amylolytic bacteria (x$10^{8}$ CFU/ml) | 1.60 | 2.22 | 2.19 | 0.15 |
| Proteolytic bacteria (x$10^{8}$ CFU/ml) | 1.71 | 2.02 | 2.13 | 0.19 |

***Source:*** *Koakhunthod et al., 2001.*

**Table 17. Effect of cassava hay (CH) in the feed block (HQFB) on milk yield and milk composition in lactating dairy cows fed urea-treated rice straw.**

| Items | Dietary treatments | | | |
|---|---|---|---|---|
| | Control | HQFB | HQFB-CH | SEM |
| Milk yield (kg/day) | $7.58^{a}$ | $8.85^{b}$ | $9.36^{b}$ | 0.44 |
| 3.5% FCM (kg/day). | $7.66^{a}$ | $8.43^{b}$ | $9.94^{c}$ | 0.46 |
| Fat (%) | $0.27^{a}$ | $0.29^{a}$ | $0.37^{b}$ | 0.02 |
| Protein (%) | $0.23^{a}$ | $0.25^{a}$ | $0.31^{b}$ | 0.02 |
| Milk compositions (%): | | | | |
| Fat | $3.39^{a}$ | $3.53^{ab}$ | $4.08^{b}$ | 0.16 |
| Protein | 2.87 | 2.96 | 3.32 | 0.11 |
| Lactose | 5.01 | 4.85 | 5.00 | 0.04 |
| Solids-not-fat | 7.98 | 8.01 | 8.01 | 0.42 |
| Total solids | $12.11^{a}$ | $12.03^{a}$ | $13.09^{b}$ | 0.25 |

[1] SEM = Standard error of the mean

Values in the same row with different superscripts are significanty different ($P<0.05$).

***Source:** Koakhunthod et al., 2001.*

## CONCLUSIONS AND RECOMMENDATIONS

Cassava could be cultivated to produce mainly cassava leaves to make hay, which has a high nutritive value. Intercropping cassava with food or feed crops could further increase biomass yield and improve soil fertility. Condensed tannins contained in cassava hay may play an important role forming a tannin-protein complex which increases rumen by-pass protein and reduces GI nematode egg counts. Feeding cassava hay as a supplemental high-protein source could increase milk yield and improve its composition, and significantly reduce concentrate use. On-farm research with small-holder farmers show a promising establishment and development of cassava hay production on farm. Harvesting of whole tops at an earlier stage and subsequent prunings to produce hay resulted in an increased protein to energy ratio in animal feeding. However, further research relating to the role of condensed tannins in cassava hay on rumen ecology, its efficient use for livestock feeding, especially dairy cattle, as well as the utilization levels with other low-quality roughage, still needs to be undertaken. Cassava hay and cassava chips as a complete concentrate could contribute to more sustainable crop/livestock production systems in the tropics.

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