CSIRO PUBLISHING

RESEARCH PAPER
https://doi.org/10.1071/AN23229

ANIMAL PRODUCTION SCIENCE

Improving growth rates of Ongole crossbred bulls by formulation and level of supplement of by-products

Gunawan[A], E. Winarti[A], A. Sofyan[A], A. D. Putridinanti[B], S. Andarwati[B], C. T. Noviandi[B], A. Agus[B], K. J. Harper[C,*] and D. P. Poppi[D]

For full list of author affiliations and declarations see end of paper

*Correspondence to:
K. J. Harper
School of Health, Medical and Applied Sciences, Central Queensland University, Rockhampton, Qld 4702, Australia
Email: k.harper@cqu.edu.au

Handling Editor:
Penny Back

Received: 26 June 2023
Accepted: 17 October 2023
Published: 10 November 2023

Cite this:
Gunawan et al. (2024)
Animal Production Science **64**, AN23229.
doi:10.1071/AN23229

ABSTRACT

Context. Formulating diets using agro-industrial by-product concentrates to increase the growth performance and cost efficiency of Ongole crossbred bulls. **Aims.** This study was conducted to evaluate the inclusion of agro-industrial by-products of dried cassava powder (DCP), mixed copra meal (CM), palm kernel cake (PKC) and soybean hull (SBH) into rations at low and high levels of feeding on bull liveweight gain and farmer profitability. **Methods.** Fifty Ongole crossbred bulls with an initial bodyweight (BW) of 227 ± 66.5 kg and aged between 12 and 18 months, were arranged in a randomised complete-block design of five treatments, with 10 heads per treatment. The control group (T_0) was provided the current feeding system (CFS) fed *ad libitum*. The supplemented treatments consisted of CFS *ad libitum* + concentrate (50% DCP, 25% CM, 25% PKC) at 1% BW/day (T_1), CFS *ad libitum* + concentrate (50% DCP, 25% CM, 25% SBH) at 1% BW/day (T_2), CFS *ad libitum* + concentrate (50% DCP, 25% CM, 25% PKC) at 2% BW/day (T_3), CFS *ad libitum* + concentrate (50% DCP, 25% CM, 25% SBH) at 2% BW/day (T_4). The experiment was conducted for 12 weeks. **Key results.** The BW gain over 12 weeks (kg) for T_0, T_1, T_2, T_3 and T_4 was 39.5, 56.2, 68.9, 57.5 and 62.1 kg respectively. The income over feed cost was significantly higher in T_2. **Conclusions.** Supplementation with by-products increased bull liveweight gain compared with current feeding practices. A concentrate supplementation of DCP mixed with CM and SBH at 1% BW/day was the most effective and profitable supplementation method to increase income of farmers in this district and there was no advantage of increasing the level of supplement. **Implications.** A combination of DCP, CM and SBH to form a concentrate supplement and fed at 1% BW/day will increase bull liveweight gain and income of farmers.

Keywords: animal nutrition, cattle feeding, cattle growth, concentrates, profit, supplements, tropical cattle.

Introduction

There are approximately 18.1 million head of beef cattle across Indonesia, and 98% of the cattle population are raised by smallholder farmers (DGLS 2022). However, Indonesia is unable to meet domestic demand for beef production. Cattle raised by smallholder farmers often have low growth rates and poor feed conversions due to the lack of feed and/or poor diet formulations. Wiyatna *et al.* (2012) and Handayanta *et al.* (2017) observed average daily gain (ADG) values of beef cattle of ~0.20–0.25 kg/day under smallholder-farmer systems. Farmers offer forage to cattle usually on the basis of availability without regard to meeting energy and protein requirements (Adiwinarti *et al.* 2011). The use of by-product supplements can increase growth rates of cattle in smallholder farms (Marsetyo *et al.* 2021; Retnaningrum *et al.* 2021, Winarti *et al.* 2022*a*, 2022*b*).

Agro-industrial by-products are potentially valuable sources of energy and protein. The dried cassava powder (DCP) has a high metabolisable energy (ME) value (approximately 12.2 MJ/kg DM), but recent feeding trials have shown that DCP inclusion should not exceed 40% of a ration for fattening bulls because feed intake and subsequent ADG are reduced at higher levels (Retnaningrum et al. 2021). The DCP has a low crude protein (CP) content (approximately 2.9% CP), so it needs to be combined with a supplement with a high protein content, such as the agro-industrial by-products of copra meal (CM), palm kernel cake (PKC) or soybean hulls (SBH). The CP content of CM is ~22% (Heuzé et al. 2015), PKC is ~16% (Gunawan 2014) and SBH is ~13% (Heuzé et al. 2017). Formulation can be facilitated by the use of a least cost ration formulator (LCR) when prices and availability of ingredients change (Poppi et al. 2021).

Previous research results showed that Ongole crossbred bulls fed a concentrated supplement of between 1% and 1.6% bodyweight (BW)/day had an ADG of 0.56–0.78 kg/day (Lestari et al. 2011; Marsetyo et al. 2021; Winarti et al. 2022a, 2022b), but it is not known how bulls under smallholder systems will respond to a higher level of feeding such as that achieved by Retnaningrum et al. (2021) under feedlot conditions. The inclusion of SBH has not been studied extensively in indigenous cattle in Indonesia.

This study aims to determine the effect of agro-industrial-derived supplements (CM, PKC, SBH) and their level of feeding on the ADG of Ongole crossbreed bulls and profitability of smallholder farmers. The hypothesis of this experiment is that supplement type and level of supplementation will increase the ADG of Ongole bulls and daily income over feed costs (IOFC).

Materials and methods

Location and animal care

Fifty Ongole crossbred bulls with an initial BW of 227 ± 66.5 kg and aged between 12 and 18 months old were used in this village experiment. This size of animal is typical of smallholder production systems. The bulls were owned by a smallholder-farmer cooperative located in Banaran and Bleberan villages, Playen Subdistrict, Gunungkidul Regency, Special Region of Yogyakarta, Indonesia. The bulls received an identification number that was attached to a neck collar. Prior to the experiment, all bulls were treated with macrocyclic lactone via an ivermectin subcutaneous injection (dose: 1 mL/50 kg BW) for the prevention of parasite infection.

Experimental design

Bulls were randomly allocated into either a control group (T_0) or one of four treatments (T_1, T_2, T_3 and T_4), as shown in Table 1, and housed in individual pens over the experimental period. Feed nutrient content of the current feeding system/CFS (T_0) and the concentrate supplement of treatments (T_1, T_2, T_3 and T_4) can be seen in Table 2. The control group (T_0) was fed the CFS, whereas treatment groups (T_1 and T_2) were fed CFS and dietary concentrate supplements at an approximate 1% BW/day on a DM basis and treatment groups (T_3 and T_4) were fed CFS and dietary concentrate supplements at an approximate 2% BW/day on a DM basis. Each treatment involved 10 bulls (five bulls in Banaran village and five bulls in Bleberan village), making the total number of bulls 50 in this experiment.

Table 1. Dietary treatments of T_0, T_1, T_2, T_3 and T_4.

Treatment	Composition of feed
T_0	Current feeding system (CFS) *ad libitum*
T_1	CFS *ad libitum* + concentrate (50% DCP, 25% CM, 25% PKC) offered at estimated DM level of 1% BW/day
T_2	CFS *ad libitum* + concentrate (50% DCP, 25% CM, 25% SBH) offered at estimated DM level of 1% BW/day
T_3	CFS *ad libitum* + concentrate (50% DCP, 25% CM, 25% PKC) offered at estimated DM level of 2% BW/day
T_4	CFS *ad libitum* + concentrate (50% DCP, 25% CM, 25% SBH) offered at estimated DM level of 2% BW/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, dried cassava powder; CM, copra meal; SBH, soybean hulls; PKC, palm kernel cake; DM, dry matter; BW, bodyweight.

Table 2. Feed nutrient content of the current feeding system (T_0) and of the concentrate supplement of treatments (T_1, T_2, T_3 and T_4).

Diet	DM (% as fed)	CP (% DM)	EE (% DM)	CF (% DM)	NFE (% DM)	TDN (% DM)	Cost (IDR/kg DM)
T_0	35.8	6.9	1.75	43.1	37.7	48.76	625
T_1/T_3	91.4	12.3	4.06	15.3	64.3	68.33	3638
T_2/T_4	90.3	13.0	1.33	11.9	69.7	67.02	4040

Note: T_0, current feeding system (CFS); concentrate in T_1 and T_3: 50% DCP, 25% CM, 25% PKC; concentrate in T_2 and T_4: 50% DCP, 25% CM, 25% SBH; DM, dry matter; CP, crude protein; EE, ether extract; CF, crude fibre; NFE, nitrogen free extract; TDN, total digestible nutrients, calculated from Harris et al. (1972), as follows: $\text{TDN} = -54.572 + 6.769\,(\text{CF}) - 51.083\,(\text{EE}) + 1.851\,(\text{NFE}) - 0.334\,(\text{CP}) - 0.049\,(\text{CF})^2 + 3.384\,(\text{EE})^2 - 0.086\,(\text{CF}) \times (\text{NFE}) + 0.687\,(\text{EE}) \times (\text{NFE}) + 0.942\,(\text{EE}) \times (\text{CP}) - 0.112\,(\text{EE})^2 \times (\text{CP})$ for T_0; and $\text{TDN} = -202\,686 - 1357\,(\text{CF}) + 2638\,(\text{EE}) + 3003\,(\text{NFE}) + 2.347\,(\text{CP}) + 0.046\,(\text{CF})^2 + 0.647\,(\text{EE})^2 + 0.041\,(\text{CF}) \times (\text{NFE}) - 0.081\,(\text{EE}) \times (\text{NFE}) + 0.553\,(\text{EE}) \times (\text{CP}) - 0.046\,(\text{EE})^2 \times (\text{CP})$ for supplements T1, T2, T3 and T4.

Diet and feeding management

This feeding trial was conducted for 12 weeks, commencing on the 29 April and concluding on the 22 July 2018. The bulls were offered the CFS *ad libitum* to each animal in the morning (about 06.00 hour to 07.00 hours) and in the afternoon (about 15.00 hours to 16.00 hours). After 1 h of offering CFS, bulls (T_1, T_2, T_3, T_4) were fed their concentrate supplements according to each treatment. The CFS predominantly consisted of native grasses (*Paspalum conjugatum*, *Cynodon dactylon*), cultivated grasses (*Pennisetum purpureum*), agricultural waste (corn stover, peanut straw) and tree leaf (*Artocarpus heterophyllus*, *Albizia chinensis*). These forages were collected in bulk and chopped by sickle to an approximate chop length of 10–20 cm. The concentrate supplement was a mixture of 50% DCP, 25% CM and 25% PKC or 50% DCP, 25% CM and 25% SBH, formulated by the use of the LCR and supplemented to a level of either 1% or 2% BW/day. The concentrate was mixed as a ground uniform mash. Drinking water was provided to each bull after the feeding in the morning and evening, each as much as 15 L. A mineral block was provided *ad libitum* to each bull in the feeding box during the experiment.

Prior to the feeding trial, bulls were adapted over 4 weeks by gradually increasing the concentrate supplement to the required level of 1% or 2% BW/day. Feed adaptation was conducted by administration of CFS *ad libitum* and adding supplement starting from 0.25% BW/day to reach 1% BW/day or 2% BW/day on a DM basis.

Parameter measurements

Parameters observed were ADG, DM intake, feed for gain ratio (FFG) and IOFC. The ADG (kg/head per day) of bulls was calculated from the BW at 12 weeks minus initial BW and dividing by the time period (84 days). All bulls were weighed individually every 3 weeks (0, 3, 6, 9 and 12 weeks), in the morning before feeding and after feed and water were removed at 22:00 hours the previous night as a further check on the ADG and to adjust level of supplement.

Dry-matter intake was calculated from the summation of the forage intake and concentrate supplement intake, following the procedures of Winarti *et al.* (2022*a*, 2022*b*). Samples of CFS were taken and stored once every 3 weeks for DM analysis. This value was used to measure DM intake as described by Winarti *et al.* (2022*a*, 2022*b*).

The amount of concentrate supplement was adjusted to 1% or 2% of BW/day in 0–3-week, 3–6-week, 6–9-week and 9–12-week periods, which were calculated by weighing of bulls every 3 weeks, namely at Weeks 0, 3, 6 and 9. Samples of supplements were collected in Weeks 1 and 12 of the experiment for the analysis of DM, ash, CP, ether extract (EE) and crude fibre (CF). All samples (CFS and supplements) were dried in a hot-air circulating oven (55°C) before chemical analysis. Dry-matter was determined by Method No. 930.15 (AOAC 2005), CP by Method No. 978.04 (AOAC 2005), EE by Method No. 930.09 (AOAC 2005) and CF was determined by Method No. 930.10 (AOAC 2005). The amount of nitrogen-free extract (NFE) was determined by the following equation: NFE (% DM) = 100 − (% EE + % ash + % CF + % CP). The concepts of NFE and CF are standards for feed analysis in Indonesia.

Feed to gain ratio (FFG) is the ratio of the DM intake to ADG (expressed kg feed DM/kg BW gain). Income over feed cost (IOFC) was obtained from the ADG multiplied by the value of the ADG (Indonesian rupiah (IDR)/kg BW) minus the average daily feed costs of DM intake (IDR/day) as previously reported by Cowley *et al.* (2020). The daily feed cost was total cost of feed (forage and supplement)/day.

Statistical analyses

The experiment was arranged in a randomised complete-block design, whereby animals were stratified by initial BW before random allocation into five dietary treatments and 10 animal replications. Data were analysed using analysis of covariance (ANCOVA) with the initial BW of bulls as covariate to control the effect of this variable on the dependent variable (Montgomery 2013) and continued by Duncan multiple-range test (DMRT) for analysing significant difference among treatments (Cohort 2022).

Ethics approval

This experiment was awarded an Animal Ethics Certificate (AEC) approval with the number SAFS/516/17/INDONESIA/VILLAGE and approved by the University of Queensland Australia. This research is part of the project No. LPS/2013/021 entitled Profitable Feeding Strategies for Smallholder Cattle in Indonesia, which is a partnership of the University of Queensland and Northern Territory Department of Industry, Tourism and Trade in Australia and Indonesian Universities and Indonesian Agency for Agricultural Research Development (IAARD) in Indonesia.

Results

The total forage intake of bulls over the 12-week experiment did not differ significantly ($P > 0.05$) among the treatments, with the CFS (T_0) being 487 kg DM/head, which was not different from the forage intake in supplemented T_1–T_4 treatments (257–441 kg DM/head) (Table 3). Total diet intake of bulls in treatment T_3 (containing PKC at 2% BW) was significantly ($P < 0.01$) higher than that in treatments T_0 and T_2 (containing SBH at 1% BW) (Table 3). The ADG of bulls in treatment T_2 was significantly ($P < 0.05$) higher than that in treatment T_0, and the PKC-containing treatments T_1 and T_3, but not differing from that in treatment T_4 (with SBH 2% BW) (Table 3). Increasing the level of concentrate supplement did not increase ADG. Feed to gain ratio of bulls did not differ among treatments ($P > 0.05$), with the value for T_0 being 14.81, which was not different from that in T_1–T_4 treatments (8.55–14.77) (Table 3). Income over feed cost of bulls in treatment T_2 was the highest and significantly ($P < 0.01$) different from that in the 2% BW-supplemented treatments T_3 and T_4, but not different from that in treatments T_0 and T_1 (Table 3).

Discussion

Previous work by Winarti *et al.* (2022*a*, 2022*b*) showed that ADG could be increased over that of the current village-based systems by feeding a supplement based on combinations of

Table 3. Growth performance of Ongole crossbred bull supplemented with concentrate (T_1, T_2, T_3 and T_4) and without concentrate (T_0) after 12 weeks of treatment.

Variable	T_0	T_1	T_2	T_3	T_4	s.e.m.	*P*-value
Forage intake (kg DM per 12 weeks)	486.9	441.1	349.4	407.2	257.0	29.04	0.136
Forage intake (% BW/day)	2.14	2.54	1.73	2.18	1.45	0.220	0.498
Concentrate intake (kg DM per 12 weeks)	0.0c	191.9b	224.1b	411.6a	397.1a	19.03	<0.01
Concentrate intake (% BW/day)	0.0c	1.10b	1.11b	2.20a	2.25a	0.091	<0.01
Total feed intake (kg DM per 12 weeks)	486.9b	633.0ab	573.5b	818.8a	654.1ab	32.18	<0.01
Initial BW (kg/head)	270.3	207.1	240.0	222.8	210.7	9.797	0.235
DM intake (% BW/day)	2.14b	3.64ab	2.84ab	4.38a	3.70ab	0.248	<0.01
BWG (kg/head per 12 weeks)	39.5c	56.2b	68.9a	57.5b	62.1ab	2.44	<0.05
ADG (kg/head.day)	0.47c	0.67b	0.82a	0.68b	0.74ab	0.03	<0.05
Feed cost (IDR/head per 12 weeks)	304 285c	973 791b	1123 771b	1751 920a	1764 952a	90 247	<0.01
Feed for gain ratio (kg FI in DM/kg ADG)	14.81	11.93	8.55	14.77	10.66	0.87	0.114
IOFC (IDR/head per 12 weeks)*	1 868 215ab	2 117 209ab	2 665 729a	1 410 580b	1 650 548b	114 127	<0.01

*The price of ADG of bull was IDR55 000/kg BW. Price of forage is 625 IDR/kg DM. At the time of the experiment, the price of DCP was 3444 IDR/kg DM, CM 4590 IDR/kg DM, PKC 4679 IDR/kg DM, SBH 4679 IDR/kg DM. Price of concentrate sT1 and T3 are 3638 IDR/kg DM. Price of concentrates T2 and T4 are 4040 IDR/kg DM.

DM, dry matter; BW, bodyweight; BWG, BW gain (WB at 12 weeks – initial BW); ADG, average daily gain, BWG at 12 weeks divided by the time period (84 days); FI, feed intake; IOFC, income over feed cost; IDR, Indonesian rupiah (currency); T_0, current feeding system (CFS) *ad libitum*; T_1, CFS *ad libitum* + concentrate 1% (50% DCP, 25% CM and 25% PKC); T_2, CFS *ad libitum* + concentrate 1% (50% DCP, 25% CM and 25% SBH); T_3, CFS *ad libitum* + concentrate 2% (50% DCP, 25% CM and 25% PKC); T_4, CFS *ad libitum* + concentrate 2% (50% DCP, 25% CM and 25% SBH). DCP, dried cassava powder; CM, copra meal; SBH, soybean hulls; PKC, palm kernel cake; s.e.m., standard error of the mean.

Different letters between treatments within a row indicate significant differences (at $P = 0.05$).

Gliricidia sepium, CM, PKC, SBH and DCP at a level of 1% BW/day. The dietary treatment rations were formulated on the basis of an LCR system and resulted in increased ADG and IOFC for smallholder farmers. In the current study, the same approach was used except that only combinations using DCP, CM and PKC were used to increase the ME content of the supplement and by feeding it at higher levels of 2% BW/day, approaching that used by Retnaningrum *et al.* (2021).

The concentrate supplements increased ADG and total weight gain over the 12-week period, but there was no effect from increasing the level of supplement from 1% to 2% BW/day (Table 3). While this was not reflected in total DM intake, it was most likely due to errors in measuring refusals of the CFS. The participants can measure what they offer easily, but refusals are a problem. The cost structure is largely dictated by the amount offered, so this is unlikely to affect the IOFC calculation. The amount of concentrate offered and consumed and the ADG are measured accurately. There may also be effects of the level of concentrate on the digestibility of the basal diet, but this could not be determined under the present housing arrangements. Treatment T_2 (mixture of DCP, CM and SBH) at 1% BW/day yielded a significantly higher ADG of 0.82 kg/day than in the control group at 0.47 kg/day (Table 3). However, increasing the level of feeding had no further increase in ADG in this experiment. The reason for this is unclear, but on first principles, the total ME intake from both levels of supplement and CFS of the total diet must be similar, even though this was not reflected in the estimate of total DM intake for reasons alluded to above, suggesting a higher level of substitution than was measured. The ADG values with these concentrate supplements were similar to the values recorded in earlier experiments of Winarti *et al.* (2022*a*, 2022*b*) and Marsetyo *et al.* (2021), but lower than achieved by Mayberry *et al.* (2014) and Cowley *et al.* (2020) with the same breed type of Ongole who measured approximately 1.4 and 1.2 kg/day ADG respectively. Nevertheless, the T_2 treatment resulted in a very high ADG for a village-based system.

Cassava and its various by-product forms are widely available in Indonesia and, with its high ME content, it can be used to increase the ME of formulated rations. It is low in CP and needs combinations with high-protein by-products such as CM, PKC and SBH, all of which are available at variable prices throughout Indonesia. The current study showed that PKC and SBH are practically interchangeable, with little effect on ADG, although the combinations T_2 and T_4 using SBH (50% DCP, 25% CM and 25% SBH) gave a significantly higher ADG result at both levels of supplement. Table 2 shows that the supplements contained 40% higher TDN (and therefore ME) contents and 100% higher CP contents than did the CFS. As such, the concentrate containing formulations achieved the objective of increasing ME and CP content of the total ration above that of the CFS, which resulted in a higher ADG. However, the lack of effect of level of feeding of the concentrate supplement was surprising, suggesting a substitution effect on intake that was not reflected in the estimates of forage intake (Table 2).

The estimate of forage intake by the methodology used here was measured as accurately as possible under close supervision. Average total forage intake of bulls over the 12 weeks ranged from 257 to 487 kg DM/head or from 3.1 to 5.8 kg DM/head.day (Table 3). In terms of %BW/day, the forage intake ranged from 2.14 to 4.38, which is considered high for long-chopped tropical pastures; however, these values are still within the scope found in other research 1.91–5.19 (Handayanta *et al.* 2017) for Ongole bulls. The higher forage intake probably reflects more the amount offered and, hence, the cost rather than intake, given the potential for error in measuring residues.

The estimate of supplement intake was accurate because amounts were weighed for the week, before being distributed to farmers. Because supplement cost is by far the greatest expenditure, then the results for IOFC (Table 3) reflect more the level of supplement than the forage intake and the lack of ADG response to higher levels of feeding of supplement.

The offered concentrate was completely consumed by bulls. Forage intake of bulls maintained under T_0 (using forage feed without concentrate) was 486.9 kg DM/head for 12 weeks (Table 3) or 5.80 kg DM/head.day or 2.12% BW/day, which was within the range found by Handayanta *et al.* (2017). The level of cassava inclusion was less than 40% of the final ration (from 15% to 30%, Table 3), and, so, would not be expected to decrease the intake and ADG (Retnaningrum *et al.* 2021). Retnaningrum *et al.* (2021) suggested possible reasons why there was a depression in intake and ADG when cassava was included at greater than 40% of the final ration. These primarily were related to HCN intake and high starch intake, although there was no conclusive reason why there was an upper limit of 40% inclusion. However, the depression of intake and ADG at high levels of inclusion of cassava has been found in a number of studies (Mayberry *et al.* 2014; Cowley *et al.* 2020; Retnaningrum *et al.* 2021; Kusmartono *et al.* 2022).

The FFG is a measure of the animal's efficiency in converting feed to liveweight. The FFG ratio of bulls (kg diet intake in DM/kg ADG) in this experiment ranged from 8.55 to 14.81, which agreed with the FFG values from Lestari *et al.* (2011), Marsetyo *et al.* (2021) and Winarti *et al.* (2022*a*, 2022*b*) who supplemented at levels up to 1.6% BW/day. However, Retnaningrum *et al.* (2021) found a very low value (5.5) in Ongole × Limousin crossbred bulls fed a feedlot formulation based on some of the same ingredients as used here. This may be a breed effect, but more likely to be due to a complete feedlot formulated ration used by Retnaningrum *et al.* (2021), with better control over feeding and husbandry.

Income over feed cost (IOFC) of bulls ranged from IDR1 410 580 to IDR2 665 729/head over 12 weeks or from IDR16 792 to IDR31 734/day. The highest IOFC was found in the T_2 treatment, which reflected the higher ADG, but there was no further advantage to a higher level of supplement at 2% BW/day; in fact, the values at a supplement level of 2% BW/day were lower than those in the CFS (Table 3). This highlighted the importance of examining IOFC for a smallholder system, because some supplementation strategies can depress IOFC and therefore profitability for the farmer, even though ADG was improved compared with the CFS. However, the cost of providing a supplement was high (Table 3) and access to funds can be difficult for a smallholder where the risk is high. The feed cost is dependent on location and season and can fluctuate widely. Having a system such as the LCR can enable extension staff and farmers to quickly modify ration composition to increase IOFC. The higher feed quality improves the growth performance of cattle as indicated by the ADG, which affects the IOFC as previously reported by Priyanti *et al.* (2012) and Cowley *et al.* (2020).

Overall, Ongole crossbred bulls supplemented with agro-industrial by-products increased ADG by 42–74% when the concentrate was supplemented at 1% or 2% BW/day (T_1, T_2, T_3 and T_4). The use of SBH gave the best results but, practically, it could be substituted by PKC. There was no significant improvement in ADG when feeding concentrate at the higher levels of 2% BW/day.

Conclusions

The use of agro-industrial by-products of DCP, CM, PKC and SBH formulated by a LCR process and fed as a supplement at 1% BW/day to Ongole bulls increased ADG, but there was no advantage in increasing the level of supplement to 2% BW/day.

References

Adiwinarti R, Fariha UR, Lestari CMS (2011) The growth of Java bulls fed rice straw and concentrates containing different levels of protein. *Indonesian Journal of Animal and Veterinary Sciences* **16**, 260–265.

AOAC (2005) Official methods of analysis of AOAC International. Association of Official Analytical Chemists, Washington, DC, USA. Available at https://www.researchgate.net/publication/292783651_AOAC_2005

Cohort (2022) CoSTAT Version 6.451. Copyright 1998-2022. Cohort Software, 798. Lighthouse Ave, Montere, CA, USA.

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 (2022) 'Livestock and animal health statistics.' (Directorate General of Livestock Services: Jakarta, Indonesia)

Gunawan (2014) Feed technology supports the development of beef cattle in Indonesia. Gadjah Mada University Press, Yogyakarta, Indonesia. Available at https://ugmpress.ugm.ac.id/en/product/peternakan/teknologi-pakan-mendukung-pengembangan-sapi-potong-di-indonesia

Handayanta E, Lutojo L, Nurdiati K (2017) Beef cattle production efficiency on smallholder farmers during the dry season in dry land agricultural areas, Gunungkidul regency. *Caraka Tani: Journal of Sustainable Agriculture* **32**, 49–54. doi:10.20961/carakatani.v32i1.15928

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

Heuzé V, Gilles T, Sauvant D, Bastianelli D (2015) Copra meal and coconut by-products. Feedipedia, a programme by INRAE. Available at https://www.feedipedia.org/node/46

Heuzé V, Thiollet H, Tran G, Lessire M, Lebas F (2017) Soybean hulls. Feedipedia, a programme by INRAE, CIRAD, AFZ and FAO. Available at https://www.feedipedia.org/node/719 [Retrieved 18 May 2021]

Kusmartono, Retnaningrum S, Mashudi, Harper KJ, Poppi DP (2022) Improving live weight gain of crossbred Limousin bulls with cassava peel silage. *Animal* **16**, 100524. doi:10.1016/j.animal.2022.100524

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, Inc.: Hoboken, NJ, USA)

Poppi DP, Kusmartono K, Kasmiyati K, Quigley SP, Harper KJ (2021) Feeding strategies for improving ruminant productivity in the post-COVID 19 pandemic era particularly for small holders. *Indonesian Journal of Animal Science* **31**(1), 84–94. doi:10.21776/ub.jiip.2021.031.01.11

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

Winarti E, Gunawan, Putridinanti AD, Noviandi CT, Andarwati S, Agus A, Harper KJ, Poppi DP (2022*a*) 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. *Animal Production Science* **62**(7), 676–681. doi:10.1071/AN21595

Winarti E, Gunawan, Sofyan A, Wirasti CA, Noviandi CT, Panjono, Agus A, Harper KJ, Poppi DP (2022*b*) Improving live weight gain in Ongole crossbred bulls through processing of *Gliricidia sepium* leaf meal and cassava in a supplement concentrate. *Animal Feed Science and Technology* **292**, 115401. doi:10.1016/j.anifeedsci.2022.115401

Wiyatna MF, Gurnadi E, Mudikdjo K (2012) Productivity of Peranakan Ongole Cattle on traditional farm system in Sumedang Region. *Journal of Animal Science Padjadjaran University* **12**, 22–25.

Data availability. The data will be stored in the Indonesia Scientific Repository after agreement from all authors. The complete dataset of this study is available in excel sheet.

Conflicts of interest. Karen Harper is Associate editor of Animal Production Science, but was blinded from the peer review process for this paper.

Declaration of funding. This research was supported by the Australian Centre for International Agricultural Research (ACIAR) in providing financial support for the research (LPS/2013/021, Profitable Feeding Strategies for Smallholder Cattle in Indonesia).

Acknowledgements. The authors express their sincere gratitude to the Australian Centre for International Agricultural Research (ACIAR), School of Agriculture and Food Sciences, University of Queensland (UQ) Australia, Faculty of Animal Sciences, University of Gadjah Mada (UGM) Yogyakarta Indonesia, Indonesian Agency for Agricultural Research Development (IAARD), Yogyakarta Assessment Institute for Agricultural Technology (BPTP Yogyakarta) and farmer groups in Bleberan and Banaran villages, Gunungkidul regency, Special Region Yogyakarta, Indonesia.

Author contributions. Gunawan: conceptualisation, methodology, formal analysis, review and editing. E. Winarti: collecting data, preparing manuscript, writing – original draft. A. Sofyan: statistical analysis, visualising data, review and editing. A. D. Putridinanti: collecting data, preparing manuscript, writing – original draft. S. Andarwati: collecting data, socioeconomic, preparing manuscript. C. T. Noviandi: reviewing manuscript. A. Agus: reviewing manuscript. K. J. Harper: conceptualisation, review and editing. D. P. Poppi: conceptualisation, review and editing.

Author affiliations

[A]Research Centre for Animal Husbandry, Research Organization for Agriculture and Food, National Research and Innovation Agency, Cibinong, Bogor 16915, Indonesia.

[B]Faculty of Animal Sciences, Universitas Gadjah Mada, Yogyakarta 55281, Indonesia.

[C]School of Health, Medical and Applied Sciences, Central Queensland University, Rockhampton, Qld 4702, Australia.

[D]School of Agriculture and Food Sustainability, University of Queensland, Gatton Campus, Gatton, Qld 4343, Australia.