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Peripartum health and welfare of Holstein-Friesian cows in a confinement-TMR system compared to a pasture-based system

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Abstract

The greatest challenge to the welfare of dairy cows occurs in the peripartum period. Given the perception that cow welfare is better in more natural environments, it was hypothesised that cows in a PASTURE-based production system (cubicle housing with grass silage pre-partum and rotational grazing with concentrate supplementation post-partum) would have improved peripartal welfare compared to cows in a HOUSED production system (cubicle housing with a total mixed ration [TMR], pre-partum and post-partum). Blood samples were analysed for acute phase proteins (APP), cortisol, white blood cell (WBC) differential and counts and other biochemical metabolites as non-specific indicators of sub-clinical ill-health and nutritional stress. Daily monitoring of rectal temperature (RT) and rumen fill (RF) scores were used to monitor ill-health and nutritional status. Reproductive health and welfare (calving difficulty, retained placenta, puerperal metritis, endometritis and oestrous cyclicity) was also recorded. No differences were found between treatments for APP, cortisol or WBC. Blood metabolite differences indicated that PASTURE cows were under greater nutritional stress than HOUSED cows. HOUSED cows showed an increase in RF score from day 0 to 10 post-partum and had a higher RF score than PASTURE cows. PASTURE cows had an overall lower RT and lower incidence of reproductive disorders. Results primarily reflect nutritional differences between treatments with PASTURE cows showing greater potential nutritional/metabolic stress in early lactation which has attendant implications for welfare. Nevertheless, this did not result in inferior health and, in accordance with our hypothesis, PASTURE cows' reproductive health and welfare tended to be better than that of HOUSED cows.

Keywords: *animal welfare, cubicle-housed, dairy cow, health, pasture-based, peripartum*

Introduction

Dairy cows have a greater likelihood of presenting health problems such as lameness, mastitis, metabolic and uterine disorders (eg metritis) in the peripartum period; a period starting three weeks pre-calving and lasting up to three weeks, post-calving (Smith & Risco 2005). These disorders are associated with an overall reduction in reproductive performance and productivity (Smith & Risco 2005; Ingvartsen 2006; Goff 2008). Dairy cow welfare can also be adversely affected during this time. Contributory factors include: suppression of the innate immune system; nutritional and environmental stress; fluctuations in hormone concentrations and management practices (Ingvartsen 2006; Goff 2008). These factors are interrelated and vary greatly between dairy production systems. Hence, any comparison of the health and welfare status of dairy cows in different production systems should pay particular attention to the peripartum period.

Pasture-based dairy production systems, in contrast to confinement systems, are believed to be more welfare-friendly; they have been associated with reduced incidence of disease (eg lameness and mastitis) and enhanced expression of natural behaviours (eg oestrous behaviours) (Hopster *et al* 2006). The objective of this study, was therefore to compare two dairy production systems (confinement vs pasture-based) throughout the peripartum and early lactation periods, through an examination of the effects on the welfare status of the dairy cow. The production systems compared differed greatly in two main aspects; feeding system and housing strategy — where the effects of these two aspects had to be investigated in combination. Although, it is recognised that each may exert an individual effect on the welfare of dairy cattle.

We hypothesised that cows in the pasture-based system would have better sub-clinical and clinical health (acute phase proteins and haematological profile, indicative of an optimal inflammatory response as well as rectal temperature and better health records), nutritional status (greater rumen fill and reduced metabolite alterations) and reproductive health and welfare (lower incidence of calving difficulty, retained placenta, puerperal metritis and endometritis as well as faster recovery of oestrous cyclicity) than cows in a confinement system during the peripartum and early lactation periods.

Table 1 Ingredient composition, total dry matter and net energy of HOUSED and PASTURE cow diets.

Ingredient ($g\ kg^{-1}$ DM)	HOUSED		PASTURE	
	Dry cow	Milking cow	Dry cow	Milking cow
Maize silage	219	257	–	–
Grass silage	219	219	999	–
Barley straw	411	22	–	–
Rolled barley	16	120	–	250
Citrus pulp	16	85	–	305
Soybean meal	118	137	–	140
Maize gluten feed	–	72	–	250
Molasses	–	72	–	–
Vegetable oil	–	10	–	25
Limestone flour	–	5	–	–
Mineral + vitamin premix [1]	1	1	1	30
Dry matter content ($g\ kg^{-1}$)	416	419	270	865
Net energy (UFL kg^{-1} DM)	0.71	0.97	0.82	1.14

[1] (250,000 IU vitamin A; 50,000 IU vitamin D; 2,000 IU vitamin E; 60 mg kg^{-1} Se; 700 mg kg^{-1} I; 4,000 mg kg^{-1} Cu; 5,000 mg kg^{-1} Zn).

Materials and methods

This study was conducted between November 2006 and January 2008 at Moorepark Research Farm, Teagasc, Fermoy, Co Cork in the south of Ireland. Animal experimental procedures were carried out under licence Number B100/3797 issued by the Irish Department of Health and Children, in accordance with the Cruelty to Animals Act, 1876 as amended by the European Communities (Amendment of Cruelty to Animals Act 1876) Regulations 2002. Procedures were also approved by the Animal Research Ethics Committee of University College Dublin (AREC-P-45-06-Antillón).

Animals

Forty-six (12 primiparous, 34 pluriparous) spring-calving Holstein-Friesian cows were blocked into 23 pairs on the basis of genetic merit (Irish Economic Breeding Index value; €60 [± 17.3]), parity (2.5 [± 1.49]), expected calving date (6th March [± 27.9]), body condition score (3.0 [± 0.69]) and predicted milk yield (+98 [± 123.4] kg) and randomly assigned from within each pair to one of two treatments. Animals were assigned to a system in which they were indoors all year round in cubicles and fed a TMR (HOUSED) or to an Irish pasture-based system (ie indoors in a cubicle-house during the dry period and outdoors on a pasture-based diet after parturition = PASTURE). Treatments commenced at drying off for cows (69 [± 19] days before the expected calving date), while heifers were allocated to treatments 49 (± 7) days before the expected calving date.

Treatments and management

Details of treatments and management can be found elsewhere (Olmos *et al* 2009). In summary, treatment groups shared the same cubicle house (1.2 cubicles per cow) during the dry period. In the dry period, HOUSED animals were offered a dry cow diet (dry cow TMR; Table 1), while the PASTURE animals were offered grass silage *ad libitum* plus vitamins and minerals (Table 1). Both diets were fed using computerised feed boxes (two cows per box).

Animals were moved from the cubicle house to a straw-bedded calving pen approximately 24 h prior to calving. After the first milking, the cows returned to their treatment group. As the PASTURE cows calved they were turned out to pasture on the day of calving for the period between morning and afternoon milking from 25th January and were full-time at pasture both day and night from 5th February 2007 onwards. The areas of the house allocated to the dry cows and milking cows were adjusted every two weeks during the calving season to maintain a ratio of 1.2 cubicles per cow.

During lactation, the HOUSED cows were offered a TMR diet formulated specifically for lactating cows (milking cow TMR; Table 1). Fresh feed was provided once daily after the morning milking. The milking cow TMR was introduced as 50% of the diet (with 50% of the dry cow TMR) for the first 3 days post-calving, to avoid digestive upsets associated with the onset of greater concentrate feeding. Thereafter, the milking cow TMR was offered *ad libitum* with a target refusal rate of 5%.

The PASTURE cows were managed in a rotational grazing system at a stocking rate of 2.5 cows per hectare. The grazing area was a permanent grassland site containing over 80% perennial ryegrass (*Lolium perenne*). This area was divided into 20 paddocks (0.48 [± 0.15 ha]). Residency time in the paddock was determined by achieving a post-grazing sward height of 5.4 (± 0.97) cm. Concentrates were fed in the milking parlour during morning and afternoon milking. The daily concentrate allocation varied across the grazing season, from 6 kg per cow per day in February–March, gradually reducing to 0 kg per cow per day during the main grazing season (April–August) and increasing to 2 kg per cow from mid-September until dry off. PASTURE cows received a total concentrate input of 410 kg per cow over the total lactation period. The ingredient composition of the concentrate is presented in Table 1. All animals were milked twice daily by the same staff.

Animal measures

Blood parameters

Blood was sampled via coccygeal venipuncture after the morning milking from all cows at –35 (± 9) (mid-dry), –15 (± 7) (pre-calving), 0 (+ 0.58) (calving), 15 (± 1) (post-calving) and 35 (± 3) (early lactation) days, relative to calving. Two samples were taken per timepoint per cow and analysed for a range of variables as described in Table 2. In summary, white blood cell (WBC) counts, WBC differential and acute phase proteins (APP) (ie serum amyloid A and haptoglobin) were used as indicators

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Table 2 Blood sampling protocol and parameters analysed for the comparison of immunocompetence, ill-health, nutritional and metabolic status of a herd (n = 46) of Holstein-Friesian cows managed under two production systems (HOUSED vs PASTURE).

Blood parameter	Collection tube[2]	Assay type	Sampling periods[4]
Haematological profile: total WBC and differential[1]	7 ml sterile vacutainers, with EDTA, analysed within 4 h after sampling	Automated electronic particle analyser (Abbott Cell Dyn 3500; CD3500, Haematology analyser)	Mid dry, pre-calving, calving, post-calving and early lactation
Acute phase proteins: haptoglobin (Hp) and serum amyloid A (SAA)	7 ml lithium heparinised vacutainers. Samples were centrifuged at 2,000 g for 10 min at 5°C and stored at –20°C until analysed	Phase™ Range and ELISA commercial kits, respectively (Tridelta Development Ltd, Maynooth, Co Kildare, Ireland)	
Cortisol		ELISA commercial kit (DRG Diagnostics, Marburg, Germany	
Metabolites: glucose, urea, NEFA, βHB, cholesterol, triglycerides, albumin, total bile acids and total bilirubin		Enzymatic and colourimetric methods using ABXu Mira Auto analyser (ABX Mira Cedex 4 France)	Pre-calving, calving and post-calving
Minerals: magnesium, calcium and phosphurus			Calving and post-calving

[1] Red blood cell (RBC) indices: mean corpuscular volume (MCV), haemoglobin (HB), haemoglobin mean corpuscular concentration (MCHC), mean corpuscular haemoglobin (MCH) and platelet number. White blood cell (WBC) differential: neutrophil, lymphocyte, monocyte and eosinophil counts.
[2] Vacutainer™, Unitech Ltd, Dublin 24, Ireland.
[3] NEFA: non-esterified fatty acids, βHB: Beta-hydroxybutyrate.
[4] Sampling periods: –35 (± 9), –15 (± 7), 0 (+ 0.5), 15 (± 1) and 35 (± 3) days relative to calving; representing five time-points: mid dry, pre-calving, calving, post-calving and early lactation, respectively.

of innate immunocompetence and health status (Petersen *et al* 2004; Sheldon *et al* 2004; Smith & Risco 2005; Radostits *et al* 2007). Additionally, blood metabolites were used as indicators of metabolic and nutritional status. Urea, total protein and albumin are indicators of protein intake and metabolism. Glucose, cholesterol, beta-hydroxybutyrate (βHB), non-esterified fatty acids (NEFA), triglycerides, total bile acids and total bilirubin were used as indicators of energy status and liver function (Grummer *et al* 2004; Oetzel 2004; Hachenberg *et al* 2007); while calcium, magnesium and phosphorus were used as indicators of mineral balance (Goff 2004).

Rectal temperature

Measures of rectal temperature (RT) were employed as another health indicator (Smith & Risco 2005). RT was recorded using a digital thermometer (GLA Agricultural Electronics, San Luis Obispo, CA, USA). RT was recorded daily during morning milking from the first morning after calving (day 1) until 10 days post-calving. Daily RT of each cow was classified as normal (38–39.4°C) or pyrexial (≥ 39.5°C).

Rumen fill

Rumen fill (RF) is the result of dry matter intake, ration composition, digestion and passage rate of ingested feed. RF was observed from the left side of the cow; the paralumbar fossa between the last rib, the transverse processes and the hipbone were assessed and scored according to Zaaijer and Noordhuizen (2003) using a scale of 1 = very empty to 5 = quite distended. The same observer recorded the RF from the first morning after calving (day 1) until 10 days post-calving.

Calving difficulty, stillbirth, reproductive health and performance

Calving difficulty was recorded as no assistance (0), vs difficult/dystocia (1) whereby farm staff or veterinarian assistance was required for the birth of the calf. Calf mortality was recorded as alive (0) or dead at birth (ie stillbirths [1]). The occurrence of twins and the weight of the calf at birth were also recorded. Records of puerperal disorders (retained placenta [> 24 h], metritis and puerperal metritis [Sheldon *et al* 2006]) in the first 10 days postpartum were kept for all animals.

The commencement of luteal activity (CLA) was determined from three-times weekly milk sampling for milk progesterone concentration obtained by an enzyme immunoassay (Ridgeway Science Ltd, Rodmore Mill Farm, Alvington, Gloucestershire, UK); a milk progesterone profile was obtained from day 7 post-calving, onwards. Cows were assumed to have resumed cyclicity when milk progesterone concentration first exceeded ≥ 3 ng ml^{-1} for two consecutive sampling days (adapted from Royal *et al* 2000).

The reproductive tract of each cow was examined using a Metricheck™ device (Simcrotech, Hamilton, New Zealand) and trans-rectal ultrasound imaging (ALOKA SSD 900V with a 7.5 MHz transducer, ALOKA Ltd, Tokyo, Japan) between 35 and 49 days post-calving. Each animal was assessed for the presence (yes = 1, no = 0) of endometritis (Mee *et al* 2009) and the resumption (yes = 1, no = 0) of ovarian cyclicity, ie presence of a corpus luteum in either ovary or uterine tone, clear mucus and a preovulatory follicle in either ovary (Mee *et al* 2009). All cows had a breeding season of 98 days starting on 23rd April 2007. Cows were artificially inseminated at spontaneous oestrus. Reproductive performance of all animals was recorded during the breeding season. In addition to records of reproductive health, records were kept for clinically ill cows (ie cows that received medication from the veterinarian or farm staff for treatment of metabolic dysfunction, uterine abnormality, mastitis or lameness).

Statistical analysis

All data were analysed using SAS software (V 9.1.3, 2006; SAS Institute Inc, Cary, NC, USA). Data were tested for normality before analysis by examination of box and normal distribution plots (Proc Univariate). Blood parameters were not normally distributed; thus Box-Cox methodology was used to identify the most appropriate transformation. The analyses were undertaken on the transformed, normally distributed data and back-transformed results are presented. Blood parameters and RT were analysed using mixed models for repeated measures (Proc Mixed). Sampling point was included as a repeated effect within cow. The most appropriate covariance structure was determined using the Akaike Information Criterion for all the models. Fixed effects tested in the model were: treatment group, parity, sample point and sample point × treatment group interaction. Covariates included in the model were calving date and sampling date centred within average for each sample point to account for variability within each sampling point relative to calving. Biologically plausible two-way interactions were also tested for significance.

Rumen fill scores were analysed using the Mann-Whitney test (Proc Npar1way) to investigate differences between treatments, between days, and between treatments at each day. Calving difficulty, stillbirth, reproductive health and performance were analysed using the Fisher's exact or Chi-square test (Proc Freq) as appropriate. The collated records for reproductive performance continuous variables were analysed using *t*-test when data followed a normal distribution; results are presented as means and standard errors. For variables not normally distributed a Wilcoxon's test (Proc Npar1way) was selected; these data are presented as medians and ranges.

Results

Blood parameters

Sample period means for the blood parameters investigated are presented in Tables 3 and 4. Sampling period relative to calving (ie time) had an effect ($P < 0.05$) on all the blood parameters with the exception of total monocyte count, albumin and magnesium. Neither treatment effects nor treatment by time interactions were observed for APP, cortisol, total WBC or WBC differential ($P > 0.05$).

Treatment had an effect on certain blood metabolites (Figure 1), where PASTURE cows had higher plasma concentrations of triglycerides (95% CI; 0.2, 0.19–0.21 vs 0.1, 0.09–0.11; $P < 0.001$) and tended to have higher concentrations of cholesterol (95% CI; 2.2, 2.09–2.31 vs 2.0, 1.89–2.11; $P = 0.088$), and calcium (95% CI; 1.95, 1.896–2.004 vs 1.84, 1.782–1.898; $P = 0.057$) than HOUSED cows. Furthermore, interactions between treatment and time were observed for plasma concentrations of urea ($P < 0.001$), βHB ($P = 0.004$), NEFA ($P = 0.012$), and magnesium ($P = 0.023$) and a tendency for an interaction was observed in total bilirubin ($P = 0.086$) plasma concentration. In summary, PASTURE cows had a lower concentration of urea, βHB, NEFA, total bilirubin (trend only) and magnesium pre-calving than HOUSED cows; however, PASTURE cows had a higher concentration of the aforementioned metabolites than HOUSED cows post-calving (Figure 1).

Rectal temperature and rumen fill

The mean RT for the herd in the first 10 days post-calving was 38.5 (± 0.09)ºC although it differed with days post-calving. Pyrexia (ie temperature ≥ 39.5ºC) was present at least once in the first 10 days post-calving in 41% of all cows (PASTURE = 39% and HOUSED = 43%). PASTURE cows had a lower RT than HOUSED cows (38.4 [± 0.07] vs 38.7 [± 0.07]ºC, $P = 0.022$) (Figure 2). No day × treatment interaction was detected ($P > 0.05$).

RF scores of HOUSED cows increased significantly from day 0 to 10 ($P < 0.032$). Furthermore, HOUSED cows had a higher RF score ($P < 0.05$) than PASTURE cows at the end of the 10 days post-calving (Figure 2).

Calving difficulty, stillbirth, reproductive health and performance

The overall incidence of calving difficulty and stillbirths was 11 and 4%, respectively. The rate of twins was 4% with the two sets of twins recorded in the HOUSED cows. There tended to be fewer PASTURE cows with retained foetal membranes compared to HOUSED cows (Table 4). Additionally, there tended to be fewer PASTURE cows with puerperal metritis ($P = 0.059$) in the first 10-days post-calving (Table 4).

In total, 89% of cows had resumed ovarian cyclicity by days 35–49 post-calving while 20% had endometritis at the same

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Table 3 Effect of time relative to calving on acute phase proteins, cortisol and haematological parameters (mean, 95% CI) in a herd of 46 spring-calving Holstein-Friesian cows.

Blood parameters		Normal range[1]	Mid dry[2]	Pre-calving[2]	Calving[2]	Post-calving[2]	Early lactation[2]	*P*-value
Acute phase proteins	Haptoglobin(g L^{-1})	≤ 0.3	0.6 (0.5–0.79)	0.5 (0.44–0.66)	0.7 (0.6–1.0)	0.9 (0.70–1.24)	0.6 (0.48–0.75)	< 0.001
	Serum amyloid A (mg L^{-1})	9.2–150	7.7 (4.63–12.28)	6.4 (3.89–10.19)	47.5 (33.22–67.73)	34.3 (24.64–47.47)	14.1 (8.39–23.13)	< 0.001
Cortisol (nmol L^{-1})		13–21	29.5 (14.43–46.86)	24.2 (11.39–39.08)	42.5 (30.13–57.01)	24.5 (15.35–35.76)	32.4 (21.72–45.18)	< 0.001
Total and differential WBC counts	WBC (× 10^9 L^{-1})	4.0–12.0	6.5 (5.95–7.02)	6.5 (6.03–7.10)	6.4 (5.71–7.31)	5.6 (5.05–6.19)	6.5 (5.98–7.11)	0.007
	Neutrophils (× 10^9 L^{-1})	0.6–4.0	2.6 (2.29–2.88)	2.8 (2.48–3.13)	3.1 (2.39–3.91)	2.7 (2.25–3.26)	3.1 (2.67–3.47)	0.004
	Lymphocytes (× 10^9 L^{-1})	2.0–7.5	3.1 (2.76–3.49)	3.1 (2.74–3.46)	2.9 (2.60–3.28)	2.6 (2.28–2.88)	2.9 (2.62–3.30)	< 0.001
	Monocytes (× 10^9 L^{-1})	0–0.8	0.2 (0.14–0.23)	0.2 (0.17–0.26)	0.2 (0.2–0.29)	0.2 (0.15–0.24)	0.2 (0.16–0.25)	0.178
	Eosinophils (× 10^9 L^{-1})	0–2.4	0.4 (0.34–0.56)	0.4 (0.31–0.49)	0.1 (0.05–0.13)	0.1 (0.04–0.12)	0.3 (0.18–0.35)	< 0.001

[1] Haptoglobin and serum amyloid A normal range as reported by Humblet *et al* (2006); cortisol, total WBC counts and differential normal range as reported by Radostits *et al* (2007). These published references refer to cattle (beef and dairy of all ages and stages of the production cycle).
[2] Number of days relative to calving for mid dry, pre-calving, calving, post-calving and early lactation was –35 (± 9), –15 (± 7), 0 (± 0.5), 15 (± 1) and 35 (± 3) days, respectively.

Table 4 Calving difficulty, uterine abnormalities 10 days post-calving, uterine involution, luteal activity, oestrous cyclicity and reproductive welfare of two groups of Holstein-Friesian cows managed under two production systems (HOUSED, n = 23 vs PASTURE, n = 23).

Variables	Unit	HOUSED	PASTURE	*P*-value
Calving and uterine abnormalities within 10 days post-calving				
Calving difficulty*	Number (%)	4 (17)	1 (4)	0.079
Retained foetal membranes	Number (%)	3 (13)	2 (9)	0.500
Puerperal metritis*	Number (%)	11 (48)	4 (17)	0.059
Uterine involution and resumption of cyclicity at 35 to 49 days post-calving				
Resumption of oestrus cyclicity	Number (%)	20 (87)	21 (91)	1.000
Endometritis*	Number (%)	7 (32)	2 (9)	0.066
Reproductive performance				
Commencement of luteal activity*	Days: median (range)	34 (28–50)	23 (20–31)	0.085
Calving to service interval	Days; mean (SE)	76 (5.2)	70 (3.6)	0.379
Calving to conception interval	Days; median (range)	107 (78–136)	102 (102–132)	0.293
Submission rate (21 days)	Number (%)	14 (61)	19 (83)	0.190
First service conception rate	Number (%)	8 (35)	9 (39)	1.000
6-week pregnancy rate	Number (%)	11 (48)	10 (43)	1.000
Overall pregnancy rate	Number (%)	14 (61)	17 (74)	0.529
Services per conception	Number; median (range)	1 (1–2)	1 (1–3)	0.292

* Tendency ($P \leq 0.10$ and $P \geq 0.05$).

time point. The percentage of cows that had resumed ovarian cyclicity at 35–49 days post-calving was similar for both treatments (Table 4). However, there tended to be a lower percentage of PASTURE cows affected by endometritis compared to HOUSED cows (Table 4). Furthermore, commencement of luteal activity tended to be earlier in PASTURE cows than in those HOUSED. The calving-to-service interval and calving to conception interval was numerically shorter in PASTURE cows while the pregnancy rate was numerically higher compared to HOUSED cows ($P > 0.05$).

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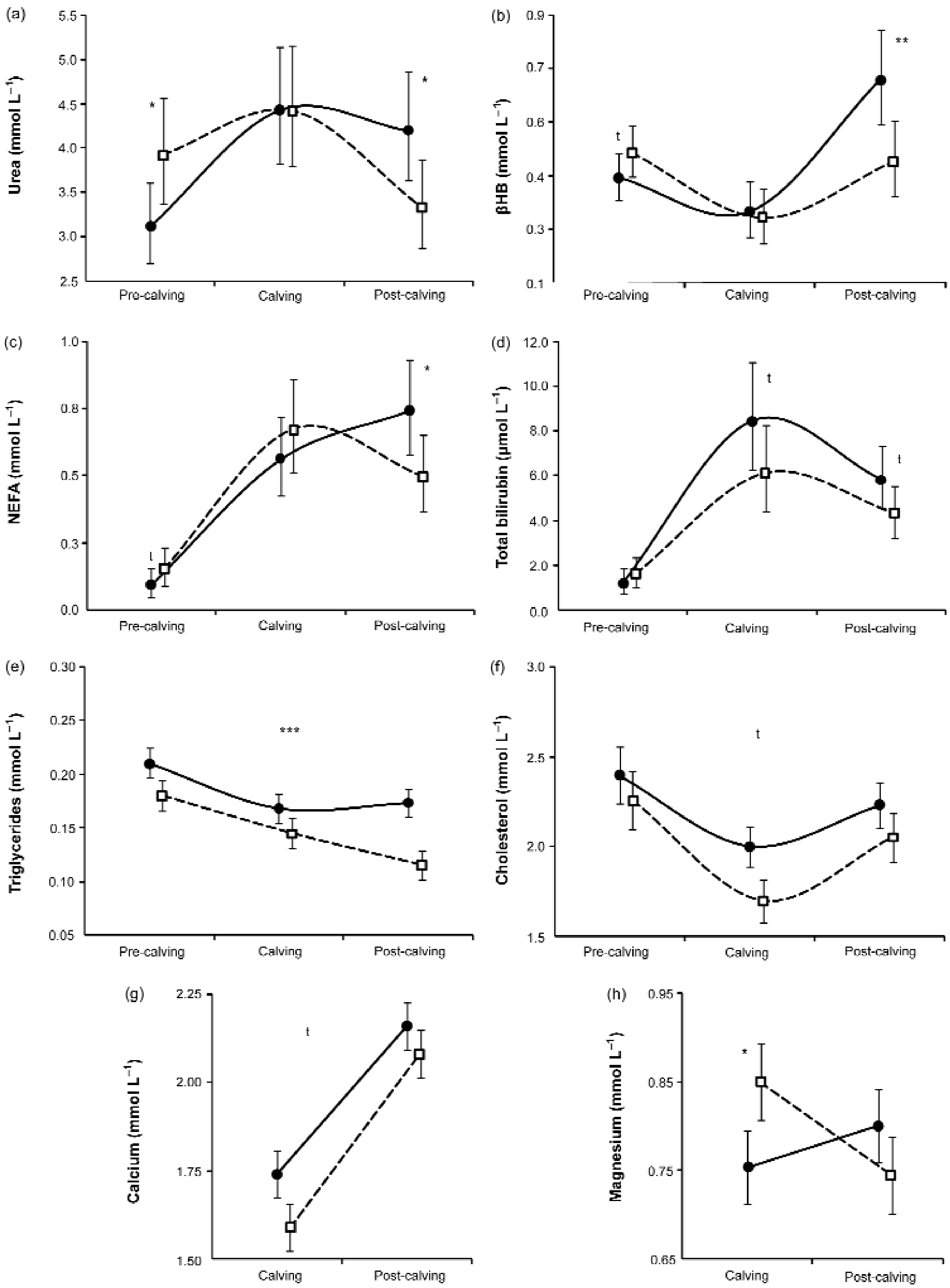
Figure 1



The effect of production system (PASTURE [-●-, n = 23] vs HOUSED [- - - -, n = 23]) on blood metabolites and minerals in periparturient Holstein-Friesian cows. Time by treatment interactions and overall treatment effect means and error bars for the 95% CI are shown. Number of days relative to calving for pre-calving, calving and post-calving was -15 (± 7), 0 (± 0.5) and 15 (± 1) days, respectively. *t* (≤ 0.1), * ($P < 0.05$), ** ($P < 0.01$), *** ($P < 0.001$) indicates time by treatment interactions (a) urea, (b) βHB, (c) NEFA, (d) total bilirubin and (h) magnesium or a treatment effect (e) triglycerides, (f) cholesterol, (g) calcium between groups (PASTURE vs HOUSED).

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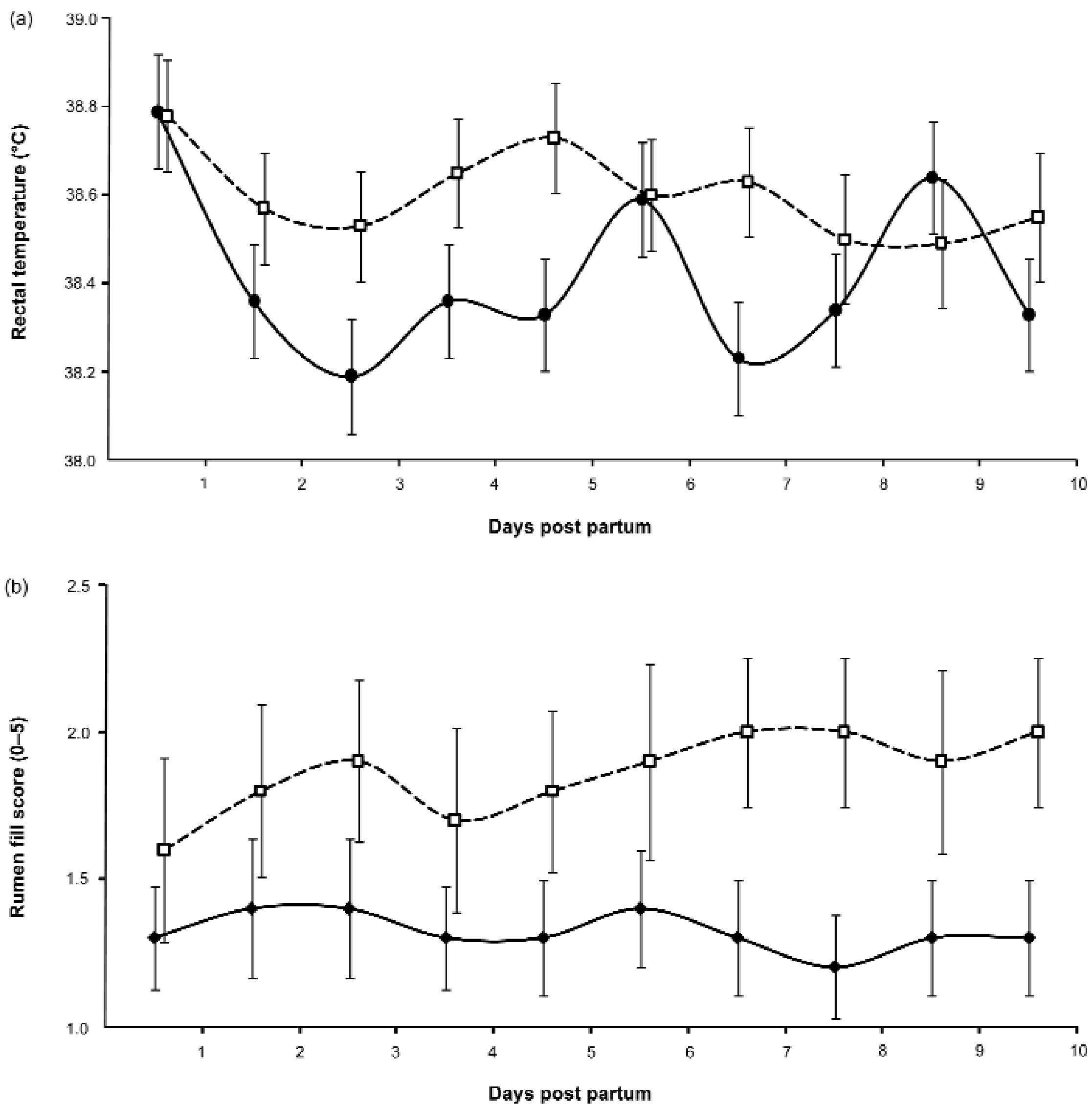
Figure 2



The effect of production system (HOUSED [- - - -, n = 23] vs. PASTURE [-●-, n = 23]) on (a) rectal temperature and (b) rumen fill of Holstein-Friesian cows in the first 10 days post-calving. Mean and error bars for the 95% CI are shown.

Discussion

The perception that health and welfare is enhanced in more natural environments (Hopster *et al* 2006) led us to hypothesise that cows at PASTURE would have better peripartum health and welfare compared to HOUSED cows. Basically, there are two aspects that might have influenced the results obtained: (i) the differences in feeding system and (ii) the differences in housing.

In the current study, total WBC counts, WBC differential, APP, cortisol and blood metabolite concentrations were within normal physiological ranges observed in healthy, well managed cows (O'Farrell *et al* 1986; Humblet *et al* 2006; Hachenberg *et al* 2007; Radostits *et al* 2007). Nevertheless, we found differences in blood metabolites concentration between treatments. PASTURE cows had higher urea post-partum than HOUSED cows. Urea is a good indicator of dietary intake of digestible crude protein (Brand *et al* 2001) which is readily available in pasture-based systems with a high daily herbage allowance (Kennedy *et al* 2005) as in the PASTURE system. High levels of digestible crude protein in the diet are beneficial only if sufficient energy is present in the diet to process it (Brand *et al* 2001). Although not outside the reference ranges, the finding that PASTURE cows had higher NEFA, βHB and triglyceride concentrations post-partum suggests that energy supply from the diet was limited which could reflect a compromised metabolic status relative to the HOUSED cows (Brand *et al* 2001; Hachenberg *et al* 2007). Additionally, PASTURE cows showed a tendency for higher concentrations of bilirubin and numerically higher bile acid concentrations (PASTURE = 32.4 vs HOUSED = 28.6 μmol L^{-1}), both linked with greater hepatic lipidosis, a condition that can lead to liver dysfunction if exacerbated (Bobe *et al* 2004; Ingvartsen 2006). In summary, these findings indicate that the degree of negative energy balance (NEB) was greater in PASTURE compared to HOUSED cows.

These findings are supported by the fact that PASTURE cows had lower RF scores in the first 10 days post-calving. Rumen fill scores reflect dry matter intake (Zaaijer & Noordhuizen 2003) which, in turn, are closely related to energy balance (Brand *et al* 2001; Grummer *et al* 2004). Moreover, RF scores in the PASTURE cows did not increase as rapidly from day 0 to 10 post-calving as they did in the HOUSED cows. HOUSED cows were fed a TMR, which increases dry matter intake and minimises feed selection. Conversely, PASTURE cows were offered low dry matter grazed grass and concentrates separately. These dietary differences explain the differences found in RF scores between treatments and combined with the blood metabolite data indicate that PASTURE cows were under greater nutritional stress than HOUSED cows.

Nutritional and metabolic stress in the peripartum period impairs peripartum immune function and cow health in early lactation (Ingvartsen 2006; Goff 2008). However, despite PASTURE cows being at greater risk of nutritional and metabolic stress than HOUSED cows, indicators of sub-clinical health (ie WBC counts, WBC differential or APP concentrations) did not differ between treatments. Additionally, there was a similar number of clinically ill animals in the first 35 days post-calving in both treatments (PASTURE = 8 cows vs HOUSED = 9 cows). Moreover, cortisol concentrations were similar in PASTURE and HOUSED cows throughout the peripartum and early lactation periods, indicating that the level of stress caused by the calving process and recovery from calving was equal across treatments (Goff 2008).

A similar number of cows in each treatment were classified as pyrexial. This is in accordance with the finding that a similar number of cows in each treatment presented clinical problems in early lactation and with the finding that cows in both treatments had similar values for other indicators of ill-health (ie WBC and APP). However, PASTURE cows had a lower average RT and a greater fluctuation in RT in the first 10 days, post calving than HOUSED cows. RT is influenced not only by health status but by the cow's age, production type, season and time of the day; with the lowest RT in the morning (Smith & Risco 2005; Radostits *et al* 2007). Rectal temperatures were taken for all cows in the early spring months, immediately before the morning milking. During this time, outdoor environmental temperatures ranged from –3 to 5°C while indoor temperatures were about 10°C. This could explain the lower core body temperature of the PASTURE cows. Additionally, HOUSED cows had higher feed intakes (Patton *et al* 2008) which would have increased their heat production causing a rise in core body temperature (Brand *et al* 2001; Ingvartsen 2006).

There tended to be more HOUSED cows with calving difficulties and retained foetal membranes. Calving difficulty results from prolonged spontaneous calving and may involve prolonged or severe assisted extraction (Mee 2004). Such circumstances can result from a lack of uterine myometrial contractility. Sub-clinical hypocalcaemia and hypomagnesaemia reduce uterine smooth-muscle contractility and can lead not only to calving difficulty but also to retained foetal membranes and uterine infections (Goff 2004; Smith & Risco 2005; Goff 2008). In contrast to PASTURE cows, HOUSED cows tended to have lower plasma calcium concentrations and reduced magnesium concentrations post-partum. These differences may explain, at least in part, observed findings in calving difficulties, retained foetal membranes and puerperal metritis recorded during the first 10 days, post calving in the HOUSED cows.

Differences between the two environments in levels of hygiene could be another plausible explanation for the higher incidence of puerperal metritis recorded in HOUSED cows. Despite frequent cleaning of floors and cubicle beds, higher stocking densities and close contact with faeces means that indoor bacterial counts will always be higher (Sheldon *et al* 2006) than at pasture, particularly if cows have access to new pasture every day. This increases the risk of contamination of the uterine lumen post-partum and thus the possibility of puerperal metritis (Sheldon *et al* 2006).

Although PASTURE cows were likely to experience greater metabolic and nutritional stress, in general they had better reproductive health and welfare (ie uterine health and reproductive performance) which was in agreement with our hypothesis. However, this is in direct contrast with studies indicating that metabolic stress and negative energy balance impairs fertility (Brand *et al* 2001; Ingvartsen 2006; Goff 2008). Based on metabolic profiles and RF scores, PASTURE cows had inferior metabolic and nutritional status in the first 10 days post-calving compared to HOUSED cows. However, this inferior metabolic or nutritional status did not necessarily appear to trigger an increased incidence of health or reproductive problems.

It is known that all cows suffer NEB post-partum, and that they need to overcome the NEB before luteal activity can commence (Ingvartsen 2006; Pollott & Coffey 2008). Cows that achieve positive energy balance sooner are likely to recommence luteal activity sooner (Pollott & Coffey 2008) and show enhanced reproductive performance, which impacts positively on their welfare. Thus, it could be argued that if HOUSED cows were in better metabolic status, they should have shown better reproductive performance than PASTURE cows; yet luteal activity tended to commence earlier in the PASTURE cows. We speculate that although HOUSED cows had greater dietary intake and more energy available, as shown by blood metabolite results (Figure 1), it was not directed towards tissue repletion and/or achieving a positive energy balance in early lactation, but instead it went to increased milk production. Indeed, HOUSED cows had significantly higher milk production than PASTURE cows (raw average milk production HOUSED = 7,299 kg vs PASTURE = 6,186 kg). However, they had similar bodyweight and body condition score changes for the first 10 weeks of lactation (Patton *et al* 2008), indicating similar energy balance during this period. A study by Pollot and Coffey (2008) showed similar effects; cows in a system with low energy and high forage and access to pasture commenced luteal activity sooner than cows in a high energy system and no access to pasture. Differences were explained by energy balance nadir and mean energy content in the first 25 days. Consequently, we speculate that a PASTURE system, with lower milk production, allowed cows to more closely match their energy requirements with energy supply, allowing an earlier return to cyclicity than HOUSED cows. Hence, the PASTURE system had a positive impact on the reproductive parameters in this study. Other, biologically plausible reasons for poor reproductive performance in HOUSED cows, include poor oestrous expression (ie low intensity), resulting in reduced probability of conception (Mee *et al* 2008). Such poor oestrous expression may have been at least partly attributable to higher incidences of lameness in the HOUSED cows (Olmos *et al* 2009), which would have reduced the willingness of these cows to mount others or be mounted.

Conclusion and animal welfare implications

From the blood metabolites and physiological indicators (ie rectal temperature and rumen fill) seen in this study, it appeared that PASTURE cows were at greater risk of nutritional and metabolic stress in the first 10 days post-calving than HOUSED cows. However, this was neither associated with superior immune status in HOUSED cows nor poorer health in PASTURE cows as no differences were found between groups in the immune health indicators. Moreover, PASTURE cows had a tendency for improved reproductive welfare compared to the HOUSED cows. We conclude that, although PASTURE cows are at greater risk of nutritional/metabolic stress, they are in a less intensive system resulting in reduced energy output (eg milk production). The ability of the cow to monitor her biometric status in the early lactation period allows a readjustment in milk energy output such that energy intake from pasture is adequate for milk production as well as maintaining the health and welfare status of the cow.

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