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Effect of two housing systems on performance and longevity of dairy cows in Northern Italy

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Abstract. The objective of the current study was to evaluate and compare performance of dairy cows housed in compost-bedded pack barns (CBP) and free stall barns, with a focus on longevity-related parameters. Study included 30 commercial dairy farms located in the Po Valley, Italy. Twenty farms had free stall barns, among which 10 used rubber mattresses (FSM) and 10 used deep straw bedding (FSS). The remaining 10 farms had CBP. Monthly dairy herd records were obtained from the Italian DHI association for each farm included in the study over a period of one year. All farms were visited to measure characteristics and dimensions of housing facilities. Linear mixed models were used to evaluate the association between housing system and the outcome variables. In CBP total available area was larger than both in FSM and FSS. However, space per cow over the bedded pack area in CBP (6.8 ± 2.4 m^2 cow^{-1}) was relatively low for this housing system. Milk production was similar among housing systems but somatic cell count and mastitis infection prevalence resulted to be higher in CBP than in FSM and FSS. Calving interval was lower in FSS compared with both FSM and CBP while no differences were found in number of services per pregnancy. Cows housed in CBP were older and had higher parities than those in FSM and FSS while no significant differences in herd turnover rate were detected among housing systems. Results confirm that CBP housing system may improve longevity of dairy cows, which is reported to be one of the most important motivations for building this kind of housing. Nevertheless, CBP housing can pose some challenges in achieving adequate udder health and high milk quality, especially with low space per cow.

Key words: compost-bedded pack barns, freestall, cows, animal welfare, longevity.

INTRODUCTION

The welfare of dairy cattle results from an interaction of several factors. Recent research shows that housing conditions and facility design play a major role in determining cow's health (von Keyserlingk et al., 2009). Gaworsky et al. (2018) in Estonian dairy farms found a decreased tendency in the prevalence of disease cases for udder diseases with an increase in cow herd size. Free stall barns represent the most widespread housing system in intensive dairy farms worldwide. Despite that, recent studies have shown this system can compromise animal welfare and hinder natural cows' behaviour (EFSA, 2009). In recent years, these welfare-related issues concerning free stalls have fostered the interest of farmers and researchers towards alternative loose housing systems, such as compost-bedded pack barns (CBP). Introduced in the US since

2001, the CBP system spread rapidly and nowadays is known worldwide to potentially improve welfare of dairy cows (Bewley et al., 2017).

As opposed to free stalls, in CBP cows are provided with a large open bedded area on which they can lie, stand and walk freely. The bedded pack is aerated once or twice per day to promote evaporation and maintain a soft and hygienic surface for the cows (Leso et al., 2013; Bewley et al., 2017). In CBP, the most commonly used bedding materials are sawdust and wood shavings (Janni et al., 2007). Other materials including straw, peanut shells, woodchips and compost have also been used (Galama, 2014; Favèro et al., 2015; Leso et al., 2018). Generally, CBP requires more space per cow compared with free stalls, as maintaining an adequate animal density over the bedded pack is crucial. Suggested space allowance in CBP ranges from 7.4 to more than 15 m^2 cow^{-1} depending on barn characteristics, bedding availability and pack management (Janni et al., 2007).

Main benefits of CBP include improved feet and leg health and more natural behaviour compared with free stalls, which are likely due to reduced exposure to concrete flooring and injury-causing obstacles within housing (Fulwider et al., 2007). Results with CBP however, strictly depend on pack management (Leso et al., 2013; Mota et al., 2018). Evidence shows that some pack characteristics, especially pack moisture, may affect cows' hygiene and risk of mastitis (Eckelkamp et al., 2016). The main reasons, that producers reported for building CBP, is the improvement of cow comfort and longevity (Barberg et al., 2007; Black et al., 2013). However, little is still known about the effect of this housing system on longevity-related traits. The objective of the current study was to evaluate and compare performance of dairy cows housed in CBP and free stall barns, with a particular interest in longevity.

MATERIALS AND METHODS

This study was performed on 30 dairy farms in the provinces of Mantua (n = 27) and Cremona (n = 3), northern Italy. Twenty farms had FS, among which 10 used rubber mattresses (FSM) and 10 used deep straw bedding (FSS). The remaining 10 farms had CBP. Main bedding materials used in the CBP were sawdust and wood shavings. Producers with CBP cultivated the pack twice or once a day, with an average of 1.4 cultivations per day. Further information about the CBP involved in the current study can be found in Leso et al. (2013). All farms included met the following criteria: used the same housing system for all lactating cows for at least two years before the beginning of the study, the primary breed was Holstein, cows were milked twice daily in a milking parlour, cows were fed with TMR. As all farms involved were located in the production area of Grana Padano cheese all rations were based on corn silage (Mantovi et al., 2015).

Monthly dairy herd records were obtained from the Italian Dairy Association (Associazione Italiana Allevatori, Rome, Italy) for each farm included in the study. The following data were collected over a period of one year (from September 2011 till September 2012): number of cows, daily milk yield, 305-day milk yield, milk fat and protein content, SCC, number of parity, DIM, calving interval, number of services per pregnancy, age at first calving and herd age. Herd age (HA) referred to the mean age (months) of all adult cows in the herd. Mastitis infection prevalence (MIP) was calculated as the number of cows infected divided by the total number of cows. Cows were considered to be infected when their test-day SCC was greater than 200,000 cells mL^{-1}.

For each farm the monthly herd turnover rate (MHTR) was calculated as the number of cows culled over a period of one month (x100) divided by the mean cow inventory for the same time period (Fetrow et al., 2006). The annual herd turnover rate (AHTR) was obtained by the sum of all the MHTR recorded over a period of one year. Monthly records were grouped by season (fall: September, October and November; winter: December, January and February; spring: March, April, May; summer: June, July and August). Each farm was visited once between July and September 2012 to collect on-site data that included: total available area, laying area (surface covered with bedding or mattresses), number of free stalls (only in free stall barns) and feed fence length. Barn dimensions were measured using a Leica DISTO A5 laser distance meter (Leica Geosystems, Heerbrugg, Switzerland). For each barn a bedded ratio (BR) was calculated by dividing the bedded area inside the barn by the total available area.

Statistical analysis

Descriptive statistics (mean and SD) were used to describe herds' performance and barns' characteristics in each group of farms with the same housing system. One-way ANOVA (R package 'stats'; R Development Core Team, 2018) was used to determine whether housing system produces significant differences in space per cow, BR, number of cows, milk yield, 305ME, SCC, MIP, calving interval, number of services per pregnancy and AHTR. In order to evaluate the association between housing systems, herd records and the main outcome variables (HA and MHTR) a linear mixed model was built. A univariate linear model (R package 'stats'; R Development Core Team, 2011) was used to identify variables to be included in the multivariate model. Variables with P-value < 0.2 were included. An automatic model selection procedure based on the R package 'glmulti' (Calcagno, 2013) was used to build the models. The Bayesian Information Criterion was used for model selection. Variables included were all significant at P-value < 0.05. Housing system was forced in all models as explanatory variable. Residuals were visually checked. Tukey's method was used for multiple comparisons of least squares means (R package 'lsmeans'; Lenth, 2016) in categorically distributed variables within mixed models.

RESULTS AND DISCUSSION

The characteristics of the barns are summarized in Table 1. Total available area per cow in CBP (11.0 ± 4.1 m^2 cow^{-1}) was larger than that in FSM (9.0 ± 2.3 m^2 cow^{-1}) and FSS (9.3 ± 5.4 m^2 cow^{-1}). Cultivated pack barns had higher BR (0.65 ± 0.18) compared with FSM (0.38 ± 0.06) and FSS (0.37 ± 0.10). The pack density in CBP was 6.8 ± 2.4 m^2 cow^{-1}. The space per cow on the bedded area found in this study was lower than that measured in CBP in other countries. Barberg et al. (2007) found an average pack density of 8.6 ± 2.6 m^2 cow^{-1} in Minnesota CBP while Lobeck et al. (2011), studying CBP in the upper Midwest of US, measured an average pack density of 7.6 ± 1.1 m^2 cow^{-1}. Other researchers from the University of Kentucky recommended that the pack area should provide at least 9.3 m^2 of resting space per cow (Bewley et al., 2012). Other experiences with CBP in the Netherlands found that at least 15 m^2 bedded pack space per cow is needed to keep the pack sufficiently dry for the whole year

(Galama, 2014). Also in Israel 15 m^2 cow^{-1} is considered to be an adequate pack density in CBP (Klaas et al., 2010). Although the optimal space per cow in CBP depends on several factors such as climate, type and depth of bedding, barn's characteristics, pack management, breed and size of cows (Bewley et al., 2017), the pack density found in Italian CBP (6.8 ± 2.4 m^2 cow^{-1}) appears to be too high for this housing system.

Table 1. Characteristics of free stall barns with deep straw bedding (FSS), free stall barns with mattresses (FSM) and cultivated pack barns (CBP) in Italy

	FSS		FSM		CBP	
	Mean	SD	Mean	SD	Mean	SD
Total area per cow (m^2 cow^{-1})	9.3	5.4	9.0	2.3	11.0	4.1
Stocking density (cows $stall^{-1}$)	1.09	0.42	0.92	0.10	-	-
Pack density (m^2 cow^{-1})	-	-	-	-	6.8	2.4
Bedded ratio	0.37	0.10	0.38	0.06	0.65	0.18
Space at feed fence (m cow^{-1})	0.63	0.18	0.66	0.07	0.58	0.20

Characteristics and performance of the herds involved in this study are summarized in Table 2. The average number of lactating cows in each housing system was 143 ± 83.9, 147 ± 102.3 and 112 ± 56.6 in FSS, FSM and CBP, respectively. Herds in CBP were smaller than those housed in FSS and FSM ($P = 0.004$), with no difference between FSS and FSM. Other studies from the US also found lower number of cows in CBP compared with free stall barns (Fulwider et al., 2007; Lobeck et al., 2011). Some authors reported an increased interest towards CBP for housing special need cows (Bewley et al., 2017). These findings led to think that although farmers have a positive perception of CBP, especially for welfare related issues, concerns about cost of bedding and ease of management could limit the use of this housing system in bigger operations (Lobeck et al., 2011).

Table 2. Characteristics and performance of cows housed in free stall barns with straw bedding (FSS), free stall barns with mattresses (FSM) and cultivated pack barns (CBP) in Italy

	FSS		FSM		CBP	
	Mean	SD	Mean	SD	Mean	SD
Cows, no.	143[a]	83.9	147[a]	102.3	112[b]	56.6
Day in milk (days)	190	26.3	204	35.7	209	33.1
Parity	2.23	0.27	2.18	0.11	2.39	0.25
Milk yield (kg cow^{-1} day^{-1})	31.4	3.91	29.8	4.6	30.8	3.6
305-day milk yield (kg)	10,901	963	10,450	1,043	10,541	663
% fat	3.93	0.36	3.75	0.32	3.67	0.28
% protein	3.43	0.13	3.38	0.15	3.48	0.16
SCC (cells*1000 mL^{-1})	310[a]	128	259[b]	115	354[a]	171
Mastitis infection prevalence (%)	29.6[a]	9.5	23.2[b]	8.4	32.8[a]	12.7
Calving interval (days)	420[a]	19.1	442[b]	37.3	449[b]	72.9
Services per pregnancy, no.	2.54	0.61	2.59	0.64	2.67	0.50

[a,b] Significant differences among columns ($P < 0.05$).

Milk yield and 305-d mature equivalent milk production (305ME) did not differ among housing systems averaging 31.4 ± 3.91 kg cow^{-1} day^{-1} and 10,901 ± 963 kg, 29.8 ± 4.6 kg cow^{-1} day-1 and 10,450 ± 1043 kg, and 30.8 ± 3.6 kg cow^{-1} day^{-1} and

10,541 ± 663 kg in FSS, FSM and CBP, respectively. Somatic cell count in FSM (259,000 ± 115,000 cells mL^{-1}) was lower than that in FSS (310,000 ± 128,000 cells mL^{-1}) and CBP (354,000 ± 171,000 cells mL^{-1}; $P < 0.001$). Mastitis infection prevalence was lower in FSM (23.2 ± 8.4%) compared with FSS (29.6 ± 9.5%) and CBP (32.8 ± 12.7%; $P < 0.001$). No differences in SCC and MIP were detected between CBP and FSS. The SCC measured in CBP involved in this study was similar to 325,000 cell mL^{-1} (Barberg et al., 2007) and 318,000 cell mL^{-1} (Black et al., 2013) previously reported in CBP located in Minnesota and Kentucky, respectively. Another research involving CBP in the upper Midwest of US found higher SCC (434,000 cells mL^{-1}) but similar MIP (33.4%). In the same study the udder health of cows housed in CBP was compared with that of cows in free stall barns finding that both SCC and MIP were lower in free stalls, even though differences were not statistically significant (Lobeck et al., 2011).

These findings suggest that CBP may pose some challenges in achieving adequate udder health and high milk quality. As the bedded pack in CBP is known to contain high bacteria concentrations, the CBP environment appears to be hazardous from an udder health standpoint (Lobeck et al., 2012; Eckelkamp et al., 2016). Many authors highlighted the importance of applying correct pack management procedures (Bewley et al., 2017). In CBP, keeping the pack dry is paramount to achieve sufficient cow hygiene and reduce the risk of mastitis (Favero et al., 2015). Also, excellent teat preparation procedures at milking have also been recommended for dairies with CBP (Janni et al., 2007, Lobeck et al., 2012, Black et al., 2014).

Calving interval was lower in FSS (420 ± 19.1 days) compared with both FSM (442 ± 37.3 days) and CBP (449 ± 72.9 days; $P < 0.001$). The number of services per pregnancy did not differ between FSS (2.54 ± 0.61), FSM (2.59 ± 0.64) and CBP (2.67 ± 0.50). Since in CBP there was more space per cow and higher BR compared with free stall barns a more natural behaviour could have been expected (Fulwider et al., 2007), thus may led to an easier heat detection. Barberg et al. (2007) reported an increase in pregnancy rate in 5 out of 7 farms after shifting from tie stall to CBP. However, results obtained in the current study indicated poorer reproductive performance in CBP than in free stall barns. More exhaustive studies are needed to evaluate effects of this kind of housing system on reproductive performance whereas it is influenced by many environmental and management factors (Schefers et al., 2010).

The open pack area and the soft surface on which cows can stand, walk and rest in CBP is more similar to the pasture environment compared to free stall housing systems (Eckelkamp et al., 2014). This reduces behavioural limitations that may result from individual free stalls and concrete paving, allowing the expression of cattle natural behaviour (Endres & Barberg, 2007). As heat detection is mostly based on behaviour monitoring (Rutten et al., 2013), CBP has the potential to improve fertility, especially in regards of heat detection rate. However, the benefits of CBP housing strictly depend on pack management. If the pack gets too wet cows may sink into the pack and thus deeply limits cow comfort in CBP, leading to undesired behavioural responses and potentially to reduced fertility performance.

Herd age and herd turnover rate

The final model for herd age (HA) included housing system, calving interval and age at first calving (Table 3). Herd age was higher in CBP (48.46 months) than in FSM and FSS (44.98 and 44.58 months, respectively; $P < 0.001$). No differences were found between FSM and FSS. Each 1-day increase in calving interval was associated with a 0.044-month increase in HA. Herd age also increased with age at first calving by 0.381 months. In literature, information about the effect of CBP on HA or cows' lifespan is still sparse.

Table 3. Least squares means and standard error of herd age (HA) in 3 housing systems: free stall barns with straw bedding (FSS), free stall barns with mattresses (FSM) and cultivated pack barns (CBP) in Italy

Housing system	LSM	SE	
FSS	44.58[b]	0.34	
FSM	44.98[b]	0.33	
CBP	48.46[a]	0.33	
Other parameters	Estimate	SE	P-value
Calving interval (days)	0.044	0.007	< 0.001
Age at first calving (months)	0.381	0.068	< 0.001

[a, b] Significant differences among rows ($P < 0.05$).

The final model for MHTR included housing system, season and housing system × season interaction. Monthly herd turnover rate was 2.98, 2.67 and 2.47% in FSS, FSM and CBP, respectively. No significant difference in MHTR were found between housing systems. Monthly herd turnover rate was higher in fall (3.69%) than in spring, summer and winter (2.38, 2.10 and 2.48%, respectively; $P < 0.001$), with no difference among the latter three.

A housing system × season interaction was observed (Table 4). During fall, MHTR was lower in CBP than in FSS ($P = 0.036$) while, during winter, CBP had lower MHTR than FSM ($P = 0.013$). The FSS barns had higher MHTR in fall than in winter ($P = 0.002$), spring ($P > 0.001$) and summer ($P = 0.008$). Monthly herd turnover rate in FSM was higher in fall than in spring (P = 0.018) and summer ($P = 0.005$) and it was higher in winter than in summer ($P = 0.027$). No differences in MHTR were detected among seasons in CBP. This is in contrast to what would have been expected because in CBP the winter season is largely seen as a critical period due to difficulties in keeping the pack dry (Lobeck et al., 2011).

Table 4. Least squares means and standard error of monthly herd turnover rate in 3 housing systems: free stall barns with straw bedding (FSS), free stall barns with mattresses (FSM) and cultivated pack barns (CBP) in Italy

	Housing system					
	FSS	FSM	CBP			
Season	LSM	SE	LSM	SE	LSM	SE
Fall	4.41[a,x]	0.38	3.58[x]	0.38	3.08[b]	0.38
Winter	2.47[y]	0.38	3.26[a,x]	0.38	1.72[b]	0.38
Spring	2.38[y]	0.38	2.00[y]	0.38	2.76	0.38
Summer	2.47[y]	0.47	1.57[y]	0.47	2.47	0.47

[a, b] Significant differences among columns (housing systems) within season ($P < 0.05$); [x, y] Significant differences among rows (seasons) within housing system ($P < 0.05$).

Annual herd turnover rate was 35.70 ± 9.31, 32.37 ± 6.59 and 29.68 ± 11.00% in FSS, FSM and CBP, respectively. No significant differences were detected in AHTR among housing systems ($P = 0.352$). This would be partially explained by the large variation in AHTR among farms. Lobeck et al. (2011) reported similar AHTR (30.1%) in CBP form US. In the same study, AHTR in CBP and free stall barns were compared and no significant differences between types of housing were found. Barberg et al. (2007) reported sensibly lower herd turnover rate (20.9%) in CBP compared with that found in the current study.

Within the dairy literature, the consensus is that lower AHTR are more profitable, with optimal rates of ≤ 3 0% (Fetrow et al., 2006). Annual herd turnover rates measured in CBP remained within this limit or barely above indicating that this alternative housing system can increase profitability of intensive dairy farms which often have higher culling rates. In a large survey carried out in the US including herds from 10 states over a 7-year period, the average culling rate was 35.1% (Hadley et al., 2006).

CONCLUSIONS

Cows housed in CBP were older than cows housed in free stall barns. Although, on average, the turnover rate was lower in CBP than in free stall barns, no significant difference was found in turnover rate among housing system. This would be partially explained by the large variation in turnover rate among farms. Results obtained partially confirm that CBP may improve longevity of dairy cows, which is reported to be one of the most important motivations for building this kind of housing. Further researches are needed to obtain more consistent results, especially about culling rates.

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