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Research Article
Nutrient Digestibility and Apparent Bioavailability of Minerals in Beef Cattle Fed with Different Levels of Concentrate and Oil-palm Fronds

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Abstract

Objective: This experiment was carried out to determine the effects of various levels of concentrate and oil-palm fronds (OPF) on nutrient digestibility and apparent mineral bioavailability in beef cattle. **Materials and Methods:** Fifteen Simmental cattle were allocated to three experimental diets in a random block design. Dietary treatment 1 (diet 1) contained 40% concentrate and 60% OPF, dietary treatment 2 (diet 2) contained 50% concentrate and 50% OPF and dietary treatment 3 (diet 3) contained 60% concentrate and 40% OPF. The concentrate consisted of rice bran, tofu waste and ex-decanter solid waste from palm-oil processing, no mineral supplement was given in this study. **Results:** The results of the study showed that the digestibility of dry matter, crude fiber, crude protein, Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF) and cellulose were significantly higher ($p<0.01$) in cattle given 60% concentrate and 40% OPF (diet 3). The apparent bioavailability of both macro and micro-minerals in diet 3 was significantly higher ($p<0.01$) than in the other diets. The apparent bioavailability of calcium (Ca), magnesium (Mg), phosphorus (P) and sulfur (S) in diet 3 were 46.5, 48.9, 53.7 and 52.1%, respectively, while the apparent bioavailability of iron (Fe), manganese (Mn), cobalt (Co) and zinc (Zn) were 38.9, 30.7, 36.6 and 41.5%, respectively. These results indicated that increasing the amount of OPF up to 60% as a main source of forage in the rations of beef cattle reduced the nutrient digestibility and apparent bioavailability of minerals. The diet containing 60% OPF resulted in a greater deficiency of minerals, whereas increasing the level of concentrate from 40-60% significantly reduced the deficiency of minerals ($p<0.01$). Furthermore, the apparent bioavailability of minerals was low overall and all three experimental diets were deficient in minerals, showing that supplementation of certain minerals is needed to support optimum production of beef cattle. **Conclusion:** Based on these results, it could be concluded that feeding beef cattle with 60% concentrate and 40% OPF results in higher digestibility of nutrients and improved bioavailability of minerals and reduces deficiency of minerals.

Key words : Oil-palm fronds, digestibility, apparent bioavailability, macro-mineral, micro-mineral

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

In Indonesia, feeding agricultural by-products and crop residues to ruminants is a common practice, especially during the dry season, when the available forage is low. Oil-palm fronds (OPF) are the largest source of biomass from agricultural by-products that has potential as ruminant feed. A previous study by Warly *et al.*[1] showed that a diet based on by-products of oil-palm improved weaned calves' performance. Song[2] reported that in 2013, Indonesia produced approximately 570 million ton of oil-palm biomass, of which 299 million ton is OPF, 134 million ton is oil-palm trunks and 28 million ton is empty fruit bunches. The biomass is conventionally applied in oil-palm plantations as soil mulch and fertilizer. However, the most significant limiting factors in utilization of agricultural by-products, including oil-palm biomass, as a feed source are low voluntary intake, low digestibility, high fiber content and deficiencies of nutrients to support animal production. These by-products have been evaluated mainly for their potential as sources of energy and protein but their role as sources of mineral nutrients has received little attention[3-5].

Under most production systems in Indonesia, ruminants receive all nutrients including minerals only from forage consumed in the field because minerals and feed supplements are not normally given to the animals. According to McDowell *et al.*[6], animals whose main source of feed is forage only are usually deficient in certain minerals because the forage rarely contains all of the minerals required by the grazing animals. Leng[7] and Judson and McFarlane[8] reported that utilization of low-quality roughage such as hay, straw and stover are limited by the low content of macro and micro-minerals that affect rumen microbial growth and activity, leading to poor feed digestibility. The ability of forage to provide adequate minerals for ruminants depends on mineral concentration and bioavailability. Furthermore, minerals associated with plant cell walls have lower bioavailability or require a longer fermentation time for maximal release[9].

Limited information exists concerning mineral availability in beef cattle given OPF-based diets in Indonesia. Therefore, this experiment was undertaken to investigate the bioavailability of several macro and micro-minerals in beef cattle fed various levels of concentrate and OPF. The term of apparent bioavailability is used in this study to evaluate the availability of mineral elements and is defined as total intake minus total fecal excretion of the element. The values are expressed as a percentage of intake.

MATERIALS AND METHODS

Animal management and experimental diets: Fifteen Simmental cattle with initial body weight of 235-414 kg were allocated to three experimental diets in a random block design. Each block consisted of 5 cattle, arranged according to their body weights. The composition of the experimental diets was as follows:

- Diet 1: 40% concentrate and 60% OPF
- Diet 2: 50% concentrate and 50% OPF
- Diet 3: 60% concentrate and 40% OPF

The composition of the concentrate consisted of rice bran, tofu waste and ex-decanter solid waste from palm-oil processing, no mineral supplement was given in this study. The chemical composition of the experimental diets is presented in Table 1 and the mineral content is presented in Table 2. The diets were prepared to be iso-protein (11.44%) and iso-energy (59% Total Digestible Nutrients (TDN)). Before starting the experiment, all animals were treated with an anthelmintic drug to control gastrointestinal roundworms. The OPF was ground through a 5 mm screen and mixed with concentrate before being fed to the animals. The experimental diets were offered *ad libitum* i.e., 15% greater than the amount consumed on the previous day and drinking water

Table 1: Chemical composition of the experimental diets

	Experimental diets (Percentages of dry matter)		
Constituents	Diet 1	Diet 2	Diet 3
Organic matter	90.62	90.72	90.76
Crude protein	11.41	11.44	11.44
Crude fat	7.30	7.17	7.04
Crude fiber	25.56	23.76	21.53
Neutral Detergent Fiber (NDF)	39.55	40.24	40.41
Acid Detergent Fiber (ADF)	28.51	28.99	29.08
Cellulose	22.97	21.12	16.63
Lignin	21.97	21.60	21.05
Total Digestible Nutrients (TDN)	58.46	59.46	59.84

Table 2: Mineral content of the experimental diets

	Experimental diets		
Mineral elements	Diet 1	Diet 2	Diet 3
Calcium (Ca) (%)	0.25	0.28	0.32
Magnesium (Mg) (%)	0.10	0.13	0.17
Phosphorus (P) (%)	0.19	0.26	0.32
Sulfur (S) (%)	0.15	0.20	0.25
Iron (Fe) (ppm)	24.60	38.00	48.30
Manganese (Mn) (ppm)	10.80	16.60	23.90
Cobalt (Co) (ppm)	0.13	0.15	0.18
Zinc (Zn) (ppm)	10.00	19.00	29.00

was freely available. The daily allowance of the experimental diets was given in two equal portions at 08:00 and 17:00 h. Refused diet was removed and weighed every day just before the morning feeding. Total feces were collected for 7 days and approximately 10% of the samples were dried in a forced-air oven at 60°C for 24 h. Composites were then made from the samples and ground through 1 mm screen for further analysis.

Laboratory analysis: The chemical composition of the feeds and feces was analyzed according to the standards of the Association of Official Agricultural Chemists (AOAC)[10]. Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF), cellulose and acid detergent lignin were analyzed by the method of Goering and Van Soest[11]. The concentrations of calcium (Ca), phosphorus (P), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), cobalt (Co) and zinc (Zn) were determined by Atomic Absorption Spectrophotometr (AAS).

Statistical analysis: All data were subjected to analysis of variance for a randomized block design and differences among the treatment means were determined by Duncan's multiple range test[12]. The following statistical model was used in the analysis:

$$Y_{ij} = \mu+\alpha_i+\beta_j+\varepsilon_{ij}$$

where, Y_{ij} is dependent variable (general observation), μ is the overall mean, α_i is the effect of the treatment, β_j is the effect of the block and ε_{ij} is the error term.

RESULTS AND DISCUSSION

Table 3 shows the effect of different levels of concentrate and OPF in the diets on digestibility of nutrients and fiber fractions in Simmental cattle. As expected, increasing levels of concentrate from 40-60% or reducing OPF from 60-40% in the diets significantly increased ($p<0.01$) the digestibility of dry matter, crude protein, crude fiber, NDF and ADF. Feeding cattle with the 60% concentrate and 40% OPF-based diet (diet 3) resulted in the highest digestibility of nutrients. The digestibility of dry matter and crude fiber were 83.7 and 76.6% or improved by 50.4 and 74.7%, respectively, for cattle fed diet 3 compared to a diet of 40% concentrate and 60% OPF (diet 1). Similarly, the digestibility of NDF, ADF and cellulose were 68.9, 64.7 and 67.7% or improved by 14.3, 13.5 and 12.5%, respectively, in cattle fed diet 3 compared to cattle fed diet 1.

Wong and Zahari[13] reported that due to high fiber content, *in vitro* dry matter degradation of OPF was 38% and the optimum level of OPF inclusion in rations for ruminant feeding was 30%. According to Leng[7] and Judson and McFarlane[8], utilization of low-quality roughage such as hay, straw and other agricultural by-products is limited by their low content of nutrients and macro and micro-minerals, which will affect rumen microbial growth and activity and lead to reduced feed digestibility. It was suggested that the improvement of nutrient digestibility in the current study due to offering additional concentrate in the experimental diets was caused by increased availability of essential nutrients that resulted in much better ruminal conditions for microbial growth and activity. This result agrees with the finding of Warly *et al.*[3] that inclusion of concentrate in a rice straw-based diet increased rumen ammonia and total VFA concentration, nutrient digestibility and weight gain in sheep.

The ability of forage to provide adequate minerals for ruminants depends on the mineral concentration and its bioavailability. The apparent bioavailability of minerals in Simmental cattle fed diets with different levels of concentrate and OPF is presented in Table 4. Consistent with nutrient digestibility values, improving concentrate from 40-60% in the experimental diets significantly increased the apparent bioavailability of minerals ($p<0.05$) with the highest values observed in the 60% concentrate and 40% OPF diet (diet 3). Although, there was great variation among the mineral

Table 3: Digestibility of nutrients and fiber fraction in Simmental cattle fed diets with various levels of concentrate and OPF

	Experimental diets (%)			
Nutrients	Diet 1	Diet 2	Diet 3	SEM
Dry matter	55.69[a]	72.04[b]	83.76[c]	2.13
Crude protein	59.40[a]	73.40[b]	82.22[c]	2.55
Crude fiber	43.89[a]	62.55[b]	76.67[c]	2.08
Neutral Detergent Fiber (NDF)	60.29[a]	64.30[b]	68.89[c]	0.30
Acid Detergent Fiber (ADF)	56.99[a]	60.47[b]	64.71[c]	0.45
Cellulose	60.07[a]	62.42[a]	67.73[b]	0.91
Hemicellulose	79.18[a]	80.72[a]	84.09[b]	0.58

[abc]Values in the same row with different superscripts differ significantly at $p<0.01$, SEM: Standard error of the mean

Table 4: Apparent bioavailability of minerals in Simmental cattle fed diets with various levels of concentrate and oil-palm fronds

	Experimental diets (%)			
Mineral elements	Diet 1	Diet 2	Diet 3	SEM
Calcium (Ca)	37.11[a]	44.69[b]	46.51[b]	4.27
Magnesium (Mg)	36.36[a]	44.95[b]	48.91[a]	5.95
Phosphorus (P)	36.41[c]	42.70[b]	53.66[c]	4.60
Sulfur (S)	33.24[a]	42.18[b]	52.13[c]	5.55
Iron (Fe)	28.49[a]	34.00[b]	38.90[c]	5.80
Manganese (Mn)	26.23[a]	28.71[ab]	30.71[b]	1.24
Cobalt (Co)	28.07[a]	31.62[a]	36.62[b]	3.78
Zinc (Zn)	34.60[a]	38.93[b]	41.15[b]	3.67

[abc]Values in the same row with different superscripts differ significantly at $p<0.01$, SEM: Standard error of the mean

elements, in general the apparent bioavailability of macro-minerals was relatively higher than that of micro-minerals in all of the experimental diets. Among the macro-mineral elements evaluated, the highest apparent bioavailability was noted for P (53.6%), while among the micro-mineral elements, the highest apparent bioavailability was noted for Zn (41.1%).

In Table 4, the apparent bioavailability of Ca, Mg, P and S was improved by 25.3, 34.5, 47.4 and 56.8%, respectively, in cattle fed diet 3 compared to those fed the diet of 40% concentrate, 60% OPF (diet 1). Among the micro-minerals, the apparent bioavailability of Fe, Mn, Co and Zn was improved by 36.5, 17.1, 30.5 and 18.9%, respectively, in Simmental cattle fed diet 3 compared to those fed diet 1. Overall, however, the apparent bioavailability of the mineral elements evaluated was below 60% of the elements consumed. These findings suggest that the low apparent bioavailability of minerals in the current study might be due to the high content of fiber, especially lignin (approximately 21.5%), in the diets. According to Nelson and Moser[14], the bioavailability of forage minerals may be affected by distribution of the minerals within the forage and the chemical form of the elements that are present. Evitayani *et al.*[15,16] reported that the high content of cell-wall constituents (NDF and ADF) in forage has been associated with the attachment of more minerals to the cell wall and could reduce mineral availability for ruminants. Furthermore, Emanuele and Staples[9] also reported that minerals associated with plant cell walls have lower bioavailability or require a longer fermentation time for maximal release.

The trend of the average percentage of macro-mineral apparent bioavailability in cattle given diet 3 was P>S>Mg>Ca, while the trend of the average percentage of micro-mineral apparent bioavailability was Zn>Fe>Co>Mn. The differences in apparent bioavailability of macro and micro-minerals in the diets might be due partly to differences of these elements' affinity with the cell wall, which could influence the solubility and hence deficiency symptoms in the animal, as reported by Ibrahim *et al.*[17]. A higher apparent bioavailability value of certain elements indicates that affinity of the element to the cell wall is lower, which should make the element more available to the animals.

Table 5 shows the deficiency of minerals in Simmental cattle fed with various levels of concentrate and OPF. The values were calculated from the concentration and apparent bioavailability of minerals in experimental diets compared to the mineral requirements of beef cattle. It can be seen that all of the experimental diets were deficient in both macro and micro-minerals. Among the macro-minerals, Ca was the element with the greatest deficiency, while Mn was noted as the most deficient micro-mineral in all of the experimental diets. The diet containing 60% OPF resulted in higher mineral deficiencies and increasing the level of concentrate from 40-60% or reducing OPF from 60-40% significantly reduced the deficiency of minerals ($p<0.01$).

Table 5: Deficiency of minerals in Simmental cattle fed diets with various levels of concentrate and oil-palm fronds

		Deficiency (%)			
Mineral elements	Requirement*	Diet 1	Diet 2	Diet 3	SEM
Calcium (%)	0.36	75.0^{c}	63.9^{b}	58.3^{a}	4.21
Magnesium (%)	0.10	60.0^{c}	40.0^{b}	20.0^{a}	3.75
Phosphorus (%)	0.19	63.2^{c}	42.1^{b}	10.5^{a}	2.64
Sulfur (%)	0.15	66.7^{c}	46.7^{b}	13.3^{a}	3.13
Iron (ppm)	50.00	86.0^{c}	74.2^{b}	62.4^{a}	5.78
Manganese (ppm)	20.00	86.0^{c}	74.1^{b}	62.3^{a}	5.41
Cobalt (ppm)	0.10	60.0^{c}	50.0^{b}	30.0^{a}	4.46
Zinc (ppm)	30.00	88.5^{c}	75.3^{b}	63.2^{a}	5.22

*NRC[20], ^{abc}Values in the same row with different superscripts differ significantly at $p<0.01$, SEM: Standard error of the mean

The higher digestibility of dry matter and fiber fraction in the diets with more concentrate provided additional available minerals by releasing minerals bound in the fiber of the OPF. However, feeding cattle with 60% concentrate and 40% OPF-based diet (diet 3) did not meet the requirements for minerals in Simmental cattle, as shown in Table 5. These findings agree with a previous study by Warly *et al.*[18,19], which showed that the mineral status of grazing goats in Sumatra, Indonesia was deficient in several elements such as Ca, P, Mg, S, Zn, Co, Cu and Mo. The results of the current study clearly indicate that although the inclusion of concentrate in OPF-based rations could improve nutrient digestibility and the apparent bioavailability of minerals, supplementation of certain deficient minerals is necessary to support high animal production.

CONCLUSION

From the results, it could be concluded that feeding beef cattle with 60% concentrate and 40% oil-palm fronds resulted in higher digestibility of nutrients and apparent bioavailability of minerals and reduced the mineral deficiencies.

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