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Utilising *Gliricidia sepium* leaf meal as a protein substitute in cassava-based supplements to increase average daily gain of Ongole bulls and income of smallholder farmers

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ABSTRACT

Context. Formulating supplements with *Gliricidia sepium* leaf meal (GLM) and cassava powder to promote liveweight gain of Ongole bulls. **Aims.** This study was conducted to evaluate the effect of using GLM as a substitute for copra meal (CM) or soybean hulls (SBH) in a concentrate containing dry cassava powder (DCP) on the average daily gain of Ongole bulls and income over feed cost. **Methods.** Forty Ongole bulls were allocated in a randomised block design with 10 head per treatment. The control group (R_0) was provided the current feeding system (CFS) fed *ad libitum*, with supplemented treatments consisting of the current feeding system fed *ad libitum* + 1% liveweight (on approximate DM basis)/day of three different concentrate supplement diets (R_1, R_2 and R_3). R_1 concentrate contained 50% DCP, 25% CM and 25% SBH; R_2 was 50% DCP, 25% GLM and 25% SBH; and R_3 was 50% DCP, 25% CM and 25% GLM. The bulls belonged to cooperative smallholder farmers in the Banaran and Bleberan villages, Playen Subdistrict, Gunungkidul Regency, Yogyakarta, Indonesia. The experiment was performed for 12 weeks from 22 December 2018 to 16 March 2019. **Key results.** The average weight gain of bulls (kg/head) in the treatments R_0, R_1, R_2 and R_3 were 0.31, 0.75, 0.61 and 0.62, respectively. The income over feed cost of supplement treatments R_1, R_2 and R_3 was double that of the control (R_0). **Conclusions.** It was concluded that GLM can replace the use of SBH and CM in a cassava-based supplement and increase the income of farmers in this district. **Implications.** Cassava powder can be combined with GLM to form a concentrate that increases the average weight gain of Ongole bulls and income of farmers.

Keywords: concentrates, feed formulations, forage trees, least cost rations, profit, protein supplements, ruminant nutrition, supplements, tropical cattle.

Introduction

Self-sufficiency in beef production is one of the goals of the Indonesian government program in 2026 (Sulaiman *et al.* 2018). Currently, Indonesian beef production is mostly supplied by smallholder farmers and is unable to meet domestic demands. There are approximately 16.4 million head of beef cattle across all of Indonesia, and 98% of the cattle population is raised by smallholder farmers (DGLS 2018). Smallholders can have quite efficient production systems, but cattle raised in smallholder farms often have low growth rates and poor feed conversions due to the lack of feed and/or poor diet formulations. Farmers offer forage to cattle usually based on availability without regard to meeting energy and protein requirements (Adiwinarti *et al.* 2011). The subsequent low farmer profitability can be addressed by better utilising available energy sources, such as dried cassava powder (DCP) or cassava pulp, and various protein sources, such as copra meal (CM), soybean hulls (SBH) or legume leaves.

The highest average daily gain (ADG0 reported for Ongole cattle in Indonesia is 1.3 kg/day; Mayberry *et al.* 2014). The protein concentrates from this experiment are too expensive for smallholder farmers (CM being 4876 Indonesian rupiah (IDR)/kg DM and SBH being 4614 IDR/kg DM). Therefore, it is important to evaluate other cheaper and more accessible sources of protein. Locally grown and processed *Gliricidia* leaf meal (GLM) as a protein source has the potential to be more profitable and adoptable for smallholder farmers.

In this study, GLM was used to replace CM or SBH in a concentrate based on cassava powder. GLM is processed from *Gliricidia sepium* leaves by drying and grinding similar to the process in making *Leucaena leucocephala* leaf meal (Gunawan and Gunardi 2000). *Gliricidia sepium* is a leguminous tree and the leaves are a good source of protein (approximately 18% crude protein (CP; Smith and van Houtert 1987). Fresh *Gliricidia* leaf is limited in use for cattle because of varying palatability issues (Smith and van Houtert 1987), and processing it into meal or pellets and mixing it with other local ingredients may be one way to improve its acceptance and use. Copra meal is a by-product of coconut oil extraction and has an appreciable CP of approximately 22% (Feedipedia 2012*a*). CM is also a potentially valuable source of energy due to its residual oil content. SBH is a by-product of the oil extraction process (Goehring *et al.* 2012), with a CP content of approximately 13% (Feedipedia 2016) and an appreciable digestibility value (77% total digestible nutrients; Negrão *et al.* 2020). There are few strategies to increase the metabolisable energy (ME) content of a concentrate mix in Indonesia, as grains are best used for humans and the poultry industry, and most by-products are not as high in ME as grains. Cassava tuber (whole or processed) provides one of the few opportunities in Indonesia, as it is widely grown and the agronomy is well established. However, farmers tend to purchase it rather than growing their own for cattle feed. There is an opportunity to combine cassava tuber with a high protein tree legume or protein meals to formulate a concentrate supplement that is cheap and readily accessible to farmers.

Dried cassava tuber has a high digestibility and ME value (approximately 12.2 MJ/kg DM) with a low protein content (approximately 2.9% CP; Feedipedia 2012*b*). Recent feeding trials have shown that cassava tuber inclusion should not exceed 40–50% of a ration for fattening bulls (Retnaningrum *et al.* 2021).

The objectives of this experiment were to determine the effect of substituting CM or SBH with GLM in a cassava-based concentrate supplement on the ADG of Ongole bulls, and whether this was a good strategy to increase the farmer's income. The hypothesis of this experiment is that GLM can replace CM and SBH as a protein source in cassava-based concentrate supplements for beef cattle. It is also hypothesised that the use of GLM will increase the ADG of Ongole bulls with a lower feed cost, thus making it more profitable for smallholder farmers.

Materials and methods

Animals

Forty Ongole bulls with an initial bodyweight of 199 ±41.1 kg and aged between 12 and 18 months were used in this village experiment. This is a typical weight of Ongole bulls in the smallholder system in Indonesia. Their weight is low, particularly for the frame size, so there is a large potential for improvement for ADG. The cattle were owned by a cooperative smallholder farmer group in Banaran and Bleberan villages. The two villages are located in Playen Subdistrict, Gunungkidul Regency, Special Region of Yogyakarta, Indonesia, and all treatments were allocated across both villages. All bulls received an identification number that was attached to a neck collar. All bulls were treated with macrocyclic lactone via an ivermectin subcutaneous injection (dose: 1 mL/50 kg liveweight (LW)) to control internal and external parasites prior to commencement of the experiment. This experiment was approved by the University of Queensland Animal Ethics Committee.

Experimental design

Bulls were randomly allocated into either a control group (R_0) or one of three treatments (R_1, R_2 and R_3), as shown in Table 1. Feed nutrient content of the current feeding system (CFS – R_0) and the concentrate diets of treatments can be seen in Table 2. The control group (R_0) was fed the CFS, whereas treatment groups were fed the CFS and dietary supplements at an approximate 1% LW/day on a DM basis. Each treatment involved 10 bulls (five bulls in Banaran and five bulls in Bleberan), so the total number of bulls (40) was used in this experiment. All treatments diets were allocated randomly in each village.

Table 1. Dietary treatments.

Treatments	Composition of feed
R_0	CFS *ad libitum*
R_1	CFS *ad libitum* + concentrate (50% DCP, 25% SBH, 25% CM) offered at estimated DM level of 1% LW/day
R_2	CFS *ad libitum* + concentrate (50% DCP, 25% SBH, 25% GLM) offered at estimated DM level of 1% LW/day
R_3	CFS *ad libitum* + concentrate (50% DCP, 25% CM, 25% GLM) offered at estimated DM level of 1% LW/day

CFS, current feeding system consisted of native grass (*Paspalum conjugatum*, *Cynodon dactylon*), cultivated grass (*Pennisetum purpureum*), agricultural waste (corn stover, peanut straw) and tree leaf (*Artocarpus heterophyllus*, *Albizia chinensis*); DCP, dry cassava powder; SBH, soybean hulls; CM, copra meal; GLM, *Gliricidia sepium* leaf meal; DM, dry matter; LW, live weight.

Table 2. Feed nutrient content of the current feeding system (R_0) and the concentrate supplements of treatments (R_1, R_2 and R_3).

Diets	DM (% as fed)	CP (% DM)	EE (% DM)	CF (% DM)	NFE (% DM)	TDN (% DM)	ME (MJ/kg DM)	Price (IDR/kg DM)
R_0	24.5	7.3	1.89	42.8	38.9	48.9	7.4	2041
R_1	89.9	8.6	2.51	15.9	67.3	68.6	10.9	4156
R_2	90.3	8.3	1.87	15.8	66.2	64.9	10.3	2998
R_3	90.1	10.2	3.28	8.7	69.5	71.7	11.5	3075

Note: R_0 = current feeding system (CFS); R_1 = 50% DCP, 25% SBH, 25% CM; R_2 = 50% DCP, 25% SBH, 25% GLM; R_3 = 50% DCP, 25% CM and 25% GLM. DM, dry matter; CP, crude protein; EE, ether extract; CF, crude fibre; NFE, nitrogen-free extract; TDN, total digestible nutrients was calculated from Harris *et al.* (1972) TDN $= -54.572 + 6.769\ (\mathrm{CF}) - 51.083\ (\mathrm{EE}) + 1.851\ (\mathrm{NFE}) - 0.334\ (\mathrm{CP}) - 0.049\ (\mathrm{CF})^2 + 3.384\ (\mathrm{EE})^2 - 0.086\ (\mathrm{CF}) \times (\mathrm{NFE}) + 0.687\ (\mathrm{EE}) \times (\mathrm{NFE}) + 0.942\ (\mathrm{EE}) \times (\mathrm{CP}) - 0.112\ (\mathrm{EE})^2 \times (\mathrm{CP})$ for R_0, whereas the supplements in R_1, R_2 and R_3 were calculated using TDN $= -202.686 - 1.357\ (\mathrm{CF}) + 2.638\ (\mathrm{EE}) + 3.003\ (\mathrm{NFE}) + 2.347\ (\mathrm{CP}) + 0.046\ (\mathrm{CF})^2 + 0.647\ (\mathrm{EE})^2 + 0.041\ (\mathrm{CF}) \times (\mathrm{NFE}) - 0.081\ (\mathrm{EE}) \times (\mathrm{NFE}) + 0.553\ (\mathrm{EE}) \times (\mathrm{CP}) - 0.046\ (\mathrm{EE})^2 \times (\mathrm{CP})$. Metabolisable energy (ME) calculated from CNCPS DE (Mcal/kg DM) = (TDN%/100) × 4.409 where ME (Mcal/kg DM) = (DE (Mcal/kg DM) × 1.01) − 0.45 then converted to MJ/kg DM by multiplying by 4.184. The price of concentrate is calculated from market price in this region. DCP is 3617 IDR/kg DM, SBH is 4614 IDR/kg DM, CM is 4876 IDR/kg DM and GLM is 557 IDR/kg DM.

Diet and feeding management

Bulls were housed individually, and CFS was offered *ad libitum* to each animal in the morning and in the afternoon. The constituents of the CFS mainly consisted of native grass (*Paspalum conjugatum*, *Cynodon dactylon*), cultivated grass (*Pennisetum purpureum*), agricultural waste (corn stover, peanut straw) and tree leaf (*Artocarpus heterophyllus*, *Albizia chinensis*). GLM, CM, SBH and DCP were used in the concentrate in various proportions (Table 1) to make up the supplemented treatments. GLM was made by harvesting fresh *G. sepium* leaves at Wanagama forest and sun-dried for 12–48 h until a moisture content of approximately 15% was obtained. Dried *Gliricidia* leaves were then ground by local farmers at Banaran village and formed the GLM. CM, SBH and DCP were purchased from local traders. Each different concentrate was mixed as a mash prior to offering. There was a 2-week adaptation period to reach an estimated DM supplement level of 1% LW/day, which was adjusted based on LW measured every 3 weeks. A mineral block was provided to each animal in the feeding trough during the experiment.

Measurements

At the start and every 3 weeks until the end of the trial, all bulls were weighed individually in the morning after food and water were removed at 22:00 hours the previous night. Average daily LW gain (kg) was calculated by regression of LWt during the experimental trial, using the initial LW as a covariate. These weights were used to calculate supplement level, which was based on LW. Individual feed intakes (FIwas observed daily by the farmers using individual spring scales and a whiteboard as a diary under the supervision of a technician. The amounts of feed offered and refused were monitored by a technician to ensure bulls had *ad libitum* access to sufficient CFS. Samples of CFS were taken and stored once every 3 weeks for DM analysis.

Samples of concentrates were collected in the first week and 12th week of the experiment for DM, ash, CP, ether extract (EE) and crude fibre (CF) analysis. Ether extract was determined by Method No 930.09 (AOAC 2005), CP by Method No. 978.04 (AOAC 2005) and CF determined by Method No. 930.10 (AOAC 2005). The amount of nitrogen-free extract (NFE) was calculated via the equation: % NFE = 100 − (% moisture + % EE + % ash + % CF + % CP). The concepts of CF and NFE are standard in animal feed analysis in Indonesia.

The feed to gain ratio (FFG) was the ratio of feed DM intake to ADG. Income over feed cost (IOFC) was obtained from the ADG multiplied by the price of the ADG (IDR/kg LW) minus the average daily feed costs of DMI (IDR/day), as previously reported by Cowley *et al.* (2020). The price of ADG was IDR 55.000/kg LW.

Statistical analyses

The experiment was a randomised complete design with four treatments and 10 animal replications. Data were analysed using analysis of covariance (ANCOVA), with the initial bodyweight of bulls as the covariate to control the effect of this variable to the dependent variable (Montgomery 2013). Least-squares means for each treatment were calculated, then continued with orthogonal contrast analysis to compare control (R_0) versus treatment (R_1, R_2 and R_3); without GLM (R_1) versus with GLM (R_2 and R_3); and R_2 (with GLM and SBH) versus R_3 (with GLM and CM).

The data analysis for forage intake, concentrate intake, total feed intake, ADG, FFG and IOFC was performed using the General Linear Model procedure in SAS (Statistical Analysis System) version 9.0.

Results

The CFS intake of bulls maintained without concentrate (R_0) was not different to the CFS intake of bulls with treatment R_1,

R_2 and R_3 (CFS + concentrate; $P > 0.05$), and ranged from 3.29 to 3.96 kg DM/head per day (Table 3). The concentrate intake of bulls with treatments R_1, R_2 and R_3 were not different (Table 3). As such, the total feed intake of bulls with concentrate supplementation (treatment R_1, R_2 and R_3) was significantly ($P < 0.01$) higher than bulls maintained under CFS (R_0) (Table 3). However, feed intake (% LW of bulls in control group (R0)) was not different to R_2, but lower than R_1 and R_3. The ADG of bulls supplemented with concentrates R_1, R_2 and R_3 was significantly ($P < 0.01$) higher than the control group (R_0; 0.31 for the control group compared with 0.60–0.75 kg/head for supplemented groups; Table 3). The FFG (kg feed DM intake/kg LW gain) did not differ among treatments. In this experiment, FFG ranged from 8.47 to 10.77 (Table 3). Concentrate supplementation (R_1, R_2 and R_3) approximately doubled ($P > 0.01$) the value of daily iIOFC compared with the control group (R_0; Table 3).

Discussion

Ongole bulls are a breed of *Bos indicus* cattle with a similar origin locality to the source of Nellore bulls in Brazil, but they have not had the same selection pressure applied. The mature weight of cows is approximately 348 kg (Mayberry *et al.* 2014), and their smaller size means they have a valuable role in smallholder systems of production. Mayberry *et al.* (2014) evaluated the nutritional requirements of cows and bulls using the Australian Ruminant Feeding Standards (Freer *et al.* 2007) and the North American Large Ruminant Nutrition System (Fox *et al.* 2004), and concluded that they have similar nutritional requirements and respond similarly as other *Bos indicus* breeds. This experiment examined strategies by which ADG of bulls could be increased at a village level. Smallholder systems have limited opportunities to increase the ME intake and ADG with available feed resources. The use of cassava and its by-products provide one way in which the ME content and presumably ME intake could be increased. Cassava is widely grown in Indonesia and other Asian and African countries, but can also be widely grown across northern Australia and Central and South America (Fukai and Hammer 1987), and as such, its use as a supplement or in a total mixed ration has wide international application. It is low in CP, so ingredients high in CP need to be added to the mix. Protein meals, such as CM and SBH, are often used in various feeding systems, but their cost and availability can vary markedly across Indonesia, and the use of locally available tree legumes, such as *Gliricidia* and *Leucaena*, offer a pathway to combine ingredients at lower cost or higher availability. This experiment has demonstrated that the ADG and IOFC of three supplement mixes based on these protein sources with a high ME (>10 MJ ME/kg DM) content ingredient (DCP) was markedly improved, and that there were no major differences between supplement types based on GLM and DCP and those based on protein meals or by-products (CM or SBH).

The ADG of Ongole bulls maintained under the CFS was 0.31 kg/head with feed intake of 1.8% LW/day (Table 3). These ADG and intake values are similar to those reported by Wiyatna *et al.* (2012) in a very similar production system with Ongole bulls (ADG of 0.25 kg/head with a feed intake of 1.3% LW/day) and Marsetyo *et al.* (2021) with fresh corn stover (0.31 kg/head). Supplementation increased the ADG to 0.60–0.75 kg/head (Table 3), which

Table 3. Daily intake of feeds, average daily gain and income over feed cost (IOFC) of Ongole bulls fed CFS (R_0) and CFS + concentrate supplements (R_1, R_2 and R_3).

Variable	Treatment				s.e.m.	*P*-value of the contrasts		
	R_0	R_1	R_2	R_3		*a*	*b*	*c*
Initial liveweight (kg/head)$^{n.s.}$	179.7	208.4	210.8	198.6	12.91	–	–	–
Forage intake (DMI/day)$^{n.s.}$	3.38	3.96	3.29	3.45	0.380	–	–	–
Concentrate intake (DMI/day)	0.00	2.34	2.30	2.21	0.059	<0.0001**	0.4663	0.9498
Total feed intake (DMI/day)	3.38	6.30	5.58	5.66	0.382	<0.0001**	0.1996	0.6211
Feed intake (% LW)	1.80	2.69	2.38	2.48	0.167	<0.0004**	0.1965	0.7687
ADG (kg/head)	0.31	0.75	0.60	0.62	0.031	<0.0001**	0.0013**	0.7821
FFG (kg FI in DM/kg ADG)$^{n.s.}$	10.77	8.47	9.84	9.44	0.852	–	–	–
IOFC (IDR/head per day)	10 201	23 396	19 719	20 219	1952	<0.0001**	0.1426	0.9891

Note: R_0 = current feeding system (CFS), R_1 = CFS + concentrate (50% DCP, 25% SBH, 25% CM), R_2 = CFS + concentrate (50% DCP, 25% SBH, 25% GLM), R_3 = CFS + concentrate (50% DCP, 25% CM, 25% GLM). All supplements fed at estimated DM level of 1% LW/day. *a* = Control (R_0) versus Treatment (R_1, R_2 and R_3); *b* = without GLM (R_1) versus with GLM (R_2 and R_3); *c* = R_2 (with GLM and SBH) versus R_3 (with GLM and CM).
**Significant ($P < 0.01$); n.s., non-significant.
ADG, average daily gain; FFG, feed for gain ratio; IOFC, income over feed cost; DM, dry matter; LW, liveweight; IDR, Indonesian rupiah; s.e.m., standard error of the mean.

was similar to Lestari *et al.* (2011) of 0.78 kg/head and Marsetyo *et al.* (2021) of 0.69 kg/head. In controlled experiments with Ongole bulls on research stations, Mayberry *et al.* (2014) recorded ADG values up to 1.3 kg/day with diets based on corn grain and protein meals. Increasing the ADG of bulls under supplementation achieved here is a major change to the production system and substantially reduces the time taken to reach sale weights. The results of Mayberry *et al.* (2014) indicate that there is still a large opportunity for improvement.

The effectiveness of a supplement to increase the ADG of a cut and carry forage system depends on the nutrient content of the supplement. The estimated ME content of the CFS and the various supplement mixes are seen in Table 2. Treatment R_1 was based on a previous mix that markedly increased the ADG in Euro × Ongole bulls, but relied on protein meals. Treatments R_2 and R_3 replaced some of the protein meal sources with GLM. This strategy increased the ME content of the supplement. and enabled a higher DM and hence ME intake to be achieved with an expected increase in ADG (Table 3). Furthermore, it provided a basis for inclusion of GLM into the supplement.

In this study, it was shown that GLM was not an equivalent substitute for SBH and CM (R_1 vs R_2 and R_3) in terms of ADG (Table 3). There was no difference in ADG between the two supplement concentrates containing GLM (R_2 vs R_3). Proximate analysis comparisons of the three feed ingredients showed TDN (and estimated ME) content in GLM was 61.5% (9.6 MJ ME/kg DM) and comparable to SBH (62.7% and 9.9 MJ ME/kg DM). These TDN (and ME) values were lower than CM (74.6% and 12.0 MJ ME/kg DM). Furthermore, CP content in GLM was comparable to CM (19.1% and 20.1%, respectively), and higher than SBH (12.5%). However, when combined with DCP, the three concentrate treatments had comparable CP, TDN and ME contents (Table 2).

Intake by bulls in R_0 (CFS) was 3.38 kg DM/head per day (1.80% of LW; Table 3), which is in agreement with Wiyatna *et al.* (2012) who reported intakes of 2.38–4.37 kg/head per day in traditional village Ongole bulls of similar LW using a cut and carry feeding system.

The feed intake in supplemented treatments (R_1, R_2 and R_3) ranged from 5.58 to 6.29 kg/head per day, which was similar to Lestari *et al.* (2011) who reported that the feed intake of Ongole bulls of similar LW, could reach 6.42 kg/head per day. Intake in treatments R_1, R_2 and R_3 ranged from 2.38 to 2.69% LW/day, which was lower than Marsetyo *et al.* (2021) who recorded an intake of 3.28% LW/day in Ongole bulls supplemented with cassava powder and fresh *G. sepium*. Marsetyo *et al.* (2021) offered a similar supplement at 1.6% LW/day, whereas in this experiment, concentrates were given at 1% LW/day. There appeared to be no substitution of the basal forage in this experiment under a supplement level of 1% LW, and this facilitated the high response in the ADG (up to 0.7 kg/day) to supplement. This lack of substitution contrasted with a substitution effect of 0.43 (kg basal diet reduction in intake/kg supplement intake) recorded by Marsetyo *et al.* (2021).

The FFG (kg feed intake in DM/kg ADG) did not differ between treatments (Table 3). The FFG in this experiment ranged from 8.47 to 10.77 which was close to the FFG of intensively raised Ongole cattle (9.2, Lestari *et al.* (2011) and 12.6, Marsetyo *et al.* (2021)). These values are higher than feedlot values derived from Retnaningrum *et al.* (2021) of 5.5. The FFG is very important in determining the profitability of any feeding system.

GLM can be used as an alternative protein source to substitute these protein meal by-products. The ADG and FGR may have been improved at higher levels of supplementation than used in the current experiment, as found by Marsetyo *et al.* (2021). The level of supplement is often set by the risk of cash outlay rather than the biological response.

The IOFC approximately doubled under supplementation, a very beneficial result to the farmer. In the current situation, GLM was much cheaper than CM and SBH. Concentrate mixtures that contain GLM (R_2 and R_3) cost 2998–3075 IDR/kg DM, whereas the concentrate that contained CM and SBH (R_1) cost 4156 IDR/kg DM (Table 2). This coupled with little difference in FFG of the supplemented groups meant that IOFC was markedly increased under supplementation. Priyanti *et al.* (2012) reported that IOFC values can be used as an initial indicator to determine the viability of a fattening operation, although the IOFC values are less responsive to daily feed cost than ADG (Cowley *et al.* 2020). These products are readily available, but range widely in price depending on the region and markets for the DCP. Dried cassava powder can be quite expensive to purchase (as done here), but if home grown, the cost can be much lower (IDR 3617/kg DM vs IDR 1000/kg DM respectively). Thus, systems can be devised to produce a supplement of even lower cost than outlined here, and hence even higher IOFC.

Conclusions

The use of concentrate supplements (at a level 1% LW/day) consisting of 25% GLM, 50% DCP and either 25% SBH or 25% CM can increase the ADG of Ongole bulls from 0.31 kg to 0.61–0.62 kg/head. Cost and availability are two factors that determine the ingredients of a supplement mix. Using DCP and various protein sources provide a practical supplement mix that will increase the ADG and IOFC for farmers. Therefore, the concentrate formula consisting of DCP, GLM and SBH or CM can be used as an alternative supplement for smallholder farmers. A least cost ration formulation system would be useful in formulating supplements for beef cattle to meet the requirement for ME content and CP content (8–10%).

References

Adiwinarti R, Fariha U, Lestari C (2011) Growth of Javanese cattle fed with rice straw and concentrates with different protein levels. *Journal Ilmu Ternak dan Veteriner* **16**, 260–265.

AOAC (2005) 'Official methods of analysis.', 18th edn. (The Association of Official Analytical Chemists: Washington, DC)

Cowley FC, Syahniar TM, Ratnawati D, Mayberry DE, Marsetyo, Pamungkas D, Poppi DP (2020) Greater farmer investment in well-formulated diets can increase liveweight gain and smallholder gross margins from cattle fattening. *Livestock Science* **242**, 104297. doi:10.1016/j.livsci.2020.104297

DGLS (2018) 'Livestock and animal health statistics.' (DGLAHS, Indonesian Ministry of Agriculture: Jakarta, Indonesia)

Feedipedia (2012*a*) Copra meal. Available at https://www.feedipedia.org/node/46

Feedipedia (2012*b*) Cassava roots. Available at https://www.feedipedia.org/node/527

Feedipedia (2016) Soybean hulls. Available at https://www.feedipedia.org/node/719

Fox DG, Tedeschi LO, Tylutki TP, Russell JB, Van Amburgh ME, Chase LE, Pell AN, Overton TR (2004) The Cornell Net Carbohydrate and Protein System model for evaluating herd nutrition and nutrient excretion. *Animal Feed Science and Technology* **112**, 29–78. doi:10.1016/j.anifeedsci.2003.10.006

Freer M, Dove H, Nolan JV (2007) 'Nutrient requirments of domesticated ruminants.' (CSIRO Publishing: Melbourne)

Fukai S, Hammer GL (1987) A simulation model of the growth of the cassava crop and its use to estimate cassava productivity in Northern Australia. *Agricultural Systems* **23**, 237–257. doi:10.1016/0308-521X(87)90046-1

Goehring DL, James BW, Tokach MD, DeRouchey JM, Nelssen JL, Goodband RD, Dritz SS (2012) The effects of dietary soybean hulls, particle size, and diet form on nursery pig performance. *Kansas Agricultural Experiment Station Research Reports* 137–147. doi:10.4148/2378-5977.7091

Gunawan, Gunardi K (2000) Models and strategies for developing native chickens in farmer groups (Tani Indah IV, Tanjung Lestari and Sumber Rezeki) in Jombang Regency. *Jurnal Pengkajian dan Pengembangan Teknologi Pertanian* **2**, 134–147.

Harris LE, Keael LC, Fonnesbeck PV (1972) Use of regression equations in predicting availability of energy and protein. *Journal of Animal Science* **35**, 658–680. doi:10.2527/jas1972.353658x

Lestari CMS, Adiwinarti R, Arifin M, Purnomoadi A (2011) The performance of Java and Ongole crossbred bull under intensive feeding management. *Journal of the Indonesian Tropical Animal Agriculture* **36**, 109–113. doi:10.14710/jitaa.36.2.109-113

Marsetyo, Sulendre IW, Takdir M, Harper KJ, Poppi DP (2021) Formulating diets based on whole cassava tuber (*Manihot esculenta*) and gliricidia (*Gliricidia sepium*) increased feed intake, liveweight gain and income over feed cost of Ongole and Bali bulls fed low quality forage in Central Sulawesi, Indonesia. *Animal Production Science* **61**, 761–769. doi:10.1071/AN20297

Mayberry DE, Syahniar TM, Antari R, Ningrum GP, Marsetyo, Pamungkas D, Poppi DP (2014) Predicting feed intake and liveweight gain of Ongole (*Bos indicus*) cattle in Indonesia. *Animal Production Science* **54**, 2089–2096. doi:10.1071/AN14538

Montgomery DC (2013) 'Design and analysis of experiments.' (John Wiley & Sons: Hoboken, NJ. doi:10.1002/9783527809080.cataz11063

Negrão F, Dantas C, Zanine A, Ferreira D, Ribeiro M, Souza A, Parente M, Parente H, Cunha I, Nascimento T, Lima A, Sá C, Bandeira D (2020) Digestive potential of soybean agro-industry byproducts. *Animals* **10**, 911. doi:10.3390/ani10050911

Priyanti A, Mahendri IGAP, Cahyadi F, Cramb RA (2012) Income over feed cost for small- to medium-scale beef cattle fattening operations in East Java. *Journal of the Indonesian Tropical Animal Agriculture* **37**, 195–201. doi:10.14710/jitaa.37.3.195-201

Retnaningrum S, Kusmartono, Mashudi, Harper KJ, Poppi DP (2021) Formulating rations with cassava meal to promote high live weight gain in crossbred Limousin bulls. *Animal* **15**, 100125. doi:10.1016/j.animal.2020.100125

Smith O, van Houtert MF (1987) The feeding value of *Gliricidia sepium*. *World Animal Review* **62**, 57–68.

Sulaiman A, Simatupang P, Kariyasa I, Subagyono K, Las I, Jamal E (2018) 'Indonesia's self-sufficiency success becomes world food granary 2045.' (IAARD Press: Jakarta, Indonesia)

Wiyatna MF, Gurnadi E, Mudikdjo K (2012) Produktivitas Sapi Peranakan Ongole pada Peternakan Rakyat di Kabupaten Sumedang (Productivity of Peranakan Ongole Cattle on traditional farm system in Sumedang Region). *Jurnal Ilmu Ternak* **12**, 22–25. doi:10.24198/jit.v12i2.5124

Data availability. The data that supports this study will be shared upon reasonable request to the corresponding author.

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