Animal Production Science, 2022, **62**, 1371–1378
https://doi.org/10.1071/AN20202

Bypass fat enhances liveweight gain and meat quality but not profitability of smallholder cattle fattening systems based on oil palm frond

O. Pimpa[A,C], *B. Binsulong*[A], *U. Pastsart*[A], *B. Pimpa*[A] and *J. B. Liang*[B]

[A]Faculty of Innovative Agriculture and Fishery Establishment Project, Prince of Songkla University, 31 Moo 6 Surat-Nasan Road, Makham Tia, Mueang Surat Thani District, Surat Thani, 84000, Thailand.
[B]Institute of Tropical Agriculture and Food Security, Universiti Putra Malaysia, 43400, Serdang, Selangor, Malaysia.
[C]Corresponding author. Email: opimpa@hotmail.com

Abstract

Context. Oil palm frond (OPF) is abundantly available throughout Southeast Asia and is a good source of forage for feedlot cattle, particularly during the dry and monsoon seasons when other forage options are limited. However, the use of OPF in ruminants feed is constrained by its complex fibrous structure and low digestibility.

Aims. The aim of this study was to investigate the impact of supplementation with bypass fat on growth, meat quality and economic returns in smallholder feedlot systems where Napier grass is replaced with OPF.

Methods. Sixteen Brahman × Charolais crossbred steers, 23 ± 2.0 months old and with initial bodyweight of 425 ± 59.9 kg (mean ± s.e.), were randomly allocated in a 2 × 2 factorial randomised complete-block design experiment with the following dietary treatments: (i) fresh chopped Napier grass-based total mixed ration (TMR; Napier grass–fat), (ii) Napier grass-based TMR + 5% bypass fat (Napier grass+fat), (iii) OPF-based TMR (OPF–fat) and (iv) OPF-based TMR + 5% bypass fat (OPF+fat). Feed intake, digestibility of the diets and average daily gain were measured. The cattle were slaughtered to determine carcass dressing percentage and meat quality. Costs and return of fattening cattle were estimated.

Key results. Despite higher intake, cattle fed OPF–fat had a lower bodyweight gain than did cattle fed grass-based diets due to lower digestibility. Bypass-fat supplementation increased the bodyweigh of cattle fed OPF but not of cattle fed Napier grass. Fat supplementation enhanced colour, backfat thickness, and fat content of meat in both the Napier grass- and OPF-based diets. However, replacing Napier grass with OPF reduced the net profit of smallholder feedlot systems, even with fat supplementation.

Conclusion. While fat supplementation increased liveweight gain and enhanced some aspects of meat quality, the increased feeding cost reduced net profit. Therefore, supplementation of OPF with bypass fat is not recommended for smallholder feedlots in developing countries.

Implications. Appropriate technology to reduce the feeding cost of OPF needs to be developed to make it an economically viable option for smallholder farmers.

Keywords: oil palm frond, total mixed ration, bypass fat, Napier grass, meat quality, feedlot cattle.

Received 23 April 2020, accepted 21 June 2021, published online 29 July 2021

Introduction

Because of the increased demand for quality beef across Southeast Asia, small-scale cattle feedlots are growing in number in this region to take advantage of the high price of beef. Concentrate-based diets are frequently used to achieve high growth rates and high-quality meat when fattening cattle. However, the high cost of concentrate feeds makes them inaccessible to many smallholder farmers; thus, alternative feeds such as agro-byproducts are often used to decrease the cost of production. Oil palm is an important crop in several tropical countries and the oil palm industry generates several waste products, including oil palm frond (OPF), which can be used as roughage source for ruminant feeding (Tuyen *et al*. 2013; Astuti *et al*. 2015; Tafsin *et al*. 2018; Hamchara *et al*. 2018). Although the use of OPF in beef production is constrained by its complex fibrous structure and low nutrient content, its wide availability and comparative cost advantage as compared with the traditional forage feed (such as cut grass) makes OPF a viable alternative forage feed for cattle.

Many approaches to improve the digestibility of OPF and, thus, its nutritive value as a forage source for ruminants have been tested. These include the use of legumes (Khamseekhiew *et al*. 2002), enzymes (Wahyuni *et al*. 2012) and treating OPF using fungi to breakdown its fibre (Chanjula *et al*. 2017; Hamchara *et al*. 2018; Tafsin *et al*. 2018), but with little or no advantages (Chanjula *et al*. 2017). In addition, the use of fungi treatment to improve the digestibility of OPF is too complicated under smallholder conditions. Offering OPF together with concentrate in total mixed ration (TMR) has been shown to improve feed palatability and intake (Dahlan *et al*. 2000). Moreover, feeding TMR was shown to be more profitable than integrating grazing and TMR or grazing alone in dairy cows (Tozer *et al*. 2003).

Supplementation with fats is often used to increase the energy content of cattle rations formulated with agricultural by-products. Mutsuba *et al*. (2019) reported that coconut and soybean oils inhibited the most potent rumen cellulolytic bacterium (*Fibrobacter succinogenes*), while palm oil had no such negative effect. Kang *et al*. (2019) reported that supplementation of palm oil in the form of 'rumen-protected fat' in Timothy hay-based diets increased the high-density lipoprotein and carbohydrate metabolites in the blood. However, this improvement was not reflected in growth performance in Korean cattle. Thus, when considering replacing cut forage with OPF in TMR, supplementation of bypass palm fat may help boost the energy content of low-quality OPF-based diets to sustain growth performance.

The present study aimed to evaluate the impact of including bypass fat in OPF-based TMR and compare this to a traditional TMR based on Napier grass. We hypothesised that addition of bypass fat would increase liveweight gain, meat quality and economic returns of the OPF-based diet. The study was designed to mimic the conditions of typical smallholder cattle feedlots in southern Thailand, which are similar to the other countries in Southeast Asia.

Materials and methods

This experiment was conducted at a smallholder commercial farm located at Amphoe Mueang district, Phatthalung Province, Thailand. The farm was selected because it is representative of smallholder cattle feedlots in Southeast Asia.

Sixteen Charolaise × Brahman crossbreds of 23 ± 2.0 months of age with an average bodyweight (BW) of 425 ± 59.92 kg (mean ± s.e.) were fattened with TMR based on either freshly chopped Napier grass (*Pennisetum purpureum*) or OPF, with or without the addition of 5% bypass fat, as follows: (i) Napier grass-based TMR (Napier grass–fat; Control), (ii) Napier grass-based TMR + 5% fat (Napier grass +fat), (iii) OPF-based TMR (OPF–fat) and (iv) OPF-based TMR + 5% fat (OPF+fat). Animals were allocated to treatments in a 2 × 2 factorial (roughage source × fat supplementation) randomised complete-block design, with initial BW of cattle used as blocking criteria. Diets were formulated to be iso-caloric and iso-nitrogenous (Table 1) and offered *ad libitum*. The animals were kept in individual pens (~8 m^2) where clean drinking water and mineral salt were available at all times throughout the experiment. The experiment consisted of a 15-day adaptation period followed by a 255-day experimental period.

Feed ingredients were purchased from local feed suppliers. Napier grass (harvested using a forage-harvester with average length of 7–8 cm) was purchased from Chumphon Animal Nutrition Development Station and the OPF (chopped to particle size of 2–3 cm, Fig. S1, available as Supplementary material to this paper) was purchased from the Oil Palm Community Enterprise, Surat Thani province, Thailand. The bypass fat was prepared by mixing crude palm oil (43 kg/100 kg) with animal fat (20 kg/100 kg) and shell powder (13 kg/100 kg), adjusted with alkaline solution (9 kg NaOH + 15 kg water) to a pH of 8.5, which was then pelleted (Fig. S2).

Feed was provided twice daily in two equal portions at 0900 hours and 1500 hours. Feed refusals were weighed and recorded daily before the morning feeding. Fresh ort samples were bulked by animal and dried at 65°C and subsamples were used for dry-matter (DM) determinations. Daily feed offered and refusals were used to determine daily feed intake of individual cattle. Feed intake was measured daily throughout the experimental period and the amount of TMR offered was adjusted every 15 days according to the weight of each animal. Representative samples of the TMR were taken every week. Composite TMR samples and refusal were analysed for DM, crude protein (CP) ether extract (EE), ash, neutral detergent fibre (NDF), acid detergent fibre (ADF) and gross energy (GE).

Cattle were weighed fortnightly and average daily gain (ADG) was estimated using linear regression.

Digestibility of the diets was estimated using total faecal collection, as described by (Velasquez *et al*. 2018), during the 9th week of feeding trial. Briefly, feed intake and faecal output were measured by individual animal for 7 days and faecal subsamples were collected, pooled by the animal at the end of 7 days to determine DM content. DM digestibility was calculated using the equation: DM digestibility = [(DM intake – DM in faeces)/DM intake] × 100 (Galyean 2010).

Metabolisable-energy (ME) intake was calculated using the DM intake (DMI) measured in the present study multiplied by the ME values of the ingredient composition in the respective TMR, by using the Thai Nutrition NRC (2010).

Laboratory analyses

Composite TMR samples and refusal were collected weekly and dried in a forced-air oven at 65°C for 24 h. Dried samples were ground to pass a 1-mm screen and then analysed for DM, CP, EE and ash, by using proximate analysis according to AOAC (2000). DM was determined by oven drying in a forced-air over at 105°C for 24 h. The N content of feed was determined using a Kjeltec Auto Analyzer (Kjeldatherm model KT and KT-L series, Gerhardt, Germany), while EE was determined in petroleum ether by using a Soxhlet Extraction SOX 416 (Gerhardt, Germany). The ash content was determined by ashing the sample in a muffle furnace at 550°C for 5 h. Neutral detergent fibre (NDF) and ADF were determined by methods of Van Soest *et al*. (1991). The GE of the feed was determined using a bomb calorimeter (IKA Calorimeter System, C 2000 basic, IKA-Werke, Staufen, Germany).

Table 1. Ingredients, cost and chemical composition of experimental diets
Costs of all ingredients were based on the price when the ingredients were purchased from the local feed supplier, inclusive of transportation cost. Napier grass-fat, fresh chopped grass in total mixed ration; Napier grass+fat, fresh chopped grass in total mixed ration supplemented with bypass fat; OPF-fat, oil palm fronds in total mixed ration; OPF+fat, oil palm fronds in total mixed ration supplemented with bypass fat; DM, dry matter; CP, crude protein; NDF, neutral detergent fibre; ADF, acid detergent fibre

Item	Treatment				Cost per kg fresh weight (US$)
	Napier grass–fat	Napier grass+fat	OPF–fat	OPF+fat	
		Ingredients (%DM)			
Napier grass	24	22.9	0	0	0.10
Oil palm frond	0	0	24	22.9	0.03
Bypass fat	0	4.8	0	4.8	1.00
Cassava chips	23.6	22.5	23.6	22.5	0.29
Palm kernel cake	20.4	19.4	20.4	19.4	0.15
Soybean milk cake[A]	11.8	11.2	11.8	11.2	0.06
Decanter cake	8	7.4	7.8	7.2	0.01
Molasses	7.0	6.7	7	6.7	0.29
Leucaena leaf meal	2.4	2.3	2.4	2.3	0.07
Shell powder	1.3	1.2	1.3	1.2	0.03
Salt	1.0	1.0	1.0	1.0	0.13
Urea	0.5	0.7	0.75	0.92	0.42
Cost US$/kg (fresh weight)	0.16	0.19	0.14	0.18	
		Chemical composition			
DM (%)	58.30	59.98	66.60	67.86	
Ash (% DM)	5.12	5.27	9.23	9.18	
CP (% DM)	12.60	12.60	12.60	12.60	
Ether extract (% DM)	5.16	9.31	4.87	9.04	
NDF (% DM)	67.45	64.07	65.12	61.86	
ADF (% DM)	20.34	19.32	20.88	19.84	
Gross energy (MJ/kg)	16.64	16.96	16.56	16.88	

[A]Soy milk cake (solid residue after extraction of soy milk, fresh).

Carcass measurements and meat quality

All cattle were slaughtered at the end of the experiment. They were transported by truck to a commercial slaughterhouse built to serve the surrounding smallholder cattle farmers of this area. The cattle were slaughtered after being fasted overnight according to the standard practice of the slaughterhouse. Fasted liveweight was recorded before slaughter and hot carcass weight within an hour of slaughter. Carcass yield percentage was calculated as ×100 (hot carcass weight/slaughter weight) as described by Françozo *et al*. (2013). The carcass was then split longitudinally into left and right halves and kept to chill at 4°C at the facility within the slaughterhouse, where all the carcass measurements were also performed. The pH of muscle was measured using a penetrating electrode (SevenGoTM pH meter SG2, Mettler Toledo, Thailand) after 24 h of chilling, as described by Mach *et al*. (2008). Cold carcass weight was determined after chilling (4°C) for 7 days (Boonsaen *et al*. 2017). The *longissimus dorsi* (LD) muscles from the right side of the 16 carcasses were excised from between the 12th and 13th ribs to determine backfat thickness and loin eye area (Boonsaen *et al*. 2017) and meat colour (CIE L*, a* and b*, Illuminant C, 0° observer; Hunterlab Miniscan colour meter Mirolta Chromameter CR-300; AMSA 2012), after cutting a slice and blooming for 15 min as described by Boonsaen *et al*. (2017). Subsequently, three 2.5 cm thick steaks were subsampled from each LD section to determine shear force by using the Instron Universal Testing Machine Model 1011, Instron Corporation, USA (AMSA 2015). In addition, ~700 g of meat from each LD muscle was collected and frozen (–20°C) for chemical composition (Andrae *et al*. 2001). Laboratory analyses of meat samples were completed 2 months after the meat was sampled. The samples were thawed at room temperature (20°C), analysed as a fresh sample (not lyophilised), ground, homogenised, and analysed in triplicate (Françozo *et al*. 2013). The DM, CP, EE and ash content were determined following the standard methods of AOAC (2000).

Economic analysis

Investment costs were estimated on the basis of the 255-day fattening period on a per animal basis. Costs included (i) cost of buying the cattle, (ii) cost of feed, (iii) cost of labour to raise the cattle, (iv) utilities (water and electricity), (v) medicines and vaccinations, (vi) transportation cost of transporting cattle from farm to the slaughterhouse, (vii) depreciation of farm buildings and machineries, specifically for cattle production, and (viii) opportunity cost. The opportunity cost was the loss of benefit that could have been saved had the study had a choice not to pay for the cost of the cattle. The opportunity cost was estimated as 7% of the cost of cattle according to the interest rate of commercial banks in Thailand at the time of the present study. Cost of feeder cattle for the present study (purchased from nearby smallholder farmers) depended on the condition of the cattle, and averaged ~3 US$ per kg liveweight. Depending on the TMR formulation, cost of feed varied marginally, averaging 0.17 US$ per kg. Labour cost per person was estimated at 10 US$ per day, with one person capable of taking care of 16 heads of cattle.

Statistical analyses

Data were analysed using the Statistical Analysis System Institute (SAS 1998) software. The mixed procedure was used to analyse the fixed effects of treatment and block on parameters, with animal serving as the experimental unit. The means were statistically compared using Duncan's multiple-range test (Steel and Torries 1980) to identify differences among means. Statistical significance was considered at $P < 0.05$. The mathematical model assumption used was

$$Y_{ijk} = \mu + Blk_i + \alpha_j + \beta_k + \alpha\beta_{jk} + \varepsilon_{ijk},$$

where Y_{ijk} = observation, μ = general mean, Blk_i = is the *i*th block effect, α_j = sources of roughage in TMR, β_k = bypass fat supplement effect, $\alpha\beta_{jk}$ = roughage sources × bypass fat-supplement effect, and ε_{ijk} = is the residual error.

Results and discussion

Effect on liveweight gain and feed intake

Provision of bypass fat to cattle fed OPF increased ADG during the fattening period (Table 2). While supplementing cattle with bypass fat did not result in a significant increase in feed intake, digestibility or feed conversion efficiency, ME intake tended to be higher. ADG of cattle fed OPF+fat (0.92 kg/day) was similar to that of cattle fed Napier grass-based TMR (0.91 to 0.93 kg/day), and also comparable to gains reported in studies with cattle fed with diets containing various agricultural by-products, such as rice straw and concentrate (Siddque *et al*. 2015) and pineapple by-products (Hattakum *et al*. 2019; Pintadis *et al*. 2020). ME intake of all diets was approximately double the 444 KJ ME/kg $BW^{0.75}$ suggested for maintenance for Charolaise crossbred cattle (Subepang *et al*. 2019), indicating that if properly formulated, diets made up of agricultural by-products could be used effectively for fattening of cattle in developing countries.

In comparison, supplementation with bypass fat did not affect ADG of cattle fed grass-based TMR. This result is consistent with Kang *et al*. (2019), who reported that supplementation with bypass fat did not affect ADG in growing Korean cattle steers fed a Timothy hay-based diet. Kang *et al*. (2019) concluded that, although not affecting growth performance, bypass-fat supplementation affected some blood lipids and carbohydrate metabolites. The reason why fat supplementation improved the ADG of cattle fed OPF, but not grass-based diet, in the present study, is unclear. However, one possibility could be that the Napier grass, being more digestible than OPF, contributed a higher proportion of the total digestible energy from the diet, thus reducing the beneficial role of the supplemented fat for weight gain, as compared with the less digestible OPF diet.

The average daily DMI of cattle fed OPF-based diets was significantly ($P < 0.01$) higher than that of cattle fed grass-based diets (Table 2). However, the OPF diets were less digestible ($P < 0.01$). The above results contradicted the general observation that DMI is positively associated with DM digestibility. Feed intake in ruminant animals is controlled by many factors, including gut fill and rate of passage (Jung and Aller 1995). However, rate of passage can be increased by chopping or grinding the feed to smaller particle sizes before feeding, so as to increase feed intake (Minson 1963), especially when it is a poor-quality roughage (Campling and Freer 1966). Thus, the higher intake of OPF-based diets in the present study could be partly influenced by the higher passage rate because of the smaller particle size (2–3 cm), which resulted in a lower digestibility (Martz and Belyea 1986;

Table 2. Feed intake and liveweight gain of cattle fed Napier grass-TMR and OPF-TMR supplemented with and without bypass fat (*n* = 4 per treatment)

Napier grass–fat, fresh chopped grass in total mixed ration without bypass fat; Napier grass+fat, fresh chopped grass in total mixed ration supplemented with bypass fat; OPF–fat, oil palm fronds in total mixed ration without bypass fat; OPF+fat, oil palm fronds in total mixed ration supplemented with bypass fat; BW, bodyweight; ADG, average daily gain; DMI, dry matter intake; DMD, DM digestibility; DDMI, digestible DM intake; CPI, crude protein intake; NDFI, neutral detergent fibre intake; GEI, gross energy intake; MEI, calculated metabolisable energy intake ; FOR, forage type; FAT, bypass fat supplement. s.e.m., stand error of the mean. Values within a row followed by different letters are significantly different (at $P = 0.05$)

Item	Treatment				s.e.m.	*P*-value			
	Napier grass–fat	Napier grass+fat	OPF-fat	OPF+fat		Block	FOR	FAT	FOR × FAT
ADG (kg/day)	0.93a	0.91a	0.79b	0.92a	0.42	0.84	0.01	0.24	0.01
DMI/ADG (kg/kg)	8.16b	7.99b	11.59a	11.41a	0.37	0.85	0.01	0.78	0.99
DMI (% BW)	1.31b	1.30b	1.66a	1.80a	0.06	0.85	0.01	0.60	0.54
DMD (%)	78.6b	76.6b	65.9a	65.3a	0.35	0.76	0.01	0.46	0.19
DDMI (% BW)	1.31	0.99	1.10	1.17	0.03	0.84	0.15	0.79	0.49
CPI (% BW)	0.17b	0.16b	0.20a	0.21a	0.01	0.84	0.03	0.92	0.58
NDFI (% BW)	0.88b	0.83b	1.08a	1.11a	0.21	0.63	0.02	0.68	0.54
GEI (% BW)	21.84b	22.08b	28.46a	31.24a	1.18	0.64	0.01	0.45	0.53
MEI (kJ/kg BW)	174.63	175.54	164.85	182.02	7.76	0.79	0.90	0.49	0.53
MEI (kJ/kg $BW^{0.75}$)	857.4	853.9	798.1	894.1	36.75	0.87	0.85	0.46	0.43

Udén 1988) than with the longer (7–8 cm) grass used in the study. There was also no difference in the intake of CP or GE, since diets were formulated to be iso-nitrogenous and iso-caloric (Table 1).

Effect on carcass characteristics and meat quality

Results from the present study showed that neither forage type nor fat supplementation had any significant effect on warm and cold dressing percentage, averaging 57.7% and 56.2% respectively (Table 3), which indicated a carcass weight loss of 2.6% during chilling. The above values were close to the 58.9–59.5% dressing percentage reported for steers of the same breed as in the present study (Charolaise × Brahman crossbred) fed TMR contained cassava chip and ground corn (Boonsaen *et al*. 2017), as well as the 55.4–60.6% for Australian commercial cross bulls fed with different levels of urea-treated OPF silage and concentrate diets (Ishida and Abu Hassan 1997). Comparing with other breeds, the present results were marginally higher than the 54.7–55% warm dressing percentage for Nellore bulls fed feedlot diets having different glycerine concentrations (Françozo *et al*. 2013) and the 53.5–54.0% for Holstein steers fed with Napier silage, corn silage and pineapple by-product silage-based TMR (Hattakum *et al*. 2019), but marginally lower than the 59.89–60.71% for Angus crossbred beef steers fed different levels of corn oil (Andrae *et al*. 2001). The minor differences recorded among studies could be due to different breeds, and the type and level of oil used in the experiments.

Fat supplementation had a bigger impact on meat quality than did forage type (Table 4). Meat from cattle fed OPF had a lower pH than did meat from cattle fed grass-based TMR ($P = 0.05$), while fat supplementation decreased pH, moisture, CP and ash content, and increased meat colour (lightness, redness, yellowness), backfat thickness and fat content ($P < 0.05$, Table 4). Meat colour is related to carcass maturity and muscle pH, and is an important component of meat-quality grades (USDA 1997). In the present study, meat from cattle supplemented with fat had higher ($P < 0.05$) lightness, redness and yellowness in meat, which are

Table 3. Carcass characteristics of cattle fed OPF-TMR or Napier grass-TMR with and without bypass fat supplementation

Napier grass–fat, fresh chopped grass in total mixed ration without bypass fat; Napier grass+fat, fresh chopped grass in total mixed ration supplemented with bypass fat; OPF–fat, oil palm fronds in total mixed ration without bypass fat; OPF+fat, oil palm fronds in total mixed ration supplemented with bypass fat; FOR, forage type; FAT, bypass fat supplement. s.e.m., standard error of the mean

Item	Treatment				s.e.m.	*P*-value			
	Napier grass–fat	Napier grass+fat	OPF–fat	OPF+fat		block	FOR	FAT	FOR × FAT
Carcass weight (kg)	345.8	328.9	330.0	358.0	12.53	0.31	0.76	0.80	0.33
Warm dressing (%)	57.8	56.3	58.6	58.2	0.40	0.32	0.14	0.27	0.50
Cold dressing (%)	56.1	55.2	56.3	57.1	0.37	0.34	0.18	0.97	0.26
Chilling weight loss (kg)	9.50	7.99	8.86	9.14	0.60	0.54	0.81	0.57	0.42
Chilling weight loss (%)	2.74	2.48	2.68	2.51	0.14	0.87	0.95	0.41	0.86

Table 4. Physical characteristics and chemical composition of *Longissimus dorsi* muscle from cattle fed Napier grass-TMR and OPF-TMR supplemented with and without bypass fat

Napier grass–fat, fresh chopped grass in total mixed ration without bypass fat; Napier grass +fat, fresh chopped grass in total mixed ration supplemented with bypass fat; OPF–fat, oil palm fronds in total mixed ration without bypass fat; OPF+fat, oil palm fronds in total mixed ration supplemented with bypass fat; CP, crude protein; FOR, forage type; FAT, bypass fat supplement. s.e.m., standard error of the mean. Values within a row followed by different letters are significantly different (at $P = 0.05$)

Item	Treatment				s.e.m.	*P*-value			
	Napier grass–fat	Napier grass+fat	OPF–fat	OPF+fat		Block	FOR	FAT	FOR × FAT
Meat pH	6.73a	5.78b	6.20b	5.45c	0.09	0.06	0.05	0.01	0.59
Meat colour									
Lightness L*	23.83b	31.79a	24.83b	34.91a	1.45	0.86	0.50	0.02	0.73
Redness a*	13.58b	16.29ab	14.26b	20.41a	0.78	0.99	0.16	0.02	0.30
Yellowness b*	10.09b	14.17ab	10.92b	18.07a	0.83	0.99	0.19	0.01	0.38
Shear force (kg/cm^2)	5.94	7.08	6.96	9.01	0.53	0.20	0.25	0.22	0.72
Loin eye area (cm^2)	98.68a	96.25a	86.89b	98.26a	0.94	0.86	0.04	0.13	0.25
Back fat thickness (cm)	1.27c	1.30b	1.33ab	1.43a	0.37	0.80	0.26	0.04	0.16
Moisture (%)	72.54a	71.71b	72.03ab	69.82c	0.36	0.48	0.04	0.01	0.23
CP (% DM)	85.19a	83.30b	87.22a	78.54c	1.24	0.55	0.52	0.02	0.12
Fat (% DM)	8.37b	11.25a	7.91b	11.83a	0.97	0.46	0.98	0.01	0.79
Ash (% DM)	4.19a	3.87b	4.13a	3.80b	0.06	0.57	0.57	0.01	0.94

preferred by the consumers. The lightness L*, redness a* and yellowness b* of meat in the present study were close to values of aged and non-aged commercial meat from Simental bulls (Gasperlin *et al*. 2001) and feedlot Nellore bulls fed with diets with different glycerine contents (Françozo *et al*. 2013) and from pasture- and concentrate-fed cattle (Realini *et al*. 2004).

Forage type also affected loin eye area and moisture content, with meat from cattle fed OPF–fat having the smallest loin eye area and meat from OPF+fat having the lowest moisture content. Warner–Bratzler shear force was not affected by forage type or bypass-fat supplementation ($P > 0.05$).

Meat pH and colour are important indicators of quality, with a low pH and higher colourimeter readings being correlated with tenderness (Purchas 1990; Watanabe *et al*. 1996; Wulf and Wise 1999). Changes in the pH of meat post-slaughter are primarily caused by the glycogen in the muscles of animals. The amount of glycogen available at the point of slaughter determines the postmortem energy metabolism in the skeletal muscles through the anaerobic glycolysis, which results in accumulation of lactic acid and, thus, a reduction in pH in the respective skeletal muscles. The pH of meat in live animals is ~7.0 and normally decreases to ~6.1 and lower (5.4–5.8) after slaughter (Page *et al*. 2001; Adzitey and Nurul 2011). Meat of abnormally high pH are usually dark, firm and dry, while meat of abnormally low pH are usually pale, soft and exudative. Results of the present study showed that pH of meat from the OPF+fat (5.45) and Napier grass+fat (5.78) groups were within the pH of normal meat and close to those reported for commercially slaughtered meat from various breeds, such as Charolais, Holstein, Bonsmara, Angus and Nguni (Gasperlin *et al*. 2001; Mounier *et al*. 2006; Pfuhl *et al*. 2007; Muchenje *et al*. 2009), while meat from cattle without fat supplementation had unfavourably higher ($P < 0.01$) pH (6.20 and 6.73 for OPF–fat and Napier grass–fat respectively), which may lead to dark firm dry meat (Adzitey and Nurul 2011). This result clearly showed the advantage of fat supplementation on meat quality in cattle fed tropical forage and agricultural by-product such as OPF.

Backfat thickness was higher in cattle supplemented with bypass fat (1.37 vs 1.30 cm, $P < 0.05$), indicating that, in addition to improving the colour of muscle, and irrespective of forage type, the additional energy from bypass-fat supplementation was utilised for production of backfat thickness in the LD muscle. This result is interesting since fat depth is usually positively correlated with dressing percentage, but no difference in dressing percentage was recorded in our study (Table 3). Backfat thickness recorded here was close to values (1.25–1.46 cm) reported for steers of similar breeds (Charolais × Brahman crossbred) fed different TMR containing cassava chip and ground corn (Boonsaen *et al*. 2017) and those (1.2–1.3 cm) fed with Napier grass hay and rice straw with or without palm oil in the concentrate (Matsuba *et al*. 2019). Others have also reported near similar backfat thickness for other breeds, such as Angus crossbred steers (1.20–1.30 cm) fed with different oil-corn diets (Andrae *et al.* 2001) and for Holstein steer (1.20–1.29 cm) fed diets containing 4 and 5 kg/day concentrate with pineapple stem by-product as roughage (Pintadis *et al*. 2020). The near similar values reported among the different studies seem to suggest that there is little difference in backfat thickness among the common cattle breeds fed various forms of agricultural by-products and concentrates.

Thicker backfat resulted in a higher fat content in meat of fat-supplemented cattle than in that of non-supplemented cattle (11.5% vs 8.1%), and lower proportions of CP and ash in cattle supplemented with bypass fat. Increased fat content was also negatively related to moisture content in both the OPF- and grass-based diets ($P = 0.01$), which is consistent with results reported elsewhere (Abubakr *et al*. 2013; Hattakum *et al*. 2019). However, the above negative relationship between moisture and fat contents did not occur when comparing the values across the present study with those of Matsuba *et al.* (2019). The above researchers, working with feedlot cattle fed

Table 5. Average cost and return (US$ per head) of fattening cattle farming using different TMR

Napier grass–fat, fresh chopped grass in total mixed ration without bypass fat; Napier grass+fat, fresh chopped grass in total mixed ration supplemented with bypass fat; OPF–fat, oil palm fronds in total mixed ration without bypass fat; OPF+fat, oil palm fronds in total mixed ration supplemented with bypass fat; FOR, forage type; FAT, bypass fat supplement. The timeframe for estimation of costs was 255 days fattening period and based on per animal. s.e.m., standard error of the mean. Values within a row followed by different letters are significantly different (at $P = 0.05$)

Item	Treatment				s.e.m.	*P*-value			
	Napier grass–fat	Napier grass+fat	OPF–fat	OPF+fat		block	FOR	FAT	FOR × FAT
Cost of cattle	1500.6	1445.4	1467.5	1544.7	51.71	0.95	0.71	0.89	0.45
Feed cost	432.3c	479.3b	467.6b	629.4a	2.17	0.96	0.03	0.01	0.14
Labour cost	60.6	58.5	57.5	61.7	1.63	0.99	0.97	0.69	0.26
Utility cost	5.1	4.9	4.8	5.2	0.14	0.49	0.96	0.68	0.24
Medicinal cost	1.9	2.1	2.2	1.7	0.04	0.45	0.86	0.15	0.01
Transportation cost	56.9	55.1	52.9	57.7	1.25	0.99	0.75	0.51	0.15
Depreciation of farm assets	34.1	35.8	33.6	36.9	0.68	0.56	0.57	0.43	0.37
Opportunity cost	146.4	145.5	146.0	163.6	4.34	0.94	0.24	0.27	0.23
Sum of investment cost	2237.9	2224.6	2232.6	2500.9	66.39	0.97	0.26	0.23	0.24
Net income	2570.3	2486.9	2392.3	2603.4	56.82	0.97	0.74	0.51	0.15
Profit	332.33a	262.3ab	159.7b	102.5c	22.44	0.95	0.01	0.12	0.86

diet supplemented with palm oil, reported lower values of moisture (65.4–68.1% vs 69.8–72.5%) and lower fat (7.2–8.1% vs 7.9–11.8%) contents of meat than in the present study.

Costs and return of fattening cattle with TMR and bypass-fat supplementation

Average total investment cost was US$2299 per head, with cost of purchasing the feeder cattle the highest cost, followed by feed cost (Table 5). Feed cost was the only cost to vary among treatments, and had an impact on net profit. Profit from cattle fed Napier grass diets was two to three fold higher ($P < 0.01$) than that from cattle fed OPF diets. Although the unit cost of OPF was much cheaper than that of cut grass (Table 1), the higher DMI, and lower feed efficiency, of cattle fed OPF diets, which increased the feeding cost but not growth rate, was the primary reason for the lower profit than with cattle fed Napier grass. While supplementation of OPF with bypass fat increases ADG, the high cost of further increased feed cost leads to the lowest profit among the four treatments.

The above finding is rather unexpected from the perspective of our intention to promote the use of OPF as animal ruminant feed. However, in the present study, it was assumed that there was no limitation in the supply of cut forage, which is not always true, particularly during the dry (low-yield) and raining (difficult to harvest) seasons. In contrast, by-products such as OPF, which are abundantly available, can be preserved in the form of silage and fed to animals throughout the year. In fact, feeding a mixture of cut grass and various agro-industrial by-products such as OPF or rice straw has been shown to be viable and is commonly practiced by farmers in Malaysia (Wong *et al*. 2012), Thailand (Chanjula *et al*. 2017; Hamchara *et al*. 2018) and other developing countries in Asia, such as Bangladesh (Siddque *et al*. 2015).

Conclusions

Results of the present study showed that although OPF-based diets were marginally cheaper than grass-based diets, the higher DMI of cattle fed OPF diets was not accompanied by higher ADG, making feeding of OPF diets less profitable. While the growth rate of cattle fed OPF diet can be improved by supplementation of bypass fat, the high cost of bypass fat made it uneconomical, unless there is demand for high-quality beef, and consumers are prepared to pay a higher price.

Conflict of interest

The authors declare no conflicts of interest.

Acknowledgements

The authors express their sincere thanks to the Thailand Research Fund (TRF) contract grant RDG5820001 for financial support. This work was conducted using the research facilities provided by the Prince of Songkla University, Surat Thani campus and the Graduate School, Prince of Songkla University, Hat Yai campus.

References

Abubakr AR, Alimon AR, Yaakub H, Abdullah N, Ivan M (2013) Growth, nitrogen metabolism and carcass composition of goats fed palm oil by-products. *Small Ruminant Research* **112**, 91–96. doi:10.1016/j.smallrumres.2012.11.003

Adzitey F, Nurul H (2011) Pale soft exudative (PSE) and dark firm dry (DFD) meats: cause and measures to reduce these incidences: a mini review. *International Food Research Journal* **18**, 11–20.

AMSA (2012) 'Meat colour measurement guidelines.' (American Meat Science Association: Chicago, IL, USA)

AMSA (2015) 'Research guidelines for cookery, sensory evaluation, and instrumental tenderness measurements of fresh meat.' (American Meat Science Association: Chicago, IL, USA)

Andrae JG, Duckett SK, Hunt CW, Pritchard GT, Owens FN (2001) Effects of feeding high-oil corn to beef steers on carcass characteristics and meat quality. *Journal of Animal Science* **79**, 582–588. doi:10.2527/2001.793582x

AOAC (2000) 'Official methods of analysis.' 17th edn. (Association of Official Analytical Chemists: Washington, DC, USA)

Astuti T, Juandes P, Yelni G, Amir YS (2015) The effect of a local biotechnological approach on rumen fluid characteristics (pH, NH_3, VFA) on the oil palm fronds as ruminant feed. *International Journal of Agriculture Innovation and Research* **3**, 1703–1705.

Boonsaen P, Soe N, Maitreejet W, Majarune S, Reungprim T, Sawanon S (2017) Effects of protein levels and energy sources in total mixed ration on feedlot performance and carcass quality of Kamphaeng Saen steers. *Agriculture and Natural Resources* **51**, 57–61. doi:10.1016/j.anres.2017.02.003

Campling RC, Freer M (1966) Factors affecting the voluntary intake of food by cows. 8. Experiments with ground, pelleted roughages. *British Journal of Nutrition* **20**, 229–244. doi:10.1079/BJN19660024

Chanjula P, Petcharat V, Cherdthong A (2017) Effects of fungal (*Lentinussajor-caju*) treated oil palm frond on performance and carcass characteristics in finishing goats. *Asian–Australasian Journal of Animal Sciences* **30**, 811–818. doi:10.5713/ajas.16.0704

Dahlan I, Islam M, Rajion MA (2000) Nutrition intake and digestibility of fresh, ensiled and pelleted oil palm (*Elaeis guineensis*) frond by goats. *Asian–Australasian Journal of Animal Sciences* **13**, 1407–1413. doi:10.5713/ajas.2000.1407

Françozo MC, Prado IN, Cecato U, Valero MV, Zawadzki F, Ribeiro OL, Prado RM, Visentainer JV (2013) Growth performance, carcass characteristics and meat quality of finishing bulls fed crude glycerin-supplemented diets. *Brazilian Archives of Biology and Technology* **56**, 327–336. doi:10.1590/S1516-89132013000200019

Galyean ML (2010) 'Laboratory procedures in animal nutrition research.' (Department of Animal and Food Science, Texas Tech University: Lubbock, TX, USA)

Gašperlin L, Zlender B, Abram V (2001) Colour of beef heated to different temperatures as related to meat ageing. *Meat Science* **59**, 23–30. doi:10.1016/S0309-1740(01)00048-1

Hamchara P, Chanjula P, Cherdthong A, Wanapat M (2018) Digestibility, ruminal fermentation, and nitrogen balance with various feeding levels of oil palm fronds treated with *Lentinus sajor-caju* in goats. *Asian–Australasian Journal of Animal Sciences* **31**, 1619–1626. doi:10.5713/ajas.17.0926

Hattakum C, Kanjanapruthipong J, Nakthong S, Wongchawalit J, Piamya P, Sawanon S (2019) Pineapple stem by-product as a feed source for growth performance, ruminal fermentation, carcass and meat quality of Holstein steers. *South African Journal of Animal Science* **49**, 147–155. doi:10.4314/sajas.v49i1.17

Ishida M, Abu Hassan O (1997) Utilization of oil palm frond as cattle feed. *Japan Agricultural Research Quarterly* **31**, 41–47.

Jung HG, Aller MS (1995) Characteristics of plant cell walls affecting intake and digestibility of forages by ruminants. *Journal of Animal Science* **73**, 2774–2790. doi:10.2527/1995.7392774x

Kang HJ, Piao MY, Park SJ, Na SW, Kim HJ, Baik M (2019) Effects of heat stress and rumen-protected fat supplementation on growth performance, rumen characteristics, and blood parameters in growing Korean cattle steers. *Asian–Australasian Journal of Animal Sciences* **32**, 826–833. doi:10.5713/ajas.18.0725

Khamseekhiew B, Liang JB, Jelan ZA, Wong CC (2002) Fibre degradability of oil palm frond pellet, supplemented with *Arachis pintoi* in cattle. *Songklanakarin Journal of Science and Technology* **24**, 209–216.

Mach N, Bach A, Velarde A, Devant M (2008) Association between animal, transportation, slaughterhouse practices, and meat pH in beef. *Meat Science* **78**, 232–238. doi:10.1016/j.meatsci.2007.06.021

Martz FA, Belyea RL (1986) Forage utilization by the lactating cow. *Journal of Dairy Science* **69**, 1996–2008. doi:10.3168/jds.S0022-0302(86)80626-9

Matsuba K, Padlom A, Khongpradit A, Boonsaen P, Thirawong P, Sawanon S, Suzuki Y, Koike S, Kobayashi Y (2019) Selection of plant oil as a supplemental energy source by monitoring rumen profiles and its dietary application in Thai crossbred beef cattle. *Asian–Australasian Journal of Animal Sciences* **32**, 1511–1520. doi:10.5713/ajas.18.0946

Minson DJ (1963) The effect of pelleting and wafering on the feeding value of roughage-a review. *Journal of the British Grassland Society* **18**, 39–44. doi:10.1111/j.1365-2494.1963.tb00324.x

Mounier L, Dubroeucq H, Andanson S, Veissier I (2006) Variations in meat pH of beef bulls in relation to conditions of transfer to slaughter and previous history of the animals. *Journal of Animal Science* **84**, 1567–1576. doi:10.2527/2006.8461567x

Muchenje V, Dzama K, Chimonyo M, Strydom PE, Raats JG (2009) Relationship between pre-slaughter stress responsiveness and beef quality in three cattle breeds. *Meat Science* **81**, 653–657. doi:10.1016/j.meatsci.2008.11.004

Page JK, Wulf DM, Schwotzer TR (2001) A survey of beef muscle color and pH. *Journal of Animal Science* **79**, 678–687. doi:10.2527/2001.793678x

Pfuhl R, Bellmann O, Kuhn C, Teuscher F, Ender K, Wegner J (2007) Beef versus dairy cattle: a comparison of feed conversion, carcass composition, and meat quality. *Archiv fur Tierzucht. Dummerstorf* **50**, 59–70. doi:10.5194/aab-50-59-2007

Pintadis S, Boonsaen P, Hattakum C, Homwong N, Sawanon S (2020) Effects of concentrate levels and pineapple stem on growth performance, carcass and meat quality of dairy steers. *Tropical Animal Health and Production* **52**, 1911–1917. doi:10.1007/s11250-019-02195-4

Purchas RW (1990) An assessment of the role of pH differences in determining the relative tenderness of meat from bulls and steers. *Meat Science* **27**, 129–140. doi:10.1016/0309-1740(90)90061-A

Realini CE, Duckett SK, Brito GW, Dalla Rizza M, Mattos D (2004) Effect of pasture vs. concentrate feeding with or without antioxidants on carcass characteristics, fatty acid composition, and quality of Uruguayan beef. *Meat Science* **66**, 567–577. doi:10.1016/S0309-1740(03)00160-8

SAS (1998) 'Statistical Analysis System. User's Guide: Statistics,' 5th edn. (SAS Institute Inc.: Cary, NC, USA)

Siddque MAB, Sarker NR, Hamid MA, Amin MN, Sultana M (2015) Growth performance, feed conversion ratio and economics of production of native and crossbred (Local × Holstein Friesian) bulls for fattening under different improved feeding. *Journal of Agricultural Science and Technology* **5**, 770–781.

Steel RGD, Torries JH (1980) 'Principles and procedures of statistics: a biometeric approach.' 2nd edn. (McGrawHill: New York, NY, USA)

Subepang S, Suzuki T, Phonbumrung T, Sommart K (2019) Enteric methane emissions, energy partitioning, and energetic efficiency of zebu beef cattle fed total mixed ration silage. *Asian–Australasian Journal of Animal Sciences* **32**, 548–555.

Tafsin M, Khairani Y, Hanafi ND, Yunilas Y (2018) *In vitro* digestibility of oil palm frond treated by local microorganism (MOL). International Conference on Agriculture, Environment, and Food Security. IOP Conference Series: Earth and Environmental Science 122, 1–6.

Thai Nutrition NRC (2010) 'Nutrient requirements of beef cattle in Indochinese Peninsula.' 1st edn. (Department of Livestock Development, Ministry of Agriculture and Cooperatives: Thailand)

Tozer PR, Bargo F, Muller LD (2003) Economic analyses of feeding systems combining pasture and total mixed ration. *Journal of Dairy Science* **86**, 808–818. doi:10.3168/jds.S0022-0302(03)73663-7

Tuyen DV, Phuong HN, Cone JW, Baars JJ, Sonnenberg ASM, Hendriks WH (2013) Effect of fungal treatments of fibrous agricultural by-products on chemical composition and in vitro rumen fermentation and methane production. *Bioresource Technology* **129**, 256–263. doi:10.1016/j.biortech.2012.10.128

Udén P (1988) The effect of grinding and pelleting hay on digestibility, fermentation rate, digesta passage and rumen and faecal particle size in cows. *Animal Feed Science and Technology* **19**, 145–157. doi:10.1016/0377-8401(88)90063-6

USDA (1997) 'Official United States standards for grades of carcass beef.' (AMS, USDA: Washington, DC, USA)

Van Soest PJ, Robertson JB, Lewis BA (1991) Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science* **74**, 3583–3597. doi:10.3168/jds.S0022-0302(91)78551-2

Velásquez AV, Da Silva GG, Sousa DO, Oliveira CA, Martins CMMR, Dos Santos PPM, Balieiro JCC, Renno FP, Fukushima RS (2018) Evaluating internal and external markers versus fecal sampling procedure interactions when estimating intake in dairy cows consuming a corn silage-based diet. *Journal of Dairy Science* **101**, 5890–5901. doi:10.3168/jds.2017-13283

Wahyuni RD, Ngampongsai W, Wattanachan C, Visessanguan W, Boonpayung S (2012) Effects of enzyme levels in total mixed ration containing oil palm frond silage on intake, rumen fermentation, and growth performance of male goat. *Songklanakarin Journal of Science and Technology* **34**, 353–360.

Watanabe A, Daly CC, Devine CE (1996) The effects of the ultimate pH of meat on tenderness changes during ageing. *Meat Science* **42**, 67–78. doi:10.1016/0309-1740(95)00012-7

Wong MJ, Rajion MA, Ping LZ, Ebrahimi M, Meng GY (2012) *In vitro* evaluation of Napier grass–oil palm frond combination as ruminant feed. *Proceedings of the Seminar in Veterinary Sciences* **7**, 68–72.

Wulf DM, Wise JW (1999) Measuring muscle color on beef carcasses using the L* a* b* color space. *Journal of Animal Science* **77**, 2418–2427. doi:10.2527/1999.7792418x

Handling editor: Di Mayberry