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ORIGINAL ARTICLE

Impacts of dietary fat level and saturation when feeding distillers grains to high producing dairy cows

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Summary

This experiment was conducted to determine whether increasing the net energy (NE_L) of a total mixed ration (TMR) with mainly unsaturated fat from corn distillers dried grains with solubles (DDGS) vs. rumen inert (RI)-saturated fat has similar impacts on animal performance. The experiment was an incomplete Youden square with three treatments and four 28-days periods, completed on a large commercial dairy using three early lactation pens each with approximately 380 multiparity cows. The TMR for all treatments was the same, except for 150 g/kg dry matter (DM) of each TMR which contained 90 g/kg high-protein DDGS (HPDDGS) and 60 g/kg beet pulp (i.e. low-fat control diet; LFC); 150 g/kg DDGS (i.e. high-fat diet with unsaturated fat; HFU); or 111 g/kg HPDDGS, 20 g/kg beet pulp and 19 g/kg RI fat (i.e. high-fat diet with saturated fat; HFS). The DM intake was highest ($p < 0.05$) for HFU-fed cows. Milk, fat and true protein yields, as well as milk energy output, were higher ($p < 0.01$) when cows were fed HFS vs. HFU and LFC diets. Milk true protein concentration was lowest ($p < 0.01$) for HFS-fed cows, but milk fat % was lowest ($p < 0.01$) for HFU and highest ($p < 0.01$) for HFS-fed cows. There were numerous differences ($p < 0.01$) in milk fatty acid levels amongst diets. The increase in body condition score was lowest ($p < 0.01$) for LFC. Whole tract digestibility of acid detergent fibre was lower ($p < 0.01$) for LFC vs. HFS cows, and fat digestion was lowest ($p < 0.01$) for LFC-fed cows. This DDGS, high in unsaturated fatty acids, was fed at high levels (i.e. 152 g/kg DM) with little impact on animal performance vs. a lower fat control diet, although addition of an RI-saturated fat to create a diet with a similarly higher fat level resulted in higher animal productivity.

Keywords milk fat depression, saturated, unsaturated, RI fat, dried distillers grains with solubles, distillers

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Introduction

High inclusion levels of supplemental fat, a concentrated source of net energy (NE_L), are common in rations of high producing dairy cows worldwide. Added lipids can be of various saturation levels. For example, polyunsaturated fatty acids (PUFA) mainly originate from plant and seed oils while saturated fatty acids (SFA) largely originate from animal by-products or a few plants such as palm oil.

Sources of PUFA, especially oils with high levels of linoleic and linolenic FA, have inhibited microbial activity with resultant decreased forestomach fibre fermentation (Palmquist and Jenkins, 1980; Hartfoot and Hazlewood, 1988; Doreau and Chilliard, 1997). At high levels, these FA can lead to an altered biohydrogenation pathway in the rumen, resulting in creation of CLA *t*10*c*12 and C18:1 *t*10 intermediates, which can inhibit fat synthesis in the mammary gland (Harvatine and Bauman, 2007).

Saturated FA are less likely to change rumen fermentation, compared to PUFA, due to their insolubility at normal rumen pH (Schneider et al., 1988; Schauff and Clark, 1989), thereby preventing an effect on fibre digestibility or lipogenesis. Because SFA largely escape the rumen without being degraded or metabolized, as well as having little effect on the rumen environment, these FA are often called rumen inert (RI). Feeding RI FA to dairy cows consistently increases milk fat proportion and, generally, yields (Palmquist and Jenkins, 1980; Scott et al., 1995).

An increasingly common ingredient added to rations of high producing dairy cows worldwide, which can increase dietary fat level, is dried distillers

grains with solubles (DDGS). Due to the growing motor fuel ethanol distillation industry in the Midwest USA and other parts of the world, there has been a steadily increasing level of DDGS from corn grain available to world animal feed market since 2000 (Anonymous, 2013), and DDGS products originating in the USA are now exported worldwide. Conventional DDGS have nutrient levels which are approximately thrice that of the corn grain from which they originate. Thus, as starch makes up approximately two-thirds of its dry matter (DM) and is almost completely fermented to create ethanol, DDGS contain approximately 30% crude protein (CP) and 11% fat on a DM basis. However, DDGS, being high in corn oil, are substantial source of PUFA. Many technical papers (i.e. Hutjens, 2004; Diaz-Royón, 2012) have reported that there is a consensus amongst commercial dairymen that high feeding levels of DDGS play a role in reducing *de novo* milk fat synthesis.

Unfortunately, recent research on DDGS has produced mixed results. A meta-analysis of 44 trials (Hollmann et al., 2011) could neither accept nor reject their hypothesis that increased inclusion of distillers grains increases the risk of milk fat depression. This may be a result of using small and statistically underpowered studies, and the authors suggest that their findings are not applicable to commercial settings. Of the recent research that has supported the hypothesis that increasing levels of DDGS may negatively impact milk fat production, all have fed diets with relatively high levels of corn silage and other corn products ranging from 42% (Abdelqaedar et al., 2009) to 63% (Zanton et al., 2013) of the basal diet DM. However, dairy rations in many parts of the world, including many areas of Europe and North America, contain much lower levels of corn products. As well, most recent studies that have shown a negative impact of increasing DDGS levels examined DDGS as a substitute for both soybean meal and corn grain (Leonardi et al., 2005; Benchaar et al., 2013), therefore altering the availability and form of FA as well as the amino acid profile and rumen degradable and rumen undegradable protein levels of the diet. In addition, a review by Schingoethe et al. (2009) finds that, in general, feeding distillers grains *per se* does not cause milk fat depression. Their explanation is that cows experiencing milk fat depression with increasing levels of distillers grains are suffering from a decrease in effective fibre from forages due to poorly formulated diets. The review also states that milk FA profile is not expected to be altered feeding distillers grains and reports only small increased levels of CLA *c*9*t*11 and C18:1 *t*11 from Leonardi et al. (2005) and Anderson et al. (2006) with DDG feeding, yet neglect to point out that FA are not associated with milk fat depression (Griinari et al., 1998) and fail to note that these same studies found increased levels of C18:1 *t*10, the C18:1 isomer highly associated with milk fat depression (Griinari et al., 1998).

The majority of research on DDGS has looked at it as a supplement to another feed ingredient, and there is a lack of research that has attempted to isolate effects of PUFA on milk synthesis. There is also a lack of statistically high powered studies that could be applicable to commercial dairy farms.

Our objective was to determine whether the form of added fat (i.e. SFA as RI FA or PUFA as corn oil in DDGS) to a relatively low-fat total mixed ration (TMR) of high producing early lactation Holstein cows impacts DM intake, nutrient digestibility, change in body condition score (BCS) as well as milk production and composition, including FA profiles of the milk fat.

Materials and methods

Animal, management and experimental design

High producing multiparity Holstein cows in three early lactation pens, each of approximately 380 cows, on a commercial dairy farm near Hanford (CA, USA) were used in this study which consisted of four 28-days experimental periods in an incomplete Youden crossover design (Cochran and Cox, 1950). Cows were sequentially assigned to pens from a common fresh cow pen. When one pen reached capacity (i.e. approximately 380 cows), the next pen was filled. This resulted in the average days in milk (DIM) of each pen being approximately 35 days earlier than the previous pen and created three treatment pens, which were at slightly different stages in lactation (Fig. 1). This unique experimental design allowed separation of the chronological period from the DIM of the cows, which are always confounded in normal Latin and Youden square studies.

Cows were milked in a double 40 parallel milking parlour three times daily starting at 01:00, 09:00 and 17:00 h for pen 7. Pens 8 and 9 were milked in sequence directly after pen 7 at approximately 90-min intervals. The TMR was delivered daily to the pens, sequentially, between 09:00 and 12:00 h prior to cows returning to their respective pens from milking. A second TMR load was delivered between 12:00 and 14:00 h according to the previous day's intake to create orts equal to approximately 10 g/kg of TMR delivered. Orts were removed daily and weighed individually by pen while cows were in the milking

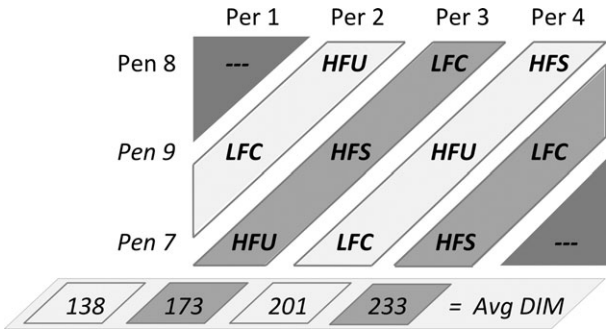

Fig. 1 Representation of the Youden crossover experimental design with three pens (i.e., 7, 8, 9), four experimental (i.e., chronological) periods (Per), three treatments (Low fat control, LFC; High fat saturated, HFS; High fat unsaturated, HFU), and four 'DIM groups' (represented by diagonal bars) with average DIM of each group at day 26 (i.e., milk test day) given in the bottom row.

parlour during the mid-morning milking, prior to the first feeding of the day.

Headlocks were set daily for 45–60 min after the morning milking for artificial insemination, general animal examination and weekly pregnancy checks. Cows were housed in covered barns with access to free stalls bedded with dried composted manure, which was renewed weekly. Each pen contained 360 head gates and free stalls. Tractors scraped the pens to remove all manure from the free stall alleyways daily while cows were at the mid-morning milking. Cows did not have access to outside pens due to wet winter conditions. Cows had *ad libitum* access to clean water on the return lanes from the milking parlour and in the pens.

The Youden crossover design created an incomplete Latin square where pen 9 was included in all four periods of the study, but pen 8 did not enter until period 2 because the pen was not completely filled at the start of the study, and pen 7 was excluded from period 4 due to their late DIM (Fig. 1). All pens received each treatment once, except pen 9 which received the control TMR twice**,** during periods 1 and 4. Diagonal bars in Fig. 1 represent similar average DIM of pens (i.e. 'DIM groups'), whereas the vertical bars represent the same chronological times. The earliest and latest DIM group received three treatments (one of which was the control) while the two intermediate DIM groups received all three treatments.

Environment

Three portable weather stations (Onset, Bourne, MA, USA) were used to record ambient temperatures every 15 min throughout the study. One station was placed in each treatment pen on a pole in the centre of the pen approximately 3 m above the floor, which was judged to be the minimum height needed to prevent the cows from disturbing them and to keep them out of direct sunlight. The study took place 2 months before and after the winter solstice to minimize weather and daylength variation.

Diets

The base portion of the TMR (i.e. 850 g/kg of DM) was the same for all diets. The remaining 150 g/kg DM of each TMR (Table 1) was formulated to create two high-fat (HF) diets of equal fat level, one high in unsaturated fats (HFU) from DDGS the other high in saturated fats (HFS) from a RI Fat, as well as a low-fat control (LFC) diet.

Sample collection

Feed and TMR samples

At the start and end of the collection week of each period (i.e. days 20 and 27), all dietary ingredients were sampled. Hays were sampled using a 'golf club' style hay probe which was 30 cm in length and 1 cm in diameter (Sierra Testing Services, Acampo, CA, USA). Twelve core samples were pooled into a plastic bag to create each sample. All other ingredients, with the exception of the RI fat and liquid whey, were sampled by hand (i.e. six handfuls of each ingredient) and composited to plastic bags. Silages were sampled from a loose pile, which had been knocked off the silage face and mixed for use that day. Wet by-products (i.e. carrot tubers, citrus pulp, pomegranate pulp) were sampled from the site, which was being used for that

Table 1 Composition of the 150 g/kg of the diets that was manipulated to create a low-fat control and two high-fat diets with different fat sources

Diets	g/kg of TMR DM
HFU	150 DDGS*
HFS	111 HPDDGS†
	20 Beet pulp (dried)
	19 EnerG II‡
LFC	90 HPDDGS†
	60 Beet pulp (dried)

HFU, High-fat unsaturated fat; HFS, High-fat saturated fat; LFC, Low-fat control.
*Dried distillers grains with solubles, corn.
†High-protein (i.e. low fat) DDGS.
‡Rumen inert fat, Ca salts of fatty acids (Virtus Nutrition, Corcoran, CA, USA).

day's TMR preparation. Commodities were sampled from the front section of the commodity bay to obtain a sample, which would be representative of that added to the TMR that day. Commodity samples from the start and end of each collection week of each experimental period were later combined to create one sample per ingredient per period prior to chemical analysis.

The TMR of each pen was sampled from the feed bunk at the morning feeding prior to the cows having access to it during the last week of each period (i.e. day 20 and 27). Ten handfuls of TMR from each pen were collected at evenly spaced predetermined intervals along the feed bunk (Robinson and Meyer, 2010). Large ingredients (i.e. carrot tubers, pomegranate) in the TMR sample were cut into small pieces while the sample was being mixed, prior to quartering. The sample was divided into quarters with two quarters placed in a plastic bag for chemical analysis while the remaining two quarters were discarded.

Milk samples

At the end of each collection week (i.e. day 27), Kings County Dairy Herd Improvement Association personnel (Hanford, CA, USA) completed a milk test on the entire herd during the morning milking. Their personnel recorded milk weights and obtained 50 ml representative milk samples into tubes containing bronopol and natamycin preservatives from all cows using Tru-test milk meters (Tru-Test, Auckland, New Zealand). Samples were transported to the Kings County Dairy Herd Improvement Association Laboratory where fat, true protein, lactose and ash were analysed by a mid-infrared component testing instrument (Bentley 2000, Bentley Instruments; AOAC, 2000; #972.16). Somatic cell count (SCC) was analysed by dual laser-based flow cytometry (Somacount 500, Bentley Instruments). A group of 20 cows from each pen was selected for additional milk analysis based on DIM (i.e. individual cows with DIM closest to the pen average). These milk samples were aliquoted into 10-ml tubes and frozen at −18 °C until later analysis for FA composition.

Body condition score

Body condition was scored at the start of the study (i.e. day 0) and at the end of each experimental period (i.e. day 28) while the cows were in lock-up immediately after the morning milking. At the start of the study, a group of 80 cows from each pen with DIM closest to the pen average were selected. Cows were scored on the standard 1–5 scoring system of Edmondson et al. (1989), but with additional intermediate values between the standard quarter points (i.e. when a cow could not clearly be allocated to a quarter point, it was allocated to the intermediate score). All cows were scored by a single trained scorer on all occasions.

Faecal collection

The same subgroup of cows selected for milk FA samples was also used for faecal collection. Faecal samples were collected on day 27 of each period while the cows were in lock-up immediately after the morning milking. Faeces were collected (at least 250 g) into plastic containers manually from the rectum of the cow. Faeces were frozen and stored at −18 °C after collection until chemical analysis.

Analytical methods

Ingredient and TMR chemical analysis

All wet ingredients and TMR samples were weighed and dried at 55 °C for 48 h prior to being sent to the UC Davis Analytical Laboratory (Davis, CA, USA) for chemical analysis. Samples were ground to pass a 0.4-mm screen on an Intermediate Wiley Mill or a 1-mm screen on a model 4 Wiley Mill (Thomas Scientific, Swedesboro, NJ, USA). Moisture was determined by gravimetric loss of free water by heating to 105 °C in a forced air oven for 3 h, and ash was the gravimetric residue after heating to 550 °C for at least 3 h. Total N, and N in acid detergent fibre (ADF), was determined with infrared detection and thermal conductivity (TruSpec CN Analyzers, St, Joseph, MI, USA) by AOAC (2006; #990.03). Neutral detergent fibre (NDF) analysis utilized a heat-stable amylase (AOAC, 2006; #2002-04), expressed exclusive of residual ash (i.e. $aNDF_{OM}$) or with residual ash (i.e. aNDF). ADF_{OM} analysis was with acid detergent (AOAC, 1997; #973.18) and expressed exclusive of residual ash. Free sugars are the sum of glucose, fructose and sucrose determined by HPLC (Johansen et al., 1996). Enzymatic hydrolysis is used to determine the amount of total glucose. The free glucose is subtracted from the total glucose, and the difference is multiplied by 0.9 to give the starch value (Smith, 1969). *In vitro* digestibility of NDF at 30 h ($dNDF_{30}$) was determined by incubating a TMR sample in ruminally cannulated cows for 30 h with 6 replicates (three cows with duplicate incubations).

Crude fat (ether extract, EE) was assayed as material extracted in ethyl ether (AOAC, 2006; #2003.05). Fatty acid profile of TMR was determined by one-step extraction-transesterification (Sukhija and Palmquist, 1988). Lignin(sa) was determined by

the sulphuric acid procedure (AOAC, 1997; #973.18). Calcium, Cu, Fe, Mg, Mn, P, K, Na, S and Zn were determined using microwave nitric acid/hydrogen peroxide digestion/dissolution by inductively coupled plasma atomic emission spectrometry (ICP-AES; Meyer and Keliher, 1992; Sah and Miller, 1992). The Cl was determined using water extraction and analysis by ion chromatography with conductivity detection (Jones, 2001). Total Se was extracted by nitric/perchloric acid digestion/dissolution and determined by vapour generation using ICP-AES (Tracy and Moeller, 1990).

Milk fatty acid analysis

Fatty acid analysis on milk samples from 8 cows/pen/period (n = 24) was determined by gas chromatography (Kraft et al., 2003**).**

Faecal

Faecal samples from the 20 cows/pen/period which were collected in each experimental period were divided into two subgroups (the 10 cows with the lowest and highest ear tag numbers became the respective groups). After samples were thawed and mixed, approximately 150 g of each sample within subgroup was pooled into a new container to create two samples/pen/period for chemical analysis (n = 20). These pooled samples were dried at 55 °C for 48 h before being sent the UC Davis Analytical Laboratory where they were further dried and ground as described earlier for the feed samples. Samples were analysed for the same components as the TMR by the same methods described to facilitate calculations of digestibility of dietary components.

Calculations

Dry matter intake

The DM intake of the TMR was calculated daily during the collection week (i.e. day 22 through day 28 for each period) based on the total weight of TMR delivered per pen corrected for all orts which were removed from that pen prior to the first TMR feeding of the day. The number of cows/pen was determined by averaging the number of cows reported in the pen on the first and last day of the collection period, because a few cows were moved in and out of the study pens once weekly and the only pen movement on days 2–6 was an occasional cow moving to the hospital pen. Daily DM intake for each pen during the 7-days collection period was averaged to estimate daily DM intake on an individual cow basis.

Energetic calculations

Milk energy (MJ/kg) was calculated using the equation of Tyrell and Reid (1965) using milk fat, CP and lactose, where true protein was converted to CP by dividing it by 0.93. Changes in BCS energy (MJ/days) were calculated by cow according to National Research Council (2001) as 1255.2 MJ/unit BSC.

Maintenance energy (MJ/days) was calculated as ($BW^{0.75}$ * 0.33) according to National Research Council (2001) for all groups, assuming an average body weight of 625 kg for all groups of cows. Total energy output was calculated as follows:

$$\text{Milk energy(MJ/days)} + \text{Change BCS (MJ/days)} + \text{Maintenance energy (MJ/days)}$$

and net energy for lactation (NE_L) density was calculated by pen and period as:

$$\text{Total Energy Output (MJ/days)/DM intake (kg/days)}.$$

Whole tract digestibility

Digestibility was calculated as the dietary component proportion remaining in faeces vs. in the diet using lignin(sa) as a marker (assuming 95% indigestibility; Stensig and Robinson, 1997).

Statistical analysis

The chemical composition and fatty acid profile of the TMR fed were statistically analysed using the GLM procedure of SAS (1998) with pen, period and treatment as effects to confirm that the diets met the objectives. The analytical values for the two TMR samples collected at the start and end of each collection week (i.e. day 21 and 27 of each period) were combined prior to statistical analysis (n = 10). The DM intake (n = 10) data were also analysed using the GLM option of SAS with pen, period, treatment and DIM group as fixed effects. The criteria for inclusion in the DM intake analysis were all cows in the pen during each 7-days collection week at the end of each experimental period.

The criteria for inclusion of cows in milk production statistical analysis were that they had to be >55 and <244 DIM when they joined the study, to have been in >1 or <6 lactation, and to have remained in the same pen for the entire study (n = 770). Cows with milk or milk component values determined visually to be biological outliers were removed. Cows with a SCC >4000 during any milk test were considered sick animals and removed. Removal selection (n = 46),

completed blind to treatment and pen assignments to avoid bias in removal or inclusion, left 724 cows which met the criteria for inclusion and were included in the data set for statistical analysis. Milk yield and components were analysed using the MIXED option of SAS with experimental unit (cow) nested within pens. The statistical model included fixed effects of pen, period (i.e. time), treatment and DIM group, with cow as a random effect.

The inclusion criteria for cows to be included in the BCS statistical analysis were that they had to meet all of the criteria required for milk analysis and have been scored at the start of the experiment, as well as the end of each experimental period. The BCS data (n = 176) were analysed with the MIXED option of SAS with the same effects as the milk parameter analysis.

Inclusion criteria of cows for digestibility of feed components statistical analysis were the same as the milk criteria. Of the 20 faecal samples/pen/period, 10 samples/pen/period were combined to create two samples/pen/per (n = 20) as described earlier. Digestibility was analysed with the MIXED option of SAS with 'faecal group', pen, period and treatment as effects.

Samples collected for milk FA analysis were from the same cows as those used for digestibility. Of the 20 milk samples/pen collected, samples from eight cows/pen that had a sample for each period were selected for FA analysis. Statistical analysis of milk FA (n = 24) was with the MIXED option of SAS with cows, pen, period, treatment and DIM group as effects.

The PDIFF option of SAS was used to indicate statistical differences between pairs of means as planned a priori. All treatment differences were accepted if $p \leq 0.05$, and tendencies to significance were accepted if $0.05 < p \leq 0.10$.

Results

Animals and environment

Ambient temperatures were consistent throughout the study (Fig. 2), with average temperatures during the collection periods ranging from 14.7 to 15.7 °C (daily highs) and −1.3 to 3.7 °C (daily lows). Temperatures were similar amongst pens (data not shown).

Chemical composition of feeds and TMR

Chemical composition of the ingredients used in the TMR (Table 2) was generally similar to the nutrient composition of feeds as listed in National Research Council (2001), as well as by Swanepoel et al. (2010) for California feeds. The TMR ingredient profiles are generally consistent with contemporary California dairy rations, and the only substantive ingredient differences in the diets were the manipulated 150 g/kg DM in each diet (Tables 3 and 4).

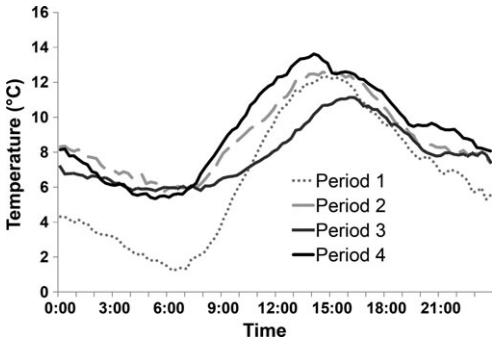

Fig. 2 Average daily temperatures during the collection week of each period.

The chemical profile of the TMR met or exceeded all minimum nutrient recommendations of the National Research Council (2001) for dairy cattle at similar production levels. Fat levels were higher for

Table 2 Chemical composition of the main feeds* used in the total mixed rations

	n	DM g/kg	EE	CP	aNDF†	$aNDF_{OM}$‡
			g/kg DM			
Alfalfa, hay	4	899.0	20.8	194.1	402.5	382.1
Almond, hulls	4	972.3	24.2	46.7	330.3	313.5
Barley, grain (rolled)	2	894.5	20.2	115.0	196.5	192.0
Beet, pulp (dried)	4	910.5	8.1	79.4	395.3	364.0
Bermuda, hay	2	924.0	18.0	104.7	669.0	638.0
Canola, pellets	4	904.3	28.9	402.8	299.3	250.5
Carrot, tubers	8	92.4	14.9	82.7	184.9	164.3
Citrus, pulp	2	133.5	24.3	93.4	257.5	245.0
Corn, flaked grain	4	846.3	31.7	75.8	89.5	87.3
Corn, silage	8	301.5	22.0	59.7	481.5	467.3
Cottonseed, whole	4	933.8	205.6	203.5	467.8	451.4
Cottonseed, pima	4	911.0	218.4	238.7	421.8	402.1
DDGS§	4	908.0	120.8	278.4	296.5	288.0
HPDDGS¶	4	920.8	47.0	400.2	325.8	309.3
Oat, hay	2	899.5	23.5	97.3	589.8	561.8
Pomegranate, pulp (wet)	6	280.9	74.1	107.2	370.9	360.4
Sorghum, silage	8	257.9	32.1	109.4	514.8	493.9
Wheat, silage	8	324.4	24.0	117.4	534.4	494.6
Wheat, middlings	2	877.0	44.7	181.3	415.5	407.0

*Values are the average of two pooled samples collected at the beginning and end of the last week of both experimental period.
†aNDF expressed inclusive of residual ash.
‡$aNDF_{OM}$ expressed exclusive of residual ash.
§Dried distillers grains with solubles, corn.
¶High-protein (i.e. low fat) DDGS.

Table 3 Ingredient composition of total mixed rations (g/kg DM)*

	Diet				p-value	
	LFC	HFU	HFS	SEM	LFC vs. HFU	LFC vs. HFS
DDGS†	0	151.9	0	1.16	<0.01	0.89
HPDDGS‡	88.1	0	107.7	0.89	<0.01	<0.01
Beet pulp, dried	59.2	0	19.8	0.25	<0.01	<0.01
Rumen inert fat§	0	0	17.7	0.13	0.87	<0.01
Alfalfa, green chop	11.0	10.4	10.9	0.32	0.33	0.82
Alfalfa, hay	48.6	49.8	51.3	1.35	0.58	0.29
Almond, hulls	93.2	92.7	93.5	0.14	0.14	0.27
Barley grain or wheat middlings¶	74.4	74.0	74.6	0.12	0.14	0.29
Bermuda or Oat, hay¶	32.7	29.8	31.2	0.48	0.05	0.16
Canola, pellets	102.1	101.7	102.5	0.16	0.17	0.27
Carrot, tubers	12.0	11.9	12.0	0.15	0.53	0.83
Corn, flaked grain	70.8	70.6	71.1	0.12	0.26	0.26
Corn, silage	116.5	117.3	118.2	1.38	0.72	0.47
Cottonseed, cracked pima	17.5	17.4	17.5	0.02	0.12	0.53
Cottonseed, whole	26.9	26.7	26.9	0.05	0.20	0.46
Molasses, liquid	25.6	25.5	25.7	0.04	0.09	0.61
Pomegranate or citrus pulp¶	36.5	36.0	36.2	0.48	0.53	0.71
Sorghum, Silage	50.7	50.4	49.5	1.24	0.87	0.55
Wheat, silage	70.3	70.1	70.3	0.82	0.89	1.00
Whey, liquid	53.7	53.4	53.1	1.11	0.83	0.73

*Mineral mixture added at 9.4 g/kg DM to all diets. Yea-sacc (Alltech, Fresno, CA, US; $1x10^8$ CFU/g) added at 0.4 g/kg DM to all diets.
†Dried distillers grains with solubles, corn.
‡High-protein (i.e. low fat) DDGS.
§EnerG II, Virtus Nutrition, Corcoran, CA, USA.
¶Ingredients listed together were used interchangeably throughout the study depending on availability.

the HFS and HFU diet vs. the LFC diet ($p < 0.01$), but did not differ from each other (Table 4). Saturated FA levels were highest for the HFS diet ($p < 0.01$), while PUFA levels were highest for the HFU diet (Table 4). The calculated NE_L of the diets (based on National Research Council (2001) tabular values) was highest for HFU, lowest for LFC ($p < 0.01$) and intermediate for HFS ($p = 0.01$; Table 4).

Milk production and body condition score

Milk and milk component yields for cows fed LFC diets were the same as for cows fed the HFU diet, except for fat yield which tended ($p = 0.04$; Table 5) to be lower in HFU cows, while all milk component yields from LFC cows were lower than those of HFS cows ($p < 0.01$). All milk and component yields from HFS cows were higher than those of HFU cows ($p < 0.01$). Concentrations of milk true protein ($p = 0.02$), fat, lactose, as well as milk energy ($p < 0.01$) from cows fed LFC were intermediate to cows fed the HF diets. Cows fed HFS had a higher level of milk fat and energy, but lower ($p < 0.01$) concentrations of protein and lactose compared to HFU-fed cows. Cows fed the LFC diet had the lowest BCS increase ($p < 0.01$), but the BCS increase did not differ between the HF cows.

Milk fatty acid profile

There were numerous differences in milk FA levels amongst treatments. However, in general, concentrations of short- and medium-chain FA of even-chain FA (i.e. C4:0-C:12:0) were highest in milk from cows fed LFC diets ($p < 0.01$; Table 6), and, of the long-chain FA, the majority of the 18:0, 18:1 and 18:2 isomers are lowest in milk from LFC cows. Levels of C18:1 *trans*-10 were lowest in LFC cows and higher in HFU-fed cows than HFS-fed cows ($p < 0.01$).

Dry matter intake and whole tract apparent digestibility

The DM intake of cows fed HFU was highest ($p = 0.05$; Table 7) with LFC- and HFS-fed cows similar. Apparent digestibility of ADF_{OM} was lower in HFS-fed cows ($p = 0.01$), while NDF_{OM} tended to be lower in cows fed HFU vs. LFC ($p = 0.06$). Whole tract apparent digestibility for crude fat of cows fed HF diets was higher ($p < 0.01$) than in cows fed LFC.

Energy balance

Milk energy output was highest for cows fed HFS diets ($p < 0.01$; Table 8), but the energy in the BCS increase for the two HF diets did not differ, and both were higher than the LFC cows ($p < 0.01$). The calculated NE_L density of the diets tended ($p = 0.09$) to be higher for cows fed the HFS vs. HFU diet.

Discussion

Increased fat level as unsaturated fat

Diet, DM intake and digestibility

The chemical composition of the diets was as anticipated, with LFC having lower fat (i.e. 37.9 g/kg) than HFU (i.e. 47.6 g/kg). The higher DM intake of cows fed the HFU diet was not expected and cannot be compared to results of other studies using DDGS products as no studies were found which directly compared DM intake when substituting traditional DDGS for

Table 4 Chemical composition of total mixed rations (g/kg DM; $n = 10$)

	Diet				p-value	
	LFC	HFU	HFS	SEM	LFC vs. HFU	LFC vs. HFS
Dry matter (g/kg)	468.0	480.6	475.4	3.67	0.08	0.27
Crude protein	172.1	172.3	174.8	1.09	0.91	0.19
Acid detergent insoluble CP (g/kg CP)	66.2	55.3	65.5	3.44	<0.01	0.63
aNeutral detergent fibre*	350.1	342.6	347.0	3.69	0.27	0.64
aNeutral detergent $fibre_{OM}$†	335.2	330.0	331.9	3.31	0.39	0.57
dNeutral detergent $fibre_{30}$ (g/kg total NDF)‡	490.6	511.8	491.4	7.76	0.07	0.93
Acid detergent $fibre_{OM}$	223.7	209.3	220.2	3.17	0.03	0.54
$Lignin_{(sa)}$ §	45.92	42.83	47.25	0.425	<0.01	0.10
Starch	135.4	146.6	135.8	2.35	0.02	0.94
Crude fat	37.94	47.62	50.34	0.628	<0.01	<0.01
Fatty Acids¶						
Saturated	5.97	7.51	11.99	4.018	0.14	<0.01
Monounsaturated	7.98	10.24	11.89	2.592	0.06	<0.01
Polyunsaturated	13.79	18.99	13.90	3.735	<0.01	0.93
Other	1.82	1.51	1.34	0.323	0.29	0.12
Sugars**	41.6	37.7	39.0	1.51	0.17	0.35
Ash	82.3	82.9	86.9	1.14	0.75	0.04
Ca	0.58	0.56	0.80	0.010	0.27	<0.01
Cl	0.70	0.68	0.69	0.020	0.59	0.94
Mg	0.27	0.29	0.26	0.004	0.01	0.17
P	0.50	0.57	0.49	0.015	0.02	0.63
K	1.83	1.94	1.81	0.042	0.17	0.74
Na	0.26	0.25	0.25	0.010	0.60	0.85
S	0.30	0.35	0.29	0.003	<0.01	0.50
Cu (mg/kg DM)	15.03	12.85	13.56	0.815	0.08	0.22
Fe (mg/kg DM)	264	200	272	14.9	0.01	0.70
Mn (mg/kg DM)	44.36	41.76	42.22	0.828	0.05	0.09
Mo (mg/kg DM)	1.24	1.22	1.23	0.030	0.55	0.87
Se (mg/kg DM)	0.52	0.56	0.52	0.021	0.10	0.75
Zn (mg/kg DM)	56.4	51.1	58.6	2.84	0.20	0.59
NE_L (MJ/kg) ††	6.73	7.00	6.86	0.029	<0.01	<0.01

*Neutral detergent fibre assayed with a heat-stable amylase.

†Neutral detergent $fibre_{OM}$ expressed exclusive of residual ash.

‡Fermented fraction of NDF after 30 h of *in vitro* fermentation.

§Lignin assayed with sulphuric acid.

¶Fatty Acids are represented by the sum of: Saturated = sum of C12:0, C14:0, C16:0, C18:0, C20:0, C22:0, C24:0; Monounsaturated = sum of C16:1, C18:1w9, C18:1w7, C20:1w9; Polyunsaturated = sum of C18:2w6, C18:3w3.

**Free glucose, sucrose and fructose.

††Estimated energy density of the ration based upon National Research Council, 2001) tabular values for a 3× maintenance NEl feeding level.

HPDDGS without added fat supplementation. Although there is a general belief that an increase in dietary PUFA will decrease DM intake, with NE_L intake usually unaffected (Coppock and Wilks, 1991), there is little recent experimental support for this belief. While it is often generally stated that increased dietary levels of PUFA reduce DM intake, a meta-analysis by Allen (2000) found a quadratic effect on DM intake, with the minimum DM intake occurring when added FA from whole or extruded oilseeds, such as distillers grains, was fed at 20 g/kg DM of the TMR. Therefore, an increase of fat from oilseeds of 10 g/kg (i.e. the fat increase from the LFC to HFU diet of our study) should have resulted in a decrease in DM intake of HFU cows compared to control. The mechanisms for satiety and intake in relation to dietary fat levels are neither simple nor clearly understood, and as there are no accurate models to predict the effect of supplemented dietary fat on DM intake (Allen, 2000), our results suggest that global generalizations of a hypophagic effect of dietary PUFA on DM intake may be unwise.

That apparent digestibility of $aNDF_{OM}$ tended to be lower for cows fed HFU diets is consistent with

Table 5 Effects of feeding unsaturated (HFU) and saturated (HFS) fats vs. a low-fat control (LFC) on milk yield, milk components and body condition score

	Diet				p-value	
	LFC	HFU	HFS	SEM	LFC vs. HFU	LFC vs. HFS
Yield (kg/day; $n = 724$)						
Milk	41.11	40.71	42.93	0.282	0.20	<0.01
Fat	1.56	1.53	1.69	0.013	0.04	<0.01
True protein	1.36	1.36	1.40	0.009	0.66	<0.01
Lactose	1.96	1.95	2.03	0.014	0.35	<0.01
Milk (MJ/day)	127.1	125.5	134.0	0.91	0.14	<0.01
Milk components (g/kg)						
Fat	38.25	37.70	39.62	0.223	<0.01	<0.01
True protein	33.33	33.47	32.83	0.092	0.02	<0.01
Lactose	47.50	47.87	47.26	0.060	<0.01	<0.01
SCC* (cells/μl)	216	239	230	14.0	0.15	0.36
Energy (MJ/kg)	3.106	3.090	3.137	0.0995	0.06	<0.01
Body condition score ($n = 176$)						
Average (units)	2.73	2.76	2.76	0.019	<0.01	0.03
Change (units/28 days)	0.014	0.071	0.079	0.0128	<0.01	<0.01

*Somatic cell count.

previous studies which have shown that higher levels of dietary PUFA have negative effects on rumen bacterial growth (Galbraith et al., 1971). The modified rumen environment leads to a decrease in carbohydrate digestion, specifically a depression in fibrolytic activity (Zinn, 1989), and many *in vitro* studies have shown a decrease in cellulolytic bacterial strain growth (Doreau and Ferlay, 1994). Apparent digestibility of fat was higher for cows fed the HFU diet, likely as a result of an increased proportion of digestible FA, vs. non-FA lipids (i.e. wax and cutin), in the EE component as a result of the increased fat level of the diet (NRC, 2001).

Milk production responses

Milk yield, milk component and milk energy yields of LFC cows did not differ from HFU cows, except that milk fat yield was slightly lower in HFU cows. Although consuming a diet higher in fat, the concentration of fat in milk decreased while that of true protein tended to increase in HFU cows compared to LFC cows. This decrease in milk fat proportion indicates that HFU cows did not use the extra dietary energy from fat for milk energy, which is consistent with the theory that increased levels of PUFA in the diet decrease lipogenesis in the mammary gland (Bauman and Griinari, 2003). When PUFA levels in the diet increase, lipogenesis as *de novo* fat synthesis in the mammary gland is inhibited, while lipogenic pathways in adipose are up-regulated (Harvatine and Bauman, 2007).

Milk fatty acid profile

That the concentration of many *de novo* synthesized FA (i.e. short and medium-chain FA) decreased in milk from cows fed HFU diets, while most long-chain fatty acids increased, is typical of cows fed increased levels of dietary PUFA (Harvatine and Bauman, 2007). This has generally been attributed to down-regulation of sterol response element-binding protein 1 (SREBP1), which regulates expression of many genes responsible for lipid synthesis in the mammary gland and thyroid hormone responsive spot 14 (SP14), which is believed to play a role in the expression of lipogenic enzymes (Harvatine and Bauman, 2006). Levels of 18:1 *trans*-10, an indicator of altered biohydrogenation, almost doubled in HFU vs. LFC-fed cows.

Body condition score and energy balance

Harvatine and Bauman (2007) found that there is a shift in energy towards increasing adipose stores and away from milk fat synthesis with increased PUFA intake. This is consistent with our findings that HFU-fed cows had higher BCS gains than LFC cows, as the HFU cows shifted energy away from milk production towards BCS recovery (Table 8).

The predicted (based upon National Research Council (2001) tabular values) NE_L level of the HFU ration (Table 4) was much higher than the estimated NE_L output of the cows (Table 8; 7.00 vs. 6.11 MJ/kg DM). This loss of net energy in the HFU-fed cows may have been due to the increased DM intake, leading to

Table 6 Effect of feeding unsaturated (HFU) and saturated (HFS) fats vs. a low-fat control (LFC) on milk fatty acids (g/kg fat)

	Diet				p-value	
	LFC	HFU	HFS	SEM	LFC vs. HFU	LFC vs. HFS
C4:0	27.91	28.61	28.88	0.45	0.08	0.02
C5:0	0.38	0.39	0.32	0.03	0.85	0.10
C6:0	19.03	17.76	17.68	0.29	<0.01	<0.01
C7:0	0.34	0.30	0.25	0.02	0.12	<0.01
C8:0	11.90	10.53	10.05	0.24	<0.01	<0.01
C9:0	0.46	0.35	0.33	0.02	<0.01	<0.01
C10:0	29.12	23.26	22.78	0.59	<0.01	<0.01
C11:0	3.20	2.69	2.40	0.08	<0.01	<0.01
C12:0	33.51	26.19	25.81	0.71	<0.01	<0.01
C13:0 iso	0.17	0.17	0.13	0.01	0.92	<0.01
C13:0 aiso	0.74	0.65	0.54	0.02	<0.01	<0.01
C13:0	1.91	1.59	1.36	0.03	<0.01	<0.01
C14:0 iso	0.60	0.54	0.49	0.03	0.04	<0.01
C14:0	98.39	86.99	84.11	0.96	<0.01	<0.01
C15:0 iso	1.17	1.06	0.99	0.02	<0.01	<0.01
C14:1 9t	0.12	0.09	0.09	0.01	0.13	0.06
C15:0 aiso	3.61	3.27	2.94	0.04	<0.01	<0.01
C14:1 9c	6.89	7.17	5.78	0.31	0.23	<0.01
C15:0	9.41	7.52	7.24	0.23	<0.01	<0.01
C16:0 iso	1.33	1.22	1.16	0.03	<0.01	<0.01
C16:0	248.66	215.11	261.73	1.88	<0.01	<0.01
C17:0 iso	2.13	2.20	1.93	0.07	0.42	0.03
C16:1 9t	0.32	0.42	0.33	0.04	0.09	0.85
C16:1 10t	0.10	0.08	0.07	0.01	0.23	0.11
C16:1 7c	0.20	0.28	0.24	0.01	<0.01	0.03
C16:1 8c	1.05	1.11	1.13	0.04	0.13	0.07
C17:0 aiso	3.01	2.72	2.47	0.07	<0.01	<0.01
C16:1 9c	8.90	8.80	9.16	0.45	0.67	0.30
C16:1 10c	0.37	0.10	0.14	0.15	0.20	0.26
C16:1 11c	0.19	0.17	0.14	0.01	0.33	<0.01
C17:0	5.16	4.38	4.03	0.06	<0.01	<0.01
C18:0 iso	0.13	0.09	0.10	0.01	0.01	0.04
C17:1 8c	0.32	0.30	0.25	0.03	0.64	0.10
C17:1 9c	1.12	1.09	0.96	0.05	0.60	<0.01
C18:0	91.20	102.43	94.93	1.56	<0.01	0.01
C18:1 4t	0.21	0.27	0.28	0.02	0.02	<0.01
C18:1 5t	0.19	0.25	0.25	0.02	0.02	0.02
C18:1 6-8t	2.31	3.49	3.26	0.08	<0.01	<0.01
C18:1 9t	1.97	2.91	2.60	0.06	<0.01	<0.01
C18:1 10t	3.89	7.03	5.07	0.36	<0.01	0.01
C18:1 11t	7.16	12.36	8.29	0.28	<0.01	<0.01
C18:1 12t	3.04	4.76	3.90	0.09	<0.01	<0.01
C18:1 13/14t	5.35	7.68	6.47	0.18	<0.01	<0.01
C18:1 9c	155.02	186.98	172.32	2.21	<0.01	<0.01
C18:1 11c	5.41	5.62	5.17	0.13	0.16	0.09
C18:1 12c	3.04	4.93	3.40	0.10	<0.01	<0.01
C18:1 13c	0.41	0.56	0.49	0.02	<0.01	0.02
C18:1 14c/16t	2.55	3.22	2.72	0.07	<0.01	0.01
C18:1 15c	1.03	1.32	1.14	0.03	<0.01	<0.01
C18:2 10t,14t	0.24	0.40	0.18	0.05	0.03	0.46
C18:2 9t,12t	0.08	0.06	0.09	0.01	0.55	0.41
C18:2 9c, 13t/8t,12c	1.47	2.19	1.79	0.07	<0.01	<0.01
11 cyclohexyl-11:0	0.99	0.84	0.76	0.04	<0.01	<0.01
C18:2 9c,14t	0.68	0.94	0.70	0.03	<0.01	0.49
C18:1 16c	0.69	0.86	0.73	0.03	<0.01	0.25
C18:2 12c,16t	0.29	0.37	0.24	0.03	0.07	0.29
C18:2 t9,c12	0.23	0.31	0.28	0.02	<0.01	0.04
C18:2 11t,15c	0.25	0.38	0.28	0.02	<0.01	0.14
C18:2 9c, 12c (n-6)	32.86	33.36	31.17	0.61	0.43	0.01
C18:2 t12,15c	0.14	0.15	0.08	0.02	0.96	<0.01
C20:0	1.06	1.16	1.04	0.02	<0.01	0.31
C18:3 t9, t12,c15	0.09	0.07	0.05	0.01	0.17	0.03
C18:3 6c,9c, 12c (n-6)	0.30	0.27	0.28	0.02	0.10	0.32
C20:1 9c	0.82	0.94	0.76	0.03	<0.01	0.11
C20:1 11c	0.36	0.43	0.37	0.02	<0.01	0.69
C18:3 c9,c12, c15 (n-3)	2.68	2.47	2.36	0.06	<0.01	<0.01
CLA c,t/t,c isomers	0.17	0.24	0.15	0.03	0.09	0.65
CLA 9c,11t	3.41	6.33	4.07	0.14	<0.01	<0.01
CLA S c,c	0.07	0.09	0.06	0.01	0.13	0.19
CLA S t,t	0.17	0.18	0.21	0.01	0.66	0.06
C21:0	0.18	0.18	0.17	0.01	0.97	0.53
C20:2 11c, 14c (n-6)	0.31	0.31	0.23	0.02	0.94	<0.01
C22:0	0.36	0.32	0.30	0.02	0.08	<0.01
C20:3 5c,8c, 11c (n-6)	1.27	1.21	1.26	0.05	0.18	0.85
C20:4 5c,8c, 11c,14c (n-6)	1.62	1.50	1.42	0.04	0.01	<0.01
C20:5 5c,8c, 11c,14c, 17c (n-3)	0.19	0.19	0.15	0.02	0.78	0.18
C24:0	0.26	0.22	0.18	0.01	0.02	<0.01
C22:4 7c,10c, 13c,16c (n-6)	0.42	0.40	0.36	0.02	0.58	0.01
C22:5 7c,10c, 13c,16c,19c (n-3)	0.38	0.35	0.32	0.02	0.24	0.02
Other	3.28	2.67	3.59	0.17	0.01	0.18

an increased ruminal rate of passage, thereby resulting in a decline in digestibility and digestible energy, although the modest reduction in whole tract digestion of NDF seems to suggest that much more of the energetic loss must have occurred due to less efficient conversion of digested energetic precursors to metabolizable energy or even to net energy itself from metabolizable energy, although no sensible hypothesis for such an occurrence is obvious.

Table 7 Digestibility of dietary components

	Diet				p-value	
	LFC	HFU	HFS	SEM	LFC vs. HFU	LFC vs. HFS
DM intake (kg/day; $n = 10$)	26.22	28.40	26.38	0.746	0.03	0.85
Whole tract digestibility (g/kg DM; $n = 20$)						
Organic matter	703	707	686	6.32	0.72	0.08
Acid detergent $fibre_{OM}$	433	422	401	7.64	0.36	0.01
aNeutral detergent $fibre_{OM}$*	489	453	471	12.1	0.06	0.32
Crude fat	790	842	847	11.4	0.01	0.01
Crude protein	653	671	646	7.13	0.10	0.45
Starch	988	991	991	1.17	0.21	0.16

LFC, low-fat control; HFU, high-fat diet with unsaturated fat; HFS, high-fat diet with saturated fat.
*$aNDF_{OM}$ expressed exclusive of residual ash.

Table 8 Effects of feeding unsaturated (HFU) and saturated (HFS) fats vs. a low-fat control (LFC) on partial energy balance (MJ/days)

	Diet				p-value	
	LFC	HFU	HFS	SEM	LFC vs. HFU	LFC vs. HFS
Energy balance						
Milk ($n = 724$)	127.1	125.5	134.0	0.909	0.14	<0.01
Change in BCS ($n = 176$)	0.63	3.22	3.56	0.573	<0.01	<0.01
NE_L*($n = 10$)	170.3	173.6	178.8	5.43	0.60	0.19
Calculated diet energy density ($n = 10$)						
NE_L density (MJ/kg DM)†	6.49	6.11	6.82	0.298	0.29	0.38

*Net energy of lactation; calculated by summing maintenance, milk and change in BCS energy, where maintenance energy is 43.12 MJ/days assuming cow average body weight was 625 kg.
†Net energy of lactation divided by DM intake.

Increased fat level as saturated fat

Diet, DM intake and digestibility

The chemical composition of the diets was as expected with LFC having lower crude fat (37.9 g/kg) than HFS (50.3 g/kg). Grummer et al. (1990) reported a decrease in DM intake when calcium salts of palm oil where fed alone or as a top-dress to lactating cows, but when calcium salts were mixed into a concentrate mixture, there was no decrease in DM intake. Why supplemental SFA can cause a decrease in DM intake is unclear, but one possibility is its smell and/or taste but, as Coppock and Wilks (1991) suggest, mixing these fats into a TMR likely reduces or eliminates this negative effect. Indeed, our HFS-fed cows had no change in DM intake vs. LFC cows, although the RI SFA was mixed into a TMR with aromatic ingredients such as silages, pomegranate and citrus pulps, which likely masked its aroma and/or flavour.

Digestibility of ADF_{OM} was lower for cows fed HFS vs. LFC diets, although digestibility of NDF was not influenced, while digestibility of fat was higher in cows fed HFS compared to those fed LFC diets. Improved apparent fat digestibility may be due to increased intestinal availability of fat in supplemented RI fat compared to the fats within feeds where some fat may remain entrapped in structural components and be unabsorbed in the intestine. Similarly, when feeding 40 g/kg DM of calcium salts, Schneider et al. (1988) reported an increase in whole tract FA digestion. The supplemental RI fat used in our HFS diet was primarily palmitic acid (430–500 g/kg total FA) and oleic acid (300–440 g/kg total FA). In a review, Doreau and Ferlay (1994) discuss how, amongst SFA, palmitic acid has the highest digestibility and, amongst 18-carbon FA, oleic acid was highest, which supports our findings of increased FA digestibility in cows fed the HFS diet.

Milk production responses

When the SFA level of a lactating dairy cow ration is increased with calcium salts of FA, milk and milk fat

yield have generally increased (*e.g.* Schneider et al., 1988), often in conjunction with a decreased milk protein concentration (Canale et al., 1990). Consistent with previous studies, yields of milk, fat and true protein, as well as milk energy yields and concentrations, of HFS cows were all higher than LFC-fed cows, except for the true protein concentration which decreased slightly, possibly due to increased milk yield.

Milk fatty acid profile

As the RI fat fed to the HFS cows contained linoleic acid at 70–130 g/kg total FA, it is likely that some of this PUFA was hydrogenated in the rumen, thereby leading to altered intermediates of biohydrogenation, as evidenced by increased levels of 18:1 *trans*-10 in milk fat of HFS-fed cows. The concentration of many *de novo* synthesized FA (i.e. short and medium-chain FA) decreased in milk from HFS cows, while most long-chain fatty acids increased, which is a pattern typical with increased PUFA consumption (Harvatine and Bauman, 2007). However, it would appear that our RI fat was fed at high enough levels to compensate for lipogenic inhibition, thereby increasing total milk fat yield by utilizing increased circulating FA. Increased levels of 16:0 in milk from HFS cows were likely due to its high level in the RI fat used in the HFS ration.

Body condition score and energy balance

The BCS increase of HFS-fed cows was higher than for LFC-fed cows. Thus, even though cows fed the HFS diet did not differ from LFC cows in NE_L intake, they partitioned more energy towards milk and BCS gain. The moderately increased 18:1 *trans*-10 levels suggest that lipogenesis in adipose tissue was up-regulated (Harvatine and Bauman, 2007), resulting in increased BCS, while increased digestibility of fat also allowed them to increase milk fat output by utilizing the long-chain FA absorbed to the blood. That the predicted NE_L intake of the HFS and LFC rations (Table 4) is similar to the estimated NE_L output of the cows (Table 8), suggests that both groups utilized feed energy precursors at expected levels.

Conclusions

Increased feeding levels of PUFA, from corn-based DDGS, increased DM intake and deceased whole tract digestibility of NDFom while having little impact on milk production and composition, although BCS gain was increased. It is likely that these changes were at least partly due to negative effects of PUFA on fibrolytic microbes in the rumen and a shift in energy towards increasing adipose stores and away from milk fat synthesis. Conversely, when SFA were increased in the diet to levels similar to those with the unsaturated fats by means of RI calcium salts of palm oil, the cows substantively increased milk and components yield as well as BCS gain. The SFA were evidently able to supply an increased amount of fat which was utilized to support milk synthesis and stimulate BCS gain, but apparently without negatively impacting rumen fermentation.

These findings indicate that use of DDGS in rations for lactating dairy cows should be limited, as their addition (i.e., to create a diet with a higher fat and calculated NEL level) had little positive overall impact on animal performance. In contrast, addition of RI calcium salts of palm oil to increase the fat, and calculated NE_L level, of the diet resulted in substantially increased animal productivity.

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