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REGULAR ARTICLES

# Effect of feeding cassava bioethanol waste on nutrient intake, digestibility, and rumen fermentation in growing goats

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**Abstract** This experiment was conducted to investigate the effects of various levels of cassava bioethanol waste (CBW) on nutrient intake, digestibility, rumen fermentation, and blood metabolites in growing goats. Twelve crossbred, male (Thai Native × Anglo Nubian) growing goats with initial body weight (BW) of 20±3 kg were randomly assigned according to a completely randomized design (CRD). The dietary treatments were total mixed ration (TMR) containing various levels of CBW at 0, 10, and 20 % dry matter (DM). CBW contained crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) at 11, 69, 47, and 23 % DM, respectively. The TMR diets were offered ad libitum and contained CP at 15 % DM. Inclusion of CBW at 10 % DM in TMR did not alter feed intake (g DM and g/kg $BW^{0.75}$) and CP intake when compared to the control fed group (0 % CBW). Total OM intake was lower in the 20 % CBW group than in the others ($P<0.01$). The digestibility coefficients of DM, OM, CP, and NDF were not changed for the TMR including 10 % CBW compared to the control group ($P>0.05$) whereas when 20 % CBW was incorporated to diet, intermediate digestibility coefficients were decreased. Average ruminal pH values ranged from 6–7. Rumen $NH_3$-N and PUN concentration at 0, 3, and 6 h post-feeding were not significantly different among treatments ($P>0.05$). Thus, inclusion of 10 % CBW in TMR diets does not adversely affect nutrient intake, digestibility, rumen fermentation, and blood metabolite in fattening goats, and CBW may be effectively used as an alternative roughage source in the diets of goats.

**Keywords** Bioethanol co-product · Digestibility · Nutrient intake · Rumen fermentation · Small ruminant

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## Introduction

Feed costs have historically represented 65–75 % of the variable costs of animal production and are even higher now for many producers. As a result, feed costs play a major role in determining the profitability of a ruminant enterprise (Tudisco et al. 2015). In recent years, there has been an increasing trend towards more efficient utilization of agro-industrial residues (Nguyen et al. 2014). Feedstuffs produced by the ethanol industry have now become mainstream commodities, particularly in the feeding of ruminants (Sahin et al. 2013). Dried distillers' grains (corn, wheat, sorghum, etc.) with soluble (DDGS), by-products of the ethanol production process, are thought to have a high-nutrient feed value for livestock production (Avelar et al. 2010). Previous research has shown that DDGS can be fed to goats as a source of both supplemental protein and energy, with optimum inclusion levels at 20–60 % of the diet dry matter (Sahin et al. 2013).

The ethanol industry in Thailand has been active since 1961 as one of the royal projects of His Majesty the King. Cassava bioethanol waste (CBW) is a by-product of bioethanol production from whole cassava root as the raw material. Twenty-five factories use cassava root with a total ethanol production capacity of 8.6 million liters/day (Sriroth et al. 2012). Thus, a vast amount of CBW is wasted and causes serious environmental pollution. CBW contains crude protein contents around 11–14 % DM and some fibers (Sriroth et al. 2012), which are available nutrients for ruminant animals. Phoemchalard et al. (2014) reported that CBW can be used in the diet of heifer cattle without adverse effects on feed utilization and growth performance. No investigation has been conducted with fattening goats, and therefore, the objective of current study was to investigate the effect of different levels of CBW on nutrient intake, digestibility, rumen fermentation, and blood metabolite in fattening goats.

## Materials and methods

### Animals, experimental design, and feeding

Twelve, crossbred male (Thai Native × Anglo Nubian) growing goats with initial body weight (BW) of 20±3 kg were randomly assigned according to a completely randomized design (CRD). Goats were randomly assigned to one of three treatments (four goats per treatment) and were adapted to the experimental diets for 14 days before the beginning of data collection. Animals were housed individually in ventilated pens (1 m × 1 m) with wooden slotted flooring in an open goat barn raised above the ground where water and mineral salt were available at all times.

The dietary treatments were total mixed ration (TMR) containing different levels of CBW at 0, 10, and 20% DM, respectively, and were formulated to be isonitrogenous and isocaloric (DM basis) and to meet requirements of fattening goats (NRC 2007). The CBW was obtained from a local bioethanol production factory and sundried for 2 days and was then added to the TMR. The ingredients and chemical composition of experimental diets are presented in Tables 1 and 2. The TMR was fed ad libitum and offered at 07:00 and 16:00 for 90 days.

### Sample collection and sampling procedures

Individual intakes were recorded daily by weighing the offered and refused feeds during the morning feeding and the offered amount was adjusted to ensure approximately 10 % refusals after feeding. Animals were weighed every 30 days in the morning prior to feeding to measure BW change. Feed offered and refusals samples were collected during the last 7 days of the experiment. Fecal samples were collected during the last 7 days of the period by using total collection method as animals were on the metabolism crates to study the nutrient digestibility. The fecal samples collected were about 5 % of total fresh weight and divided into two parts; the first part for DM analysis every day, and the second part was kept in a refrigerator and pooled with the other goats' fecal samples at the end period for chemical analysis and calculation of digestibility.

The samples were dried at 60 °C and ground (1 mm screen using a Cyclotech Mill, Tecator, Sweden) and analyzed using AOAC (1995) method for DM, CP, EE, ash, acid detergent fiber (ADF), and acid detergent lignin (ADL). Neutral detergent fiber (NDF) in samples was estimated according to Van Soest et al. (1991) with addition of α-amylase but without sodium sulfite and results are expressed inclusive of residual ash.Approximately, 45 mL of rumen fluid was taken from the rumen by a stomach tube connected to a vacuum pump at 0, 3, and 6 h after feeding on the last day of period. Ruminal pH was determined using a portable pH and temperature meter (HANNA Instruments HI 8424 microcomputer, Singapore). Ruminal ammonia-nitrogen ($NH_3$-N) concentration was analyzed using Kjeltech Auto 1030 Analyzer (AOAC 1995). A blood sample (about 10 mL) was collected from the jugular vein at the same time as rumen fluid sampling into tubes containing 12 mg of EDTA, and plasma was separated by centrifugation at 500×$g$ for 10 min at 4 °C and stored at −20 °C until analysis of plasma urea N (PUN) using a diagnostic kit (L type Wako PUN, Tokyo, Japan).

### Statistical analysis

All data from the experiment were statistically analyzed as a completely randomized design (CRD) using the GLM procedure of SAS (1996). Data were analyzed using the model:

$$Y_{ij} = \mu + M_i + \varepsilon_{ij}$$

where $Y_{ij}$ is dependent variable; $\mu$ is the overall mean, $M_i$ is effect of the level of CBW ($i$ = 0, 10, and 20 % DM), and $\varepsilon_{ij}$ is the residual effect. Results are presented as mean values with the standard error of the means. Differences among means with $P < 0.05$ were accepted as representing statistically significant differences.

## Results and discussion

### Chemical composition of experimental feedstuffs

The chemical composition of experimental diets is presented in Table 2. The TMR diets were offered ad libitum and contained CP at 15 % DM. The concentrations of NDF, ADF, and ADL in the diets were different among treatments and ranged from 38–45, 21–29, and 4–7 % DM, respectively. Fiber contents increased with increasing the levels of CBW in the TMR; it could be due to fiber contents in CBW. CBW contained NDF, ADF, and ADL at 69, 47, and 23 % DM, respectively. Moreover, CP content in CBW was 11 % DM and was similar to those reported by Sriroth et al. (2012; 11–14 % CP). However, Phoemchalard et al. (2014) found that CP content in CBW was only 6 % DM. This could possibly be because the differences between bioethanol factories, cassava varieties, seasons, and CBW-preparing processes before

**Table 1** Ingredients of experimental diets (% of dry matter)

| Item | Levels of cassava bioethanol waste (CBW, %DM) | | |
|---|---|---|---|
| | 0 | 10 | 20 |
| Ingredients, %DM | | | |
| Rice straw | 30.0 | 30.0 | 30.0 |
| Cassava bioethanol waste (CBW) | 0.0 | 10.0 | 20.0 |
| Cassava chip | 40.0 | 30.0 | 20.0 |
| Rice bran | 4.0 | 5.0 | 3.0 |
| Soybean meal | 9.5 | 8.5 | 7.0 |
| Corn meal | 4.0 | 6.0 | 9.0 |
| Coconut meal | 6.5 | 2.0 | 1.0 |
| Molasses | 3.0 | 3.5 | 3.5 |
| Vegetable oil | 0.0 | 2.0 | 3.5 |
| Urea | 2.0 | 2.0 | 2.0 |
| Salt | 0.2 | 0.2 | 0.2 |
| Sulfur | 0.2 | 0.2 | 0.2 |
| Mineral premix[a] | 0.4 | 0.4 | 0.4 |
| Dicalcium | 0.2 | 0.2 | 0.2 |

[a] Minerals and vitamins (each kilogram) contain the following: vitamin A: 10,000,000 IU; vitamin E: 70,000 IU; vitamin D: 1,600,000 IU; Fe: 50 g; Zn: 40 g; Mn: 40 g; Co:0.1 g; Cu: 10 g; Se: 0.1 g; I: 0.5 g

mixing in the diet, etc. Furthermore, DDGS are also residues from bioethanol production that uses corn and wheat as raw material in the process. The CP content of DDGS was higher than that of CBW and ranged from 30 to 46 % DM (Avelar et al. 2010). Rice straw (*Oryza sativ*a) contained 90 % DM, 3 % CP, 80 % NDF, and 56 % ADF on a DM basis and was used as a roughage source in TMR.

## Voluntary feed intake and nutrient intakes

Table 3 presents the voluntary feed intake (VFI) and nutrient intakes of animals fed various levels of CBW. Nutritional value and filling effect are the main characteristics of feed involved in VFI (Tudisco et al. 2014). Inclusion of CBW at 10 % DM in TMR did not alter feed intake (g DM and g/kg $BW^{0.75}$), and CP intake when compared to the control group (0 % CBW). Goats fed in the 20 % CBW group had lower DM intake than the 0 and 10 % of those in the CBW fed group, which could be due to the low amount of supplied CBW. Similarly, Phoemchalard et al. (2014) also reported that roughage intake, concentrate intake, and total feed intake of cattle decreased with CBW supplementation at 15–30 % DM in concentrates in terms of BW/day and grams/kilogram $BW^{0.75}$/day. However, Sahin et al. (2013) observed no

**Table 2** Chemical composition of experimental diets (% of dry matter)

| Item | Levels of cassava bioethanol waste (CBW, %DM) | | | CBW | Rice straw |
|---|---|---|---|---|---|
| | 0 | 10 | 20 | | |
| Chemical composition | | | | | |
| Dry matter, % | 91 | 91 | 91 | 94 | 90 |
| Organic matter, %DM | 94 | 92 | 91 | 84 | 86 |
| Ash, %DM | 6 | 8 | 9 | 16 | 14 |
| Crude protein, %DM | 15 | 15 | 15 | 11 | 3 |
| Ether extract, %DM | 2 | 4 | 5 | 2 | 1 |
| Neutral detergent fiber, %DM | 38 | 40 | 45 | 69 | 80 |
| Acid detergent fiber, %DM | 21 | 25 | 29 | 47 | 56 |
| Acid detergent lignin, %DM | 4 | 5 | 7 | 23 | 9 |
| Metabolizable energy[a], MJ/kg DM | 11 | 11 | 11 | 7 | 8 |

[a] Metabolizable energy (ME) was calculated according to the equation of Cherdthong et al. (2015)

**Table 3** Voluntary feed intake and nutrient intakes of goats fed various levels of cassava bioethanol waste (CBW, %DM)

| Item | Levels of cassava bioethanol waste (CBW, %D M) | | | SEM | *P* value |
|---|---|---|---|---|---|
| | 0 | 10 | 20 | | |
| Voluntary feed intake/day | | | | | |
| g Dry matter | 688[a] | 724[a] | 545[b] | 20 | <0.01 |
| %BW | 3 | 3 | 3 | 0.1 | 0.07 |
| g/kg $BW^{0.75}$ | 62[a] | 66[a] | 54[b] | 2 | <0.01 |
| Nutrient intakes, g/day | | | | | |
| Organic matter | 508[a] | 518[a] | 361[b] | 13 | <0.01 |
| Crude protein | 77[a] | 83[a] | 55[b] | 2 | <0.01 |
| Neutral detergent fiber | 142[a] | 164[b] | 129[a] | 9 | <0.01 |
| Acid detergent fiber | 63[a] | 82[b] | 60[a] | 3 | <0.01 |

[a,b] Means in the same row with different superscripts differ ($P < 0.05$)

significant difference in feed intake between lambs supplemented with DDGS and the control. This situation may be related to differences in the by-products used for the trials. The average final BW of goats was 27 ± 2 kg.

Total OM intake was lower (361 g per day) in the 20 % CBW group than the others, and this could be attributed to the low OM content in CBW. Intakes of NDF and ADF were significantly improved in goats fed with 10 % of CBW ($P < 0.01$) while inclusion of CBW at 20 % DM in TMR reduced fiber intake. Roughly, the most important physical factors that limit the feed intake are the fiber content of feeds and fiber digestibility kinetics in the rumen, whereas the main limiting physiological factor is undoubtedly the content of soluble carbohydrates (Calabrò et al. 2012; Tudisco et al. 2014). If NDF and ADF contents of feed ingredients are high, it probably causes a depressive effect on the feed intake level, due to the rumen fill. Moreover, high fiber content of feeds increases the bulkiness of diets and is negatively related to the capacity of the reticulorumen (Tudisco et al. 2015).

## Apparent digestibility coefficients

Apparent digestibility coefficients of goats fed various levels of CBW are presented in Table 4. The digestibility coefficients of DM, OM, CP, and NDF were not different for the diet ration including 10 % CBW compared to the control group ($P > 0.05$), whereas when 20 % CBW was incorporated into the diet, intermediate digestibility rates decreased. Phoemchalard et al. (2014) reported that DM, OM, CP, and EE digestibility of cattle-fed 30 % CBW was lower than 15 % CBW. These results were in agreement with Felix et al. (2012), who revealed that when the DDGS ratio increases from 20 to 40 or 60 % in the rations, DM digestibility as well as the growth performance of lambs is reduced. Furthermore, Sahin et al. (2013) reported that digestibility rates of DM, OM, and CP were significantly reduced in lambs supplemented with 10 % DDGS when compared to values measured in the control. These discrepancies would be due to the use of by-products from different sources.

Apparent digestibility coefficient of ADF was significantly higher in 10 % CBW-supplemented feed (46 %; $P = 0.02$), which could be related to high ADF intake (Table 3). In addition, the optimum concentration of fiber in ruminant diets may improve cellulolytic bacterial activity and could influence fiber digestion in the rumen (Cherdthong et al. 2015).

## Rumen fermentation and plasma urea nitrogen

Ruminal pH, $NH_3$-N concentration, and plasma urea nitrogen (PUN) are presented in Table 5. Average ruminal pH values ranged from 6–7 and these ranges were considered as optimal

**Table 4** Apparent digestibility coefficients of goats fed various levels of cassava bioethanol waste (CBW, %DM)

| Item | Levels of cassava bioethanol waste (CBW, %DM) | | | SEM | *P* value |
|---|---|---|---|---|---|
| | 0 | 10 | 20 | | |
| Apparent digestibility coefficient (%) | | | | | |
| Dry matter, % | 74[a] | 73[a] | 68[b] | 1 | <0.01 |
| Organic matter, %DM | 79[a] | 78[a] | 73[b] | 1 | <0.01 |
| Crude protein, %DM | 77[a] | 76[a] | 69[b] | 0.4 | <0.01 |
| Neutral detergent fiber, %DM | 54[a] | 56[a] | 53[b] | 1 | 0.03 |
| Acid detergent fiber, %DM | 43[a] | 46[b] | 43[a] | 1 | 0.02 |

[a,b] Means in the same row with different superscripts differ ($P < 0.05$)

**Table 5** Ruminal pH, ammonia-nitrogen concentration in rumen, and plasma urea nitrogen of goats fed various levels of cassava bioethanol waste (CBW, %DM)

| Item | Levels of cassava bioethanol waste (CBW, %DM) | | | SEM | *P* value |
|---|---|---|---|---|---|
| | 0 | 10 | 20 | | |
| Ruminal pH | | | | | |
| 0 h post-feeding | 7 | 7 | 7 | 0.09 | 0.20 |
| 3 h post-feeding | 6 | 7 | 7 | 0.1 | 0.19 |
| 6 h post-feeding | 7 | 7 | 7 | 0.4 | 0.67 |
| Mean | 7 | 7 | 7 | 0.2 | 0.41 |
| Rumen ammonia-nitrogen, mg% | | | | | |
| 0 h post-feeding | 13 | 13 | 14 | 1 | 0.70 |
| 3 h post-feeding | 21 | 20 | 21 | 2 | 0.93 |
| 6 h post-feeding | 15 | 15 | 17 | 1 | 0.21 |
| Mean | 16 | 16 | 17 | 2 | 0.06 |
| Plasma urea nitrogen, mg% | | | | | |
| 0 h post-feeding | 15 | 15 | 15 | 1 | 0.11 |
| 3 h post-feeding | 20 | 22 | 19 | 3 | 0.20 |
| 6 h post-feeding | 17 | 18 | 16 | 3 | 0.10 |
| Mean | 18 | 19 | 17 | 2 | 0.08 |

levels for microbial digestion of fiber and microbial protein synthesis (Cherdthong et al. 2015). Ruminal pH in goats at the end of the experimental period was not affected by CBW inclusion in TMR diets. This may be because most of the starch is removed from CBW; therefore, inclusion did not result in ruminal pH changes. Similarly, Sahin et al. (2013) observed no significantly differences in ruminal pH in lambs when 10–20 % DDGS was included.

Rumen $NH_3$-N and PUN concentration at 0, 3, and 6 h post-feeding were not significantly different among treatments ($P > 0.05$) with mean values ranging from 16–17 and 17–19 mg%, respectively.This is in agreement with results from Sahin et al. (2013), who reported no differences in ruminal $NH_3$ and PUN concentrations in lambs and growing Kiko × Spanish male goats when 10–20 % DDGS was added to the basal diet. Furthermore, McEachern et al. (2009) revealed that replacing cottonseed meal with 60 % DDGS in lamb growth did not alter PUN. The current values were within the normal range for goats (McEachern et al. 2009; Chanjula et al. 2015) and give no indication of problems with using CBW in the feeding program. The PUN concentrations could be useful as an indicator of protein status within a group of goats and could help to fine-tune diets or identify problems with a feeding regime (McEachern et al. 2009).

Based on this study, it could be concluded that, inclusion of 10 % CBW in TMR diets did not adversely affect feed intake, nutrient digestibility, ruminal fermentation characteristics, and blood metabolites in goat. Therefore, CBW is attractive for growing goat diets and may be effectively used as an alternative roughage source in the diets of goats. However, these findings should be studied further in production trials in order to investigate performance and carcass characteristics in growing goats.

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**Compliance with ethical standards**

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical approval** Animals involved in this study were cared for according to the guidelines of the Khon Kaen University Animal Care and Use Committee. All standard procedures concerning animal care and management were taken throughout the entire period of the experiment.

**Informed consent** Informed consent was obtained from all individual participants included in the study.

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