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Utilising locally based energy supplements in leucaena and corn stover diets to increase the average daily gain of male Bali cattle and the income of smallholder farmers

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ABSTRACT

Context. Supplementing a leucaena-based diet with locally available energy sources is an important strategy to extend the use of leucaena, increase liveweight (LW) gain of Bali cattle and increase profit for the smallholder. **Aims.** This study was conducted to evaluate the effect of various local energy supplements in leucaena-based diets on the LW gain of Bali cattle and income-over-feed costs (IOFC). **Methods.** Forty male Bali cattle were divided into five treatment groups ($n = 8$) and each was fed one of the following diets: (A) control diet, including leucaena *ad libitum*, with corn stover at 0.5% DM LW and mineral mix, (B) control + cassava meal at 1.0% DM LW, (C) control + cassava peel at 1.0% DM LW, (D) control + cassava peel and corn grain mix at 1.0% DM LW or (E) control + commercial feed at 1.0% DM LW. The experiment was run for 140 days, which included a 20-day adaptation period. Parameters measured included intake, digestibility, imbibed-water intake, LW gain, rumen and faecal parameters, feed conversion and IOFC. **Key results.** Supplementation of local energy sources in combination with leucaena and corn stover diets increased LW gain of male Bali cattle above that of the control diet ($P < 0.05$). The bulls receiving the cassava peel and corn mix supplement had the highest LW gain (0.57 ± 0.09 kg/day), which was associated with an increase in digestible organic-matter intake (DOMI). There were no treatment differences ($P > 0.05$) in the rumen parameters (rumen fluid pH, rumen ammonia-N concentration and volatile fatty acids) and all parameters were optimum for rumen digestion. **Conclusions.** The addition of local energy supplements supplied at 1% of LW improved growth rate and extended the use of a limited amount of leucaena and provided a higher IOFC. **Implications.** Replacing approximately 40% of leucaena with energy sources can have three benefits, including an increase in LW gain, an increased capacity of farmers to feed more cattle per hectare and an increased income per cattle being fattened. This can increase the production scale and subsequent farmer income, provided that the energy sources are available at affordable prices and obtainable.

Keywords: cattle feeding, cattle growth, food conversion efficiency, leucaena, profitability, small holder farmers, stubble, supplements.

Introduction

Leucaena (*Leucaena leucocephala*) has been an effective solution to the lack of high-quality feeds in the dry tropical areas such as West Nusa Tenggara, eastern Indonesia. Since the introduction of leucaena cv. Tarramba in 2011, the number of farmers adopting the leucaena-based cattle fattening system in Sumbawa Island has increased markedly and, by the end of 2018, this system had been adopted by 2500 farmers (Dahlanuddin *et al.* 2019). It is envisaged that the number of farmers utilising leucaena for fattening is increasing due to the suitability of leucaena to these dryland farming systems.

The high adoption rate of the leucaena-based cattle fattening system has been attributable to its ability to grow well in marginal dry land areas. It is highly nutritious with a crude protein (CP) content of 15–40% dry matter (DM) (Dalzell *et al.* 1998) and highly palatable with a high *in vitro* dry-matter digestibility (IVDMD) of ≥65% (Hartadi *et al.* 1997;

Shelton 1998). Leucaena is also tolerant of heavy and frequent harvesting and can be established into existing production systems (Shelton 1998; Panjaitan *et al.* 2014*a*). Leucaena can be utilised in the predominant local cut and carry systems, because logistically the transportation of this forage to cattle houses is not demanding compared with other forages.

Feeding a high proportion of leucaena to male Bali cattle (*Bos javanicus* D'Alton) can increase liveweight (LW) gain from 0.2 to 0.4 kg/day (Dahlanuddin *et al.* 2014*a*; Panjaitan *et al.* 2014*b*; Soares *et al.* 2018). Feeding a high level of leucaena (70–100%) in the diet is a common practice, although it is considered a waste of the high-protein diet since there are regular feed shortages during the dry season and, moreover, the excess nitrogen in leucaena cannot be efficiently utilised by the rumen microbes and is likely to be excreted in the urine (Norton 1994). Supplementation with energy sources is required to better utilise the excess nitrogen (Harper *et al.* 2019) and to extend nutrient utilisation (Tillman *et al.* 1984).

Supplementation of non-structural carbohydrates to a leucaena-based diet is one option and has been reported to increase LW gain (Quigley *et al.* 2014; Dahlanuddin *et al.* 2018; Kariyani *et al.* 2021). There are a variety of non-structural energy sources that could be sourced locally, including corn grain and cassava, and its various by-products. Alternatively, low-quality corn stover could be used to extend the use of a limited amount of leucaena (Soares *et al.* 2018; Supriadi *et al.* 2022).

Corn grain is a locally sourced high-energy feed in Sumbawa and is used in the highly competitive monogastric industries; however, at certain times of the year, it is cheap locally and could be used for cattle. Cassava and its derivative by-products such as cassava peel are alternative energy sources that are often available at a much lower cost. The objective of this experiment was to assess various locally available fermentable energy sources that can be supplemented to a leucaena basal diet to increase LW gain of male Bali cattle.

Materials and methods

All procedures were approved with approval number of AFS/517/17/Indonesia by the University of Queensland Animal Ethics Committee.

Animals, experimental design, diets and feeding

This experiment was conducted in the Agricultural Techno Park, West Sumbawa District (8°54′37″S, 116°84′93″E), across 140 days that included 20 days of adaptation and 120 days of data collection. Forty male Bali cattle aged 20–24 months (179.0 ± 17.5 kg; mean ± s.d.) were used in this experiment. The cattle were treated with anthelmintic (albendazole) prior to commencement of the experiment and weighed (unfasted) and ranked on LW. The animals were then allocated to individual pens and treatments in a completely randomised block design. There were five treatments and each treatment consisted of eight animals as replication. The treatment diets were as follows: (A) control, including leucaena *ad libitum* + corn stover at 0.5% LW + mineral mix, (B) control + cassava meal at 1.0% LW, (C) control + cassava peels at 1.0% LW, (D) control + cassava peels mixed with grain–corn (1:1) at 1.0% LW and (E) control + commercial feed at 1.0% LW.

Corn stover was sourced from the surrounding area of Agricultural Techno Park either as field standing hay or manually collecting the remaining green foliage following the harvesting of corn grain. This was achieved by cutting the lower stems with a machete and tying up bundles for transportation. The corn stover was then chopped to 3–5 cm lengths and sun dried on a tarpaulin or concrete floor for 2–3 days. The chopped corn stover was turned regularly to hasten the drying process and the dried corn stover was placed in sacks and stored in a shed prior to use. Following harvesting, leucaena was sourced both from the Agricultural Techno Park and surrounding areas. Fresh leucaena was separated into leaves and associated twigs (edible parts) separate from inedible branches. The mixed edible parts were chopped to 3–5 cm in length and sun dried for 2–3 days, with regular turning to hasten the drying process. The dried leucaena was placed in sacks and stored in a shed prior to use. Cassava peels are the waste product of production of cassava chips and include whole tips. Cassava peels were collected from local villages that process cassava. Cassava peels were sun dried to half dried and ground to pass a sieve of 1 cm in diameter then completely dried in the sun. The dried ground cassava peels were then placed in sacks and stored in a shed prior to use. Gaplek or milled cassava chips are chopped whole cassava tubers, sun dried and ground into cassava meal and were sourced from East Java, transported to Sumbawa and then stored prior to use. A commercial feed from a feed company in East Java is available locally and has been promoted as a product to increase LW gain. The component proportions are commercial-in-confidence but the components are described as corn grain, corn gluten feed, wheat bran, molasses, soybean meal, copra meal, palm kernel meal and rice bran. The nutrient composition of all ingredients used in the experiment is described in Table 1.

Animals were fed twice a day, i.e. morning and afternoon. Before the morning feed at approximately 07:30 hours, all animals received 15–20 g of mixed commercial mineral mix and salt. The whole daily allowance of corn stover was offered at the first feeding and drinking water was provided in a 10 L bucket for animals to drink to satiety on the completion of the corn stover feeding. Energy supplements were then offered to approximately 30% of the daily allowance for each treatment except for the control group, which was offered half the allocation of leucaena in the morning. To complete the final stage of morning feeding, leucaena was offered to all energy-supplemented animals at the rate of approximately

Table 1. Nutrient composition of feed ingredients and the Feed treatments A, B, C, D and E.

Feed ingredient	Nutrient composition (%)				
	DM	OM	EE	CP	NDF
Corn stover	90.1	92.4	0.39	4.40	71.6
Leucaena hay	92.4	93.6	1.99	18.45	52.4
Cassava meal	88.8	90.8	0.27	3.09	25.3
Cassava peel	92.0	90.9	0.29	3.44	47.6
Cassava peel–corn grain mix (1:1)	90.8	91.3	0.72	5.00	45.0
Commercial feed	91.4	83.7	1.92	10.50	56.6
Feed treatment					
A	91.8	93.3	1.62	15.16	56.9
B	90.5	92.2	0.97	9.40	45.4
C	91.8	92.3	1.01	9.81	54.5
D	91.3	92.4	1.15	10.13	53.2
E	91.6	89.6	1.64	12.62	57.8

Treatment A, control, including leucaena *ad libitum* + corn stover at 0.5% DM LW + mineral mix; Treatment B, control + cassava meal at 1.0% DM LW; Treatment C, control + cassava peels at 1.0% DM LW; Treatment D, control + cassava peels mixed with corn (1:1) at 1.0% DM LW; and Treatment E, control + commercial feed at 1.0% DM LW. EE, ether extract; NDF, neutral detergent fibre; OM, organic matter.

30% of the daily allowance. Afternoon feeding commenced at 1400 hours and all animals were offered the remaining level of energy supplement except for the control group, which were offered the remaining allocation of leucaena. Once energy supplements were largely consumed, drinking water was provided in a 10 L bucket for animals to drink to satiety. On completion of the afternoon drinking, the remaining leucaena was offered to all animals. Leucaena was offered *ad libitum* and the amount offered daily was set at the intake of the previous day plus 0.5 kg, as fed.

Experimental data were collected over 17 weeks, which consisted of 16 weeks of data collection and 1 week of a feed digestibility trial. LW was measured weekly and feed intake was measured daily. Samples of feed and feed residues were taken every day and bulked over a month. Subsamples of feed and feed residues were taken for analysis every month. A digestibility study was conducted at the end of the experimental period and water intake was also measured. During this period, total faeces were collected during close monitoring for 24 h. Faecal matter was immediately collected from the concrete floor by shovel and placed in 20 L round bucket allocated to each animal. Daily total faeces collected were weighed every morning and the pen floor was cleaned prior to the next 24 h faecal collection to avoid contamination with foreign material. During the digestibility trial, a 10% subsample of daily faecal output was collected and frozen. On the last day of the digestibility trial, faecal samples were thawed, bulked and mixed well, with duplicate subsamples being collected for analysis. The subsamples of feed, feed residue and faecal material were then analysed for DM, organic matter (OM), CP, neutral detergent fibre (NDF) and acid detergent fibre (ADF) (AOAC 2005).

Rumen fluid was collected 3 h following the morning feeding on the last day of the experimental period. Rumen fluid samples were collected using a stomach tube equipped with a metal filter. The pH of bulk rumen fluid was determined immediately with an electronic portable pH meter (Senz-pH, TTBH Pte Ltd, Singapore). The rumen fluid (50 mL) was then transferred into 80 mL plastic bottles and sulfuric acid was added to ensure a pH below 2; the rumen fluid was then stored in the freezer at −20°C for rumen ammonia (NH_3) and volatile fatty acid (VFA) analysis.

Income-over-food cost (IOFC) was measured in Indonesian Rupiah on the basis of daily production and was calculated according to Priyanti *et al.* (2012) and Cowley *et al.* (2020).

The statistical significance of treatment effects was tested by ANOVA. The significant pairwise differences were tested using the Duncan's Multiple Range Test procedure. All data were analysed using statistical package IBM SPSS Statistics (Ver. 20) (IBM Corp 2020).

Results

The nutrient composition of each feed component and the experimental treatment rations are presented in Table 1. Leucaena hay had a CP content of over 18%, while the cassava by-products had a CP content of ~3%. Cassava meal had a low NDF content of 25%, while the highest NDF was in corn stover at 71%. Supplement concentrations were devised on the basis of 1% LW, so as to keep the cassava concentration below an estimated 40% of the ration, which was projected to be a total DM intake of 25 g/kg LW. This resulted in the estimated CP supply for Treatments B, C and D of 185, 185 and 183 g CP/kg digestible organic matter (DOM) respectively, in excess of the minimum requirement for rumen microbes of 130 g CP/kg DOM suggested by Poppi and McLennan (1995). Treatment A (leucaena alone) had a supply of 301 g CP/kg DOM and Treatment E (the commercial supplement) had an estimated supply of 262 g CP/kg DOM. These latter treatments could not be equated to other treatments and were well in excess of rumen microbial requirements.

The control diet (A), composed of leucaena and corn stover without supplementation, had a CP content of 15.16%. Supplementation of various energy sources decreased CP content, which ranged between 9.40% and 12.62%, although it remained greater than the minimum requirement for rumen microbial function. As such, these treatments were able to ascertain effect of various types of energy supplementation to the LW gain of male Bali cattle fed leucaena corn stover diets.

Energy supplementation increased the LW gain of Bali bulls fed leucaena corn stover-based diets above that of the control treatments, except with cassava peel supplementation

Table 2. Initial liveweight (LW) and LW gain of male Bali bulls fed Experimental treatments A, B, C, D and E.

Parameter	Treatment				
	A	B	C	D	E
Initial weight (kg)	181.80 ± 22.00	177.22 ± 16.87	174.71 ± 16.62	179.24 ± 17.55	179.85 ± 18.04
LW gain					
Total (kg)	47.62c ± 7.44	57.93b ± 9.40	53.01bc ± 3.44	68.25a ± 10.43	60.89ab ± 9.20
Daily (kg/day)	0.40c ± 0.06	0.48b ± 0.08	0.44bc ± 0.03	0.57a ± 0.09	0.51ab ± 0.08

Treatment A, control, including leucaena *ad libitum* + corn stover at 0.5% DM LW + mineral mix; Treatment B, control + cassava meal at 1.0% DM LW; Treatment C, control + cassava peels at 1.0% DM LW; Treatment D, control + cassava peels mixed with corn (1:1) at 1.0% DM LW; and Treatment E, control + commercial feed at 1.0% DM LW.
Within a row, values with different letters differ significantly (at $P = 0.05$).

(Table 2). There was a 20% improvement in LW gain when Bali bulls were supplemented with cassava meal, and 27% improvement when supplemented with commercial mix. The greatest LW gain was a 42% improvement when cassava peel–corn grain mix was supplemented at a 1% level. There was no statistical difference between commercial feed and cassava peel–corn grain mix supplement.

Supplementation with cassava peel–corn grain mix (D) or with commercial feed (E) at 1% of bodyweight increased total feed intake (DM intake (DMI) and OM intake (OMI)) of Bali bulls by up to 16% compared with that of bulls fed leucaena corn stover diets ($P < 0.05$). Supplementation with cassava chips and cassava peels at this level did result in increases in DMI, but they were not significantly different from the control (Table 3). Digestible OMI (DOMI) was highest in bulls in the cassava peel–corn grain mix treatment (D). The DMD and OMD values were higher in the cassava treatment (B, 60.25% and 63.8% respectively) and cassava peel plus corn grain mix treatment (D, 57.01% and 62.67% respectively) than in the control treatment (A, 50.18% and 54.53% respectively). A lower imbibed-water intake was recorded in cattle supplemented with cassava meal treatment (B). This value was significantly lower than that in the control (A) and cassava peel-supplemented (C) treatments, but not in the commercial diet-supplemented bulls (D).

The mean total VFA concentration in the rumen fluid was not affected by the type of energy supplementation ($P > 0.05$; Table 3). Similarly, there was no difference in the molar percentage of acetate to propionate ratio for any treatment. Rumen ammonia concentration was greater than the minimum requirement (50 mg ammonia N/L) (Satter and Slyter 1974) for rumen microbes and there was no statistical difference among the treatments. Rumen pH was not affected by the type of energy supplementation. Faecal pH was significantly lower with supplementation of cassava peel–corn grain mix (Table 4).

The feed-for-gain conversion was significantly lower in the cassava (B) and peel and grain (D) treatments than in the control (Table 5). The highest feed cost per gain resulted in a lower IOFC with commercial feed supplementation. Cassava-based energy supplementation increased IOFC of Bali bulls above that of the control treatments ($P < 0.05$). Feed costs and prices/kg of weight gain were based on those available in 2020.

Table 3. Intake and digestibility data for Bali bulls for Experimental treatments A, B, C, D and E.

Parameter	Treatment				
	A	B	C	D	E
DMI (g/kg LW)	20.39b ± 1.88	21.39b ± 3.57	21.74b ± 1.96	23.48a ± 1.51	23.70a ± 3.07
OMI (g/kg LW)	18.83c ± 1.19	17.03c ± 2.49	20.13bc ± 1.79	20.68ab ± 1.27	21.80a ± 3.02
IWI (g/kg LW)	89.75a ± 2.91	75.68b ± 7.34	87.16a ± 5.16	87.08a ± 18.9	85.25ab ± 3.73
DMD (%)	50.18bc ± 2.39	60.25a ± 4.45	52.06b ± 2.24	57.01a ± 4.25	47.62c ± 2.56
OMD (%)	54.53bc ± 2.58	63.80a ± 4.52	57.28b ± 1.90	62.67a ± 4.09	52.08c ± 2.47
ME (MJ/kg DM)	7.0	8.4	7.5	8.3	6.7
DOMI (g/kg LW)	10.26b ± 0.71	10.91b ± 2.03	11.54b ± 1.17	12.95a ± 1.11	11.39b ± 1.97

Treatment A, control, including leucaena *ad libitum* + corn stover at 0.5% DM LW + mineral mix; Treatment B, control + cassava meal at 1.0% DM LW; Treatment C, control + cassava peels at 1.0% DM LW; Treatment D, control + cassava peels mixed with corn (1:1) at 1.0% DM LW; and Treatment E, control + commercial feed at 1.0% DM LW.
DMI, dry-matter intake; OMI, organic-matter intake; IWI, imbibed-water intake; DMD, dry-matter digestibility; OMD, organic-matter digestibility; ME, metabolisable energy estimated from Minson (1984); DOMI, digestible organic-matter intake.
Within a row, values with different letters differ significantly (at $P = 0.05$).

Table 4. Rumen and faecal parameters of male Bali cattle fed Experimental treatments A, B, C, D and E.

Parameter	Treatment				
	A	B	C	D	E
$N\text{-}NH_3$ (mg/L)	139.9a ± 6.06	134.3a ± 2.57	151.4a ± 3.22	160.0a ± 5.06	142.5a ± 3.55
Total VFA (mMol)	142.4a ± 43.20	116.3a ± 31.79	81.8a ± 29.87	93.9a ± 37.87	105.0a ± 38.80
VFA (%)					
Acetate (C_2)	68.4ab ± 2.41	66.1b ± 1.40	68.1ab ± 1.35	66.5b ± 1.55	69.4a ± 1.17
Propionate (C_3)	23.5a ± 0.96	24.3a ± 2.48	22.5a ± 2.20	24.4a ± 2.52	22.1a ± 1.33
Butyrate (C_4)	8.1a ± 1.92	9.6a ± 1.08	9.4a ± 1.60	9.1a ± 1.31	8.5a ± 0.16
Acetate:propionate ratio	2.92a ± 0.20	2.75a ± 0.37	3.05a ± 0.33	2.75a ± 0.35	3.15a ± 0.24
Rumen fluid pH	6.5a ± 0.08	6.3a ± 0.20	6.5a ± 0.11	6.3a ± 0.19	6.5a ± 0.06
Faecal pH	7.1a ± 0.06	6.8b ± 0.19	7.0a ± 0.08	6.6c ± 0.17	7.0a ± 0.05

Treatment A, control, including leucaena *ad libitum* + corn stover at 0.5% DM LW + mineral mix; Treatment B, control + cassava meal at 1.0% DM LW; Treatment C, control + cassava peels at 1.0% DM LW; Treatment D, control + cassava peels mixed with corn (1:1) at 1.0% DM LW; Treatment E, control + commercial feed at 1.0% DM LW.
Within a row, values with different letters differ significantly (at $P = 0.05$).

Table 5. Feed conversion and daily income-over-feed costs (IOFC) of male Bali cattle fed Experimental treatments A, B, C, D and E.

Parameter	Treatment					*P*-value
	A	B	C	D	E	
Feed-for-gain conversion	11.54 ± 1.59c	9.95 ± 1.82ab	10.90 ± 0.89bc	9.32 ± 1.35a	10.42 ± 1.08bc	0.039
Feed cost (IDR/day)	9161 ± 786b	10 876 ± 1865c	8201 ± 718a	12 008 ± 821d	13 362 ± 1812e	<0.001
Income/gain (IDR)	19 049 ± 286a	23 172 ± 3827b	21 205 ± 1426ab	27 299 ± 4168c	24 355 ± 2646bc	<0.001
IOFC (IDR/day)	9888 ± 2628a	12 297 ± 3262ab	13 004 ± 1239ab	15 291 ± 3927b	10 993 ± 2550a	0.016

Treatment A, control, including leucaena *ad libitum* + corn stover at 0.5% DM LW + mineral mix; Treatment B, control + cassava meal at 1.0% DM LW; Treatment C, control + cassava peels at 1.0% DM LW; Treatment D, control + cassava peels mixed with corn (1:1) at 1.0% DM LW; Treatment E, control + commercial feed at 1.0% DM LW.
IDR, Indonesian rupiah.
Within a row, values followed by the same letter are not significantly different (at $P = 0.05$).

Discussion

Supplementation with high energy-content locally available products increased LW gain of Bali bulls fed a leucaena corn stover basal diet to high levels for this breed of cattle. The best gain was achieved with the supplementation of a cassava peel and corn grain mixture. In general, the growth rates in this study were comparable to the values of 0.4–0.6 kg/day for male Bali cattle fed similar diets (Dahlanuddin *et al.* 2014*b*; Panjaitan *et al.* 2014*b*; Soares *et al.* 2018) and approaching the genetic potential of Bali bulls (0.85 kg/day) reported by Mastika (2003). This strategy was used to increase the utilisation of the high CP-content leucaena both in terms of utilising the high CP in the plant and extending the use of a limited amount of leucaena.

Poppi *et al.* (2021) outlined how various cattle-fattening systems in Indonesia could be made more profitable. One approach was to better utilise the expanding leucaena-based systems in eastern Indonesia by adding a fermentable carbohydrate source to capture the excess CP in leucaena and also to use the intake substitution effect to allow more animals to be carried on a unit area. Farmers in these areas fatten from two to three bulls, up to larger numbers in excess of 30 bulls. Leucaena grows year-round and any energy supplement would need to be collected and stored or simply used when available. Corn grain is readily available during the usual harvesting period and prices are lower then, as is damaged grain that cannot be exported to other areas of Indonesia. So, for both cassava and corn, there are opportunistic periods of the year for use and also, with some forward planning, the ability to buy and store these products at a much lower cost. Poppi *et al.* (2021) calculated the potential of these leucaena systems for Bali bulls to be 2000 kg LW gain/ha.year, and with cassava added at appropriate rates as used here, it could rise to 3700 kg LW gain/ha.year.

Cassava meal and cassava peels did not increase LW gain by much, but the highest increase occurred when some corn grain was added to the mixture. Corn grain is better used by monogastrics, but there are opportunities to use it in this corn-growing area and the current result shows that it can be used effectively. All three strategies of using a fermentable carbohydrate source from cassava products or mixed with corn grain to better utilise the high CP of leucaena or to extend limited amounts of leucaena appeared to have some benefit either in LW gain or IOFC or both. This is in agreement with Quigley *et al.* (2009), who demonstrated a significant increase in LW gain when growing Bali bulls were fed a basal diet of leucaena (0.43 kg LW/day) and offered maize grain (0.61 kg LW/day) compared with rice bran (0.56 kg LW/day) supplements at 10 g DM/kg LW.day (or 1% DM LW.day). Similar results were found by Dahlanuddin *et al.* (2018) who reported a LW gain of 0.66 kg/day in Bali bulls fed a basal diet of leucaena *ad libitum* supplemented with maize grain at 10 g DM/kg LW.day. The commercial feed mix based on corn grain, corn gluten feed, wheat bran, molasses, copra meal and rice bran gave a similar result, but at a much higher cost (Table 5).

The current study shows that cassava products can be used effectively to fatten cattle. Kariyani *et al.* (2021) and Retnaningrum *et al.* (2021) suggested that the level of inclusion should be below 40% of the ration, as used here, because higher levels markedly reduced intake and LW gain. A limitation to feeding cassava, particularly the peel, is the presence of cyanogenic (HCN) compounds. To minimise this issue, cassava products were properly dried to ensure a low HCN concentration in either cassava chips or cassava peels (Lebot 2009; Lukuyu *et al.* 2014). The drying of cassava and the limited amounts provided ensured a safe intake of cassava. This was confirmed with the high intakes and high LW gain in this study.

The LW gains were associated with increases in DMI ($P < 0.05$), in line with other experiments (Dahlanuddin *et al.* 2012; Marsetyo *et al.* 2012; Quigley *et al.* 2014). The highest feed intakes were recorded with supplementation of the commercial feed and the cassava peel–corn grain mix, but the feed-for-gain conversion was higher with the cassava–corn grain mix. Because there are limited details of the ingredient mix proportions of the commercial supplement, it is hard to determine the reasons behind the response; nevertheless, the results outline the response and higher costs involved to get a response similar to that from feeding locally available ingredients. The partial budget analysis indicated that the IOFC of commercial feed (10 993 ± 2550) was significantly lower than that of the cassava peel + corn grain mix (15 291 ± 3927) due to higher feed cost per gain on commercial feed supplementation. The high LW gain in the cassava peel–corn grain mix treatment (D) was also associated with a higher DMD (57.0%) than in the control (50.1%). As DOMI is a function of feed intake and OMD, this in turn provided a significantly higher DOMI (12.95 g/kg LW) than did all the other treatments. This was also reflected in the estimated ME content of the various rations, ranging from 6.7 to 8.4 MJ ME/kg DM (Table 3).

It was of interest that a low digestibility was associated with the commercial-supplement treatment (E), which was statistically the same as the control diet without supplement. Although the commercial feed proportional composition is not known, the ingredients were corn grain, corn gluten feed, wheat bran, molasses, soybean meal, copra meal, palm kernel meal and rice bran, all being considered as common high-quality feed ingredients in Indonesia. However, the chemical composition showed that there was a lower OM content, indicating another source of contamination.

The cassava and corn grain have high concentrations of starch, which could decrease rumen pH. In this study, rumen fluid pH was unaffected by energy-source supplementation and ranged from 6.3 to 6.5, which, while low, is within the recommended range suggested by Russell and Dombrowski (1980), although still reflects the likely higher starch digestion within the rumen. Supplements were fed over two feeds throughout the day, feeding the high-fibre ingredients first and having a generally high fibre content of the diets to minimise any acidosis within the rumen, and this strategy appeared successful. Faecal pH values were not unusual, suggesting no large-scale escape of starch from the rumen.

There were minimal differences in rumen VFA parameters associated with the different treatments and they were within the normal range of 70–150 mmol/L (McDonald *et al.* 1995). Similarly, percentages of acetate, propionate and butyrate in all treatments were quite similar. The overall molar percentages were 67.7%, 23.4% and 8.9% for acetate, propionate and butyrate respectively, and supplementation did not markedly increase the molar percentage of propionate.

The CP content of the supplement-treatment rations ranged between 9.40% and 12.62% and was lower than that of the control diet (15.16%), but still greater than the minimum requirement to meet intake and rumen microbe function (Satter and Slyter 1974; Poppi and McLennan 1995). The values in all diets were greater than the rumen microbial CP requirement of 130 g MCP/kg DOM suggested by Poppi and McLennan (1995). This resulted in no treatment difference in the ammonia-N concentration in the rumen fluid, which ranged from 134 to 160 mg N/L, being well above the minimum 50 mg ammonia-N/L suggested by Satter and Slyter (1974).

In a smallholder system, water is often supplied to the cattle in buckets. As such, it is important to determine the differences in water intake associated with the different diets. The highest water intake was recorded with the control diet. All feed ingredients used to compose treatment diets had a DM content greater than the minimum threshold for storage stability, since the microbial activity is minimised at DM content of 80% or more (Smith *et al.* 2020). The imbibed-water intakes in all treatments were lower than the values of 87–136 g/kg LW reported previously by Dahlanuddin *et al.* (2014*a*) with a similar class of Bali cattle fed diets with higher CP content and intake. The values represent volumes that need to be provided because limitations in water intake can depress DM intake. Of course, if freshly harvested leucaena is fed, then a significant water intake would come from that in the leucaena and, depending on the amount of dry supplement provided, the quantity of water needed to be provided externally will be much less, if water is required at all.

Feed cost generally represents 70% of the beef cost production, and feed-for-gain and IOFC are ways to determine the profitability of a system. Supplementation with cassava products, especially when combined with corn grain, increased IOFC, a measure of profit for smallholders. In fact, using corn grain, when available locally, provided the highest profit for a farmer. Use of a commercial feed supplement was not profitable. Other studies with high-quality corn stover in central Sulawesi have given IOFC of IDR7700/day, rising to IDR12 500/day with supplements (Marsetyo *et al.* 2012). Leucaena with or without supplements can provide the highest IOFC, depending on yields achieved, with IOFC values of ~IDR20 000/day (Dahlanuddin *et al.* 2014*b*; Panjaitan *et al.* 2014*b*) when farmers grow their own leucaena. The IOFC in this experiment reflects the cost of buying leucaena commercially from other farmers.

Conclusions

Supplementation with a fermentable carbohydrate in a leucaena-based diet improves LW gain of Bali bulls. Supplementation with a mix of cassava peel and corn grain (1:1) at about 42% of the diet (10 g DM/kg LW.day) resulted in the best growth rate and IOFC. Replacing approximately 40% of the leucaena with cassava products or a mixture with corn grain improved cattle growth, feed conversion and income and can extend the use of a limited amount of leucaena. This practice would increase the capacity of farmers to feed more cattle per hectare in a leucaena-based production system and increase income per cattle being fattened. This can expand the production scale and subsequent farmer income, provided that the energy sources are available at affordable prices and easy to obtain.

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