**Interpretive summary**

Previous studies have reported bedded packs can improve cow welfare and comfort, and have advantages for manure management, soil health, and water quality. This observational study explored whether facility type was associated with bulk tank milk quality, udder health, udder hygiene and milk production during the non-grazing season on small-midsize organic dairies in Vermont. The measured outcomes for bedded packs did not differ compared to tiestalls and freestalls, the most commonly-used housing types for organic dairies in Vermont. We therefore feel that bedded packs can be a viable option for dairy cattle housing during the non-grazing season in the Northeast.

**Running head:**

Milk quality and hygiene on VT organic dairies

**Relationship Between Facility Type and Bulk Tank Milk Bacteriology, Udder Health, Udder Hygiene, and Milk Production on Vermont Organic Dairy Farms**

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**Abstract**

The primary objective of this cross-sectional observational study on organic dairies was to describe whether bulk tank milk quality, udder health, udder hygiene and milk production outcomes were associated with facility type. A secondary objective was to identify other management-related risk factors associated with bulk tank milk quality, udder health, udder hygiene, and milk production on organic dairy herds in Vermont. We aimed to collect bulk tank milk samples, udder hygiene scores, and complete a survey on mastitis risk and bedding management practices on 40 farms, in order to compare the two most common housing systems used during the non-grazing season for dairy cattle in the state (freestalls, tiestalls) with those using a bedded pack. The study was completed on 21 farms (5 bedded packs, 6 freestalls, 10 tiestalls) before interruption due to the COVID-19 pandemic. Data captured from Dairy Herd Improvement Association records from the test closest to the date of the farm visit included avg. somatic cell score (SCS), standardized 150-day milk (pounds), % cows with current high SCS ≥4.0, % cows with newly elevated SCS (i.e., previous test SCS <4.0 to current ≥4.0), and % cows with chronically elevated SCS ≥4.0 last two tests. Multivariable linear regression models to describe outcomes by facility type was completed, but suffered from limited statistical power due to small group sample sizes. Final results from unconditional comparisons showed that farms using each of the three facility types did not differ in cow-level udder health measures captured from Dairy Herd Improvement Association test day somatic cell count records, bulk tank milk somatic cell count (BTSCC), bulk tank aerobic culture data, milk production, and udder hygiene scores. Subsequently, a secondary analysis was conducted using univariate linear regression to identify associations between herd management factors and outcomes for all 21 farms combined. Although not all differences found were statistically significant, numeric differences that may be biologically important are reported showing farms with deeper bedding had a lower BTSCC, lower newly elevated SCS, lower current SCS, lower average SCS, and improved hygiene metrics. Farms with lower mean udder hygiene scores had numerically lower percent cows with chronic SCS, current SCS, and average SCS. Although statistical power was limited, the current study provides insight on factors affecting bulk tank milk quality, udder health and hygiene measures on organic dairy farms in Vermont. Because outcomes for bedded packs were comparable to more commonly used indoor housing systems, we conclude that bedded pack facilities are a viable option for confinement during the non-grazing season for pasture-based herds interested in a loose-housing system in the Northeast.

**Keywords:** Mastitis, organic dairy cattle, housing, bedded pack, milk quality

**Introduction**

Mastitis due to environmental pathogens, such as those commonly found in bedding material, has now become the “most common and costly form of mastitis in modern dairy herds” that have implemented standard mastitis control practices limiting the effect of contagious pathogens (Klaas and Zadoks, 2018). Teats of dairy cattle may be in direct contact with bedding materials for 40 to 60% of the day, making this an important potential source of exposure to opportunistic environmental mastitis pathogens (Tucker and Weary, 2004, Cook et al., 2005, Hogan and Smith, 2012). Work exploring how bedding materials relate to a cow’s risk of getting mastitis has understandably focused on the most frequently used bedding materials and housing systems in the dairy industry. Currently, the most common type of dairy cattle housing for organic farms in Vermont is a tiestall barn, with freestall barns a distant second (Andrews et al., 2021). As consumer opinion about confinement housing of dairy cattle evolves and influences dairy policy, both the dairy industry and consumers are looking to move away from traditional housing systems which restrict cow movement (Barkema et al., 2015). Many smaller-scale organic dairy farmers in Vermont with aging facilities, and especially tiestall barns, may be looking to adopt a bedded pack system on their farms as a form of loose-housing (Andrews et al., 2021). These loose-housing structures are perceived to integrate well into pasture-based farm systems, and state and federal agencies in the U.S. are providing financial incentives for dairies to build these structures as part of manure management practices which improve water quality and contribute to soil conservation (Andrews et al., 2021).

As interest in bedded packs grows, it will be important to better understand milk quality, udder health and hygiene on farms using these housing alternatives. Understanding mastitis risk for cattle housed on bedded packs will be especially important for organic dairy farmers, as they have limited effective options for treating intramammary infections (Ruegg, 2009). Traditionally, bedded packs have been thought to increase risk of mastitis due to the presence of pathogenic bacteria (Black et al., 2014) and the favorable moisture and temperature for the growth of these pathogens (Favero et al., 2015). Previous work describing mastitis risk and cow hygiene on bedded pack systems includes descriptive studies of actively-managed composting bedded packs (Barberg et al., 2007b, Black et al., 2013, Fávero et al., 2015, Eckelkamp et al., 2016b, Albino et al., 2018, Heins et al., 2019). However, research comparing milk quality and cow hygiene between bedded pack systems and more traditional housing types has so far been limited to freestalls with sand, which is an uncommon housing type for organic farms in Vermont (Andrews et al. 2021). These include a study comparing actively-managed composting bedded packs (CBP) and sand-bedded freestalls for farms with a history of low bulk tank somatic cell counts (Eckelkamp et al., 2016a), work describing hygiene and bulk tank milk somatic cell count (BTSCC) for sand-bedded freestalls and CBP (Adkins et al., 2022), and a comparison of CBP and two types of freestall barns (Lobeck et al., 2011). It is unclear whether the herds included in these prior studies were conventionally-managed or organic dairies. To the best of our knowledge, no studies describe and compare bulk tank milk quality, udder health and hygiene on bedded pack farms and tiestall barns of similar size and management style.

In order to better inform organic dairy producers in the Northeast who may be interested in using a bedded pack barn for housing their cattle during the non-grazing season, we carried out a cross-sectional, observational study on organic dairies in Vermont. This study aimed to quantify bulk tank milk bacteriology, udder health and hygiene measures for the two most common indoor housing systems in the state for organic farms (freestalls, tiestalls) and for farms using a bedded pack. The objectives of this project were to identify whether bulk tank milk quality, udder health and hygiene outcomes differed by facility type, with a view to determining if bedded pack systems are a viable option for indoor housing in VT during the non-grazing season. We hypothesized that udder health, hygiene, and bulk tank milk bacteriology of bedded pack herds may be inferior to that of more traditional housing types, as has been suggested by some previous research. A secondary objective was to identify other (non-facility) management-related risk factors associated with bulk tank milk quality, udder health, udder hygiene, and milk production in organic VT dairy herds.

**Materials and Methods**

STROBE-VET (Strengthening the Reporting of Observational Studies in Epidemiology–Veterinary Extension) statement guidelines were followed in the reporting of this study (O'Connor et al., 2016).

1. **Herd enrollment and selection**

The source population for this study was the 145 farms that responded to a survey sent to all certified organic dairy farms producing cow milk in Vermont in Winter 2018-2019 (all farms, n = 177). Certified organic dairy farms in the United States are required to allow their cows daily access to pasture during the grazing season, and cows must get 30% of their dry matter intake from grazing (Rinehart and Baier, 2011). During the non-grazing season (typically November-May in Vermont), organic farms house cows indoors in a variety of facility types. The Winter 2018-2019 survey aimed to quantify the frequency and diversity of indoor housing and bedding types used by organic dairy farmers in the state when cows were not on pasture (Andrews et al., 2021). Dairy farms were eligible for enrollment in the current study if they: 1) responded to the initial survey in the Winter 2018-2019, 2) indicated they met the enrollment criteria of testing with the Dairy Herd Improvement Association (DHIA) at least monthly, 3) milked between 35 and 120 cows, and 4) indicated they would be interested in further participation. Eligible farms were contacted from this source population if they responded that they were using one of four categories of bedding/housing combinations for their indoor housing system: 1) freestall barn bedded with sand, 2) freestall barn bedded with shavings or sawdust, 3) tiestall barn bedded with shavings or sawdust, or 4) an enclosed loose housing facility deeply bedded with organic material (hereafter, “bedded pack”). The first three housing and bedding combinations were found to be the top three used by organic dairies in Vermont to house cows during the non-grazing season, and bedded packs were included as they were the housing type of interest for this project.

A convenience sample of farms was enrolled in Spring 2019 from a list of eligible farms (grouped by housing/bedding combination) using the phone number or email address provided in the 2018-2019 survey. Our aim was to complete the current survey and sampling at 40 farms, with 10 farms from each of the four housing/bedding categories described above. As this study design was outlined before getting the full results from the 2018-2019 survey, and the University of Vermont Sustainable Agriculture Extension group had been promoting adoption of bedded-pack systems, it was anticipated that it would be possible to enroll 10 organic Vermont dairies using a bedded pack system as their primary indoor housing system. However, out of the 17 farms from 2018-2019 survey which indicated at least some use of a bedded pack system, one farm was not interested in any further participation, five did not use DHIA testing, and six only used a bedded pack system as a secondary housing system in conjunction with a tiestall barn, or cows were only on the pack a few hours a day. Because the number of farms using bedded packs was significantly smaller than anticipated, the eligibility requirements were relaxed to include one farm where cows spend the majority (two-thirds) of their time in a bedded pack, with the remaining time in a tiestall with wood shavings. Additionally, two bedded pack farms were included that had limited DHIA information: one farm did not utilize cow-level testing, and cow-level data for a second farm was limited due to their seasonal lactation schedule. The survey was intended to study cows while they were in their indoor housing system, so all herds visits were completed before any grazing had begun for the season.

Of the intended 40 herds to be recruited in the study, 21 herds (1 freestall bedded with sand, 5 freestalls bedded with wood shavings/sawdust, 10 tiestalls bedded with wood shavings/sawdust, 5 bedded packs) that were contacted agreed to participate and the survey and sampling were completed April-May 2019. All herds sampled during this period were housing their cows as they would in the non-grazing season. Completion of the survey and sampling was suspended in mid-May as farms began turning their cows out to pasture for the grazing season, with the intention of resuming in April 2020 to complete the remaining 19 herds. Due to COVID-19 pandemic activity restrictions, the decision was made to not resume the survey and sampling, and the final analysis included the 21 herds sampled in 2019. As there was only one farm sampled using a freestall facility bedded with sand, the initial plan to group farms by the four housing/bedding combinations specified was abandoned in favor of grouping farms by the three facility types used. The single sand freestall was combined with freestalls bedded with wood shavings/sawdust (FS; n = 6), there were 10 tiestalls bedded with wood shavings/sawdust (TS), and 5 bedded packs (BP).

1. **Survey administration, sampling, and udder hygiene scoring**

At each farm visit, a questionnaire was administered by the first author (CJ). The interview questionnaire collected information which aimed to acquire a comprehensive understanding of housing and bedding management, as well as other practices on the farm that could impact mastitis risk. The questionnaire is included in Supplemental Data (XXX). Survey and interview protocols were registered with the University of Vermont Institutional Review Board (IRB certification 19-0057). The questionnaire was created and administered on a tablet using KoboCollect software (http://www.kobotoolbox.org). Questions about mastitis risk explored producer concerns about bedding/mastitis risk; mastitis control, identification and record keeping; milking facilities, procedures, and hygiene practices; information about diet, vitamin and mineral supplementation, and water source; typical calving and periparturient practices; and fly control. Questions about housing and bedding management included describing type of housing system used for both lactating and dry cows; classification and description of any bedding material used; and bedding management practices for each housing type used. The questionnaire also collected some basic herd information (production numbers; number of lactating, dry, and youngstock; breed; record-keeping systems). As the focus of this study was the use of bedded pack systems by organic dairy producers in Vermont, additional questions were asked of these farms to gather more detailed information about bedded pack construction, management, monitoring practices, and perceptions comparing bedded packs to any previously used systems. Completion of the survey took about 45 minutes on average, ranging from about 30 minutes to 1.5 hours.

At each farm visit, a co-author (TA) collected a bulk tank milk sample, bedding samples, and conducted a facility inspection. The bulk tank milk sample was collected directly from the top of the bulk tank after at least 5 minutes of agitation using a 250-mL sterile single-use vial (Blue Dippas™, Dynalon Products, England). Samples were kept on ice in a cooler until they could be frozen and stored at −20°C in the laboratory, before being sent to a diagnostic lab for analysis. The facility inspection collected information about the bulk tank, cow identification, a subjective assessment of air quality, and any outdoor exercise area. The on-farm observation sheet is included in Supplemental Data (XXX). Measurements of the housing facilities were recorded for freestalls and tiestalls where appropriate (stall sizes, pen sizes, bedding depth, stocking density, trainer use), as well as observations about bedded packs when applicable (temperature, depth, pen size, and stocking density in m2 per animal). If multiple pens were present (e.g. freestall barn), used bedding samples were collected from the pen containing the largest group of lactating cows, or from the highest producing group of animals if there were multiple pens of equal size. Bedding depth of freestalls and tiestalls was included as a producer reported value in the questionnaire. Bedding depth of bedded pack facilities was measured where the pack met a cement knee wall. Udder hygiene scoring was completed by co-author (TA) for a minimum of 30 randomly selected cows housed in the same pens from which used bedding samples were collected. A four-point udder hygiene scoring system was used, where 1 = free of dirt, 2 = slightly dirty (2–10% of surface area), 3 = moderately covered with dirt (10–30% of surface area), and 4 = covered with caked on-dirt (>30% of surface area) (Schreiner and Ruegg, 2002). Materials were left with producers to record and collect milk samples of cows with clinical mastitis in the 30 days following the farm visit, but producer compliance in this aspect of the study was inconsistent and not included in any analyses. Animal use for this project was approved by the University of Vermont Institutional Animal Care and Use Committee (IACUC; protocol #PROTO202000089).

1. **Herd-level udder health measurements**

Herd-level DHIA test results for the test day closest in time to the farm visit (either preceding or following day of farm visit, whichever was shorter) were captured from the record processing center working with each herd (Lancaster DHIA, Manheim, PA; Dairy One Co-Op. Inc., Ithaca, NY). Information captured included test date, number of lactating cows, standardized 150-day milk production (STD 150-day milk), and test-day average cow-level somatic cell score (SCS). The following udder health measures were also captured from DHIA records: proportion of cows with an SCC ≥200,000 cells/mL on most recent test day (“elevSCS”), where elevated SCS was defined as a somatic cell score of ≥4.0; the proportion of cows with a newly elevated SCS (“newSCS”), which was defined as a SCS changing from <4.0 to ≥4.0 over the last 2 tests; and the proportion of cows with a chronically elevated SCS (“chronSCS”), which was defined as having a SCS ≥4.0 on the last two tests (Schukken et al., 2003).

1. **Bulk tank milk culture and bulk tank somatic cell count measures**

An aliquot of the bulk tank milk sample was stored at -4°C until it could be transported to the laboratory of a dairy processing plant (St. Alban’s Cooperative/Dairy Farmers of America, St. Albans, VT) within 48 hours of collection for determination of the bulk tank somatic cell count (BTSCC).

Frozen bulk tank milk samples were shipped on ice to the Laboratory for Udder Health (University of Minnesota Veterinary Diagnostic Laboratory, St. Paul) for analysis. Methodology for bulk tank milk cultures at the Laboratory of Udder Health are described elsewhere (Patel et al., 2019). Briefly, thawed, room-temperature bulk tank milk and a 10-fold dilution of each bulk tank milk sample were plated onto MacConkey, Factor (gram-positive selective agar; University of Minnesota), and Focus (selective for SSLO bacteria; University of Minnesota) media plates and incubated for two days at 37°C. Any lactose-fermenting colonies on MacConkey medium were counted and reported as coliform bacteria. Any β-hemolytic colonies on Focus medium were counted and identified to the species level using a MALDI Biotyper (suspect *Streptococcus agalactiae*). All remaining colonies on Focus medium that were not identified as *Strep. agalactiae* were counted and recorded as streptococci or strep-like organisms (SSLO). Hemolytic colonies on Factor medium were counted and identified to the species level using a MALDI Biotyper (suspect *Staph. aureus*). Any hemolytic colonies with a confidence score ≥2.0 for *Staph. aureus* were counted and reported as such. Remaining colonies of staphylococci on Factor media (based on colony morphology, catalase reaction, or Gram stain) were counted and reported as *Staph.* spp. Bulk tank samples were also cultured for *Mycoplasma* spp. (0.1 mL milk was swabbed across a Mycoplasma agar plate, then placed in a 7% CO2 incubator at 37°C for 7 days, after which they were examined for *Mycoplasma* spp. by a trained microbiology technician). For each bulk tank milk sample, total colony-forming units (cfu) per mL were calculated for coliform organisms, *Staph.* spp., streptococci and strep-like organisms (SSLO), *Staph. aureus*, *Strep. agalactiae*, and *Mycoplasma* spp. The lower threshold of detection for bacteria in this bulk tank milk culture protocol was 5 cfu/mL, and the upper threshold was 62,500 cfu/mL.

1. **Data management and analysis**

Survey data collected through KoboCollect software (KoboCollect: Simple, Robust and Powerful Tools for Data Collection. 2019 http://www.kobotoolbox.org) was downloaded as an Excel worksheet (Microsoft Corp., Redmond, WA), which contained the information from the questionnaire covering herd information, description of housing and bedding management, milking hygiene, and mastitis control practices. Udder hygiene scores for individual cows were used to calculate two farm-level udder hygiene measures: 1) mean udder hygiene score, and 2) proportion of cows with dirty udders (udder hygiene score ≥3). Bulk tank milk culture results, BTSCC, DHIA test results, and farm-level udder hygiene outcomes were entered into an Excel database that included the accompanying data for each farm from the questionnaire and farm observations. This Excel database was then imported into the R Statistical Programming Environment (R Core Team, 2023) for data cleaning, checking, and statistical analysis. The distribution of outcome variables was visually assessed in R to check for normality, and descriptive statistics (means, variances, and percentiles for numeric continuous variables; frequencies tabulations and percentages for categorical variables) were calculated to evaluate the distribution and data integrity and to identify missing data. Descriptive statistics included description of general herd characteristics/farm traits, lactating cow housing/facilities, lactating cow bedding material/bedding management practices, milking hygiene procedures, and mastitis control practices for all 21 herds included in the study. Additionally, descriptive statistics were also produced to describe udder hygiene, bulk tank milk quality and bacteriology, and DHIA udder health outcomes, both for all herds (n = 21) and for herds stratified by facility type (freestall, bedded pack, tiestall). Distribution of the raw bulk tank somatic cell count (BTSCC) data, log2 transformed BTSCC data, and log10 transformed BTSCC data was assessed, and all were found to be similarly close to being normally distributed; therefore, the raw BTSCC data was chosen for ease of interpretation.

*Objective 1. Evaluation of relationships between housing system and measures of milk quality, udder health, udder hygiene and milk production.* Unconditional comparisons of bulk tank udder health measures, aerobic culture data, and hygiene scores by facility type were carried out using an appropriate test. BTSCC, newSCS, chronSCS, elevSCS, STD 150-day milk, mean hygiene and proportion dirty udders met the assumptions for a One-way Fisher’s ANOVA (no outliers, normality using a Shapiro-Wilk test at p ≤0.05, and homogeneity of variances using both Levene’s test and visual assessment of a residuals vs. fitted values plot). Welch’s ANOVA was used for analysis of average SCS, as the data were normally distributed but had unequal variances. The Tukey method was used for adjusting p-values for multiple comparisons (“TukeyHSD” function of the “stats” package in R). As most measures of aerobic culture data were not normally distributed even after log transformation, a Kruskal-Wallis test was used to compare cfu counts between the three facility types. Statistical significance for ANOVA and Kruskal-Wallis tests were declared at *P* ≤0.05.

Continuous variables underwent correlation analysis to identify predictor variables that were highly correlated (correlation coefficient ≥0.60), and unconditional associations among categorical variables were evaluated using a Pearson’s chi-squared or Fischer’s Exact test as appropriate (*P* ≤0.05). An ANOVA was used to check for correlation between numeric continuous variables and categorical variables (*P* ≤0.05). When a categorical variable had multiple groups with a small number of observations in each, groups were combined when biologically reasonable to have all categories of predictor variables contain at least five observations. If any predictor had only one observation in a group and there was no way to combine groups in a logical way, it was excluded from further analysis (but listed in descriptive statistic tables).

Univariate linear regression was performed in R using the “lme4” package to investigate the unconditional relationship between the six udder health and production outcomes (BTSCC, avg. SCS, newSCS, elevSCS, chronSCS, STD 150-day milk) and two hygiene outcomes (mean hygiene score, proportion of dirty udders) for each farm and the previously-described herd-level independent variables. The two udder hygiene metrics (proportion dirty udders and average udder hygiene score) were used as both predictor variables (in models for other outcome variables) and outcome variables in models of their own. Any explanatory variable that was unconditionally associated with 1 or more of the outcomes of interest at *P* <0.20 was then offered into a multivariable model investigating the relationship between the udder health and production or hygiene outcome and the herd-level predictor variables. If any predictor variables were found to be correlated with each other, the one with the more highly significant relationship from univariate analysis was offered to the multivariable model when appropriate. The two udder hygiene metrics were highly correlated (derived from the same data), so whichever one had a smaller *P-*value from the univariate analysis was chosen for inclusion in the model-building process. Predictors selected from univariate analysis offered to multivariable models for eight udder health, production, and hygiene outcomes are detailed in Supplemental Table S1. Facility type was forced into these multivariable models, as it was the primary explanatory predictor of interest. A backward stepwise variable selection process was then used, with the least significant variables being removed one by one until all remaining predictors had *P* ≤0.10.The multivariable modelling approach described above aimed to investigate the conditional relationship between facility type and the eight outcomes of interest while controlling for different farm management practices, housing characteristics, milking procedures and mastitis control practices.

*Objective 2. Identify other (non-facility) management-related risk factors associated with bulk tank milk quality, udder health, and milk production in organic dairy herds.* After grouping all 21 farms together, we used linear regression between independent predictors and outcomes of interest. Unconditional relationships between the eight outcome variables and independent predictors are reported for a significance level of *P* ≤0.20, and only for predictor variables with group sizes of at least n = 5.

**Results**

**Description of study herds**

Of the 21 herds enrolled, 5 used a bedded pack system, 1 used a freestall bedded with sand, 5 used a freestall bedded with shavings/sawdust, and 10 used a tiestall bedded with shavings/sawdust (Supplemental Table S2). Of the 5 BP farms, two bedded with shavings/sawdust and cultivated 2 times a day to promote aerobic composting, 1 bedded with straw and woodchips and cultivated 2 times/week, and 2 bedded mainly with straw, adding woodchips as needed, and did not cultivate the pack at all. The predominant breeds on all farms were Holstein (n = 8 farms), Jersey (n = 10), and mixed Holstein-Jersey crosses/other (n = 3). The median (mean; range) number of lactating cows was 68 (64.9; 32-99). The median annual rolling herd average milk production for the farms was 6,367 (6,424; 4,082-9,618) kg. Nineteen of the 21 farms tested with DHIA monthly while their cows were in milk, with one farm testing 5-8 times/year and one testing every other month. On average, DHIA data was captured from a test day 4 days before the farm visit (range: -28 days to +33). Detailed descriptions further characterizing study farm management practices and housing characteristics for lactating animals (e.g., laying surface, ventilation, stocking density), and details about bedding material and bedding management practices for lactating animals (e.g., bedding depth, frequency of adding new bedding, manure removal) are provided in Supplemental Tables S2 and S3, respectively. Detailed descriptions of routine milking procedures and mastitis control practices are provided in Supplemental Tables S4 and S5, respectively.

**Description of bulk tank milk quality, udder health measures, milk production, and udder hygiene scores**

None of the 21 bulk tank milk samples were positive for *Strep. agalactiae* or *Mycoplasma* spp. Results of aerobic cultures are presented in Table 1. Sixteen of the 21 bulk tank milk samples were negative for coliforms on aerobic culture, while 5 farms had a coliform count of 5 cfu/mL. *Staph. aureus* was found in the bulk tank milk from 13/21 herds, with a median (mean; range) cfu/mL of 50 (70; 15-320) when present. The median (mean; range) *Staph.* spp. count found in the 21 bulk tank milk samples was 65 (96; 0-665) cfu/mL, while the median SSLO count was 45 (156; 10-1250) cfu/mL.

The mean (SD; range) raw somatic cell count for the 21 bulk tank milk samples collected was 144,286 cells/mL (53,934; 54,000-250,000) (Table 2). For the 19 herds with available DHIA test-day data, the mean % cows with newly elevated SCS was 5.7 (3.7; 0-12.3), mean % cows with chronically elevated SCS was 13.6 (5.8; 2.9-23.1), and mean % cows with elevated SCS was 25 (7.8; 8.6-36.9). For the 18 herds with available data, mean standardized 150-day milk was 50 pounds (10.1; 33.5-68). For the 20 herds with available cow-level test data, the average SCS was 2.44 (0.42; 1.7-3.3).

The overall mean (95% CI) of herd-level udder hygiene scores for all 21 farms was 2.32 (2.16-2.49). The mean (95% CI) hygiene score was 2.2 (1.91-2.44) for bedded pack farms (n = 5), 2.5 (2.24-2.76) for tiestall farms (n = 10), and 2.15 (1.93-2.37) for freestall farms (n = 6).The overall mean (95% CI) proportion of cows with dirty udders in a herd (udder hygiene score ≥3) was 40% (31-48%). The mean proportion of cows with dirty udders (95% CI) was 32% (18-46%) for bedded pack farms (n = 5), 49% (35-62%) for tiestall farms (n = 10), and 32% (20-44%) for freestall farms (n = 6).

**Objective 1. Analysis of relationship between facility type and measures of bulk tank milk quality, udder health, milk production, and udder hygiene scores**

Final multivariable models are summarized in Table XX. All 21 farms were able to be included in the models for BTSCC, average hygiene score, and proportion of dirty udders. However, for only XX herds were used for models exploring… For the models exploring newSCS, chronSCS, and elevSCS, two bedded pack farms did not have available DHIA data (group sizes: FS =6, TS = 10, BP = 3). One bedded pack farm did not have average cow-level SCS data (group sizes: FS = 6, TS = 10, BP = 4). For STD 150-day milk, one bedded pack farm and two tiestall farms were missing DHIA data (group sizes: FS = 6, TS = 8, BP = 4).

*Bulk tank milk quality outcomes*

A Kruskal-Wallis chi-squared test was performed for each of the four aerobic culture outcomes, which found no difference in cfu count between the three facility types (*P* > 0.05; Table 1). Multiple attempts were made to model the four aerobic culture outcomes for bulk tank milk, but all suffered from over-parametrization and were not pursued further.

A one-way Fisher’s ANOVA revealed that there was no difference in BTSCC between the three facility types (*P* = 0.15; Table 2). Predominant breed and herd size were offered to a multivariable model for BTSCC. No models were produced for BTSCC that were statistically significant overall (F-test, *P* >0.05) or which had any significant predictors, including facility type.

*Udder health outcomes*

A one-way Fisher’s ANOVA revealed that there was no difference in newSCS between the three facility types (*P* = 0.81; Table 2). Herd size category, use of bedding amendment, air quality as assessed by researcher, glove use at milking, and clinical mastitis record keeping practices were offered to a multivariable model for newSCS. The model with the lowest AIC value (91.36) was an improvement on the reduced model with only facility type (ANOVA, *P* = 0.01), and included bedding amendment use, air quality, glove use, and mastitis record keeping practices. However, this model was only a marginal improvement on the full model (AIC = 91.76). Bedding amendment use and air quality were significant predictors of newSCS in this best model (overall *P =* 0.014), while facility type was not.

A one-way Fisher’s ANOVA revealed that there was no difference in chronSCS between the three facility types (*P* = 0.74; Table 2). (in a one-way model, facility type not associated with the outcome). Aad’l vars were signif at p=0.2 Feeding additional supplemental selenium, use of a bedding amendment, udder hair clipping, and proportion of dirty udders were offered to a multivariable model for chronSCS. The full model was the best (overall *P* = 0.04), and was an improvement on the reduced model (ANOVA, *P* = 0.02), but the only predictor found to be significant was the proportion of dirty udders (*P* = 0.018). Facility type was not found to be a significant predictor of chronSCS.

A one-way Fisher’s ANOVA revealed that there was no difference in elevSCS between the three facility types (*P* = 0.90; Table 2). For modelling elevSCS, bedding amendment use, and mean hygiene were offered. No models were produced that were statistically significant overall, and none had any significant predictors, including facility type (*P* >0.05).

In univariable models, vasirables that were significantly associated with avg SCS Variables that were signf at p<0.2 Were … name them. Final multivariable model included (name what stayed in; list fac type [forced], selenium, etc). Facility type was not found to be a significant predictor in this model. Fac type not associatdwith outcome in final model (Table 2).

A one-way Welch’s ANOVA revealed that there was no difference in average SCS between the three facility types (*P* = 0.97; Table 2). Feeding additional supplemental selenium, use of a bedding amendment, use of organic approved intramammary product at dry-off, use of injectable selenium and vitamin E product, and mean hygiene were offered to a multivariable model for herd average SCS. The best model for avg. SCS included use of bedding amendment, dry product, injectable selenium, and mean hygiene score, with all of these predictors except use of dry product found to be significant.. Facility type was not found to be a significant predictor in this model.

*Milk production outcome*

A one-way Fisher’s ANOVA revealed that there was no difference in STD 150-day milk between the three facility types (*P* = 0.65; Table 2). For modelling STD 150-day milk, use of injectable selenium and vitamin E product, whether producers cultured high SCC cows, and herd size category were offered. No models were statistically significant overall, and none had any significant predictors, including facility type (*P* >0.05).

*Udder hygiene outcomes*

A one-way Fisher’s ANOVA revealed that there was no difference in proportion of cows with dirty udders in a herd between the three facility types (*P* = 0.15). The only predictor offered to the model for proportion of dirty udders was air quality assessed by researcher. The model was not significant, and was no better than the reduced model only containing facility type (*P* >0.05). Facility type was not found to be a significant predictor in this model.

A one-way Fisher’s ANOVA revealed that there was no difference in mean hygiene score of cows in a herd between the three facility types (*P* = 0.13). For modelling average hygiene score, the predictors meeting the threshold to be offered to the model were whether the producer ever cultured quarter milk samples and whether the producer generally followed recommended practices for mastitis control. No models were statistically significant overall, and neither predictor was significant (*P* > 0.05). Facility type was not found to be a significant predictor in this model.

**Objective 2. Analysis of farm management factors (non-facility) associated with bulk tank milk quality, udder health, milk production, and udder hygiene scores for all farms combined** Selected results of univariate linear regression models identifying management factors beyond facility type which were unconditionally associated with bulk tank milk quality, udder health, milk production and hygiene outcomes for all farms combined (n = 21) at *P* < 0.20 are presented in Table 4. We report the results of these univariate regression models as they may be biologically important, even though many failed to reach threshold for declaring statistical significance, possibly due to small sample size.

The depth of bedding in stalls for freestall and tiestall herds was unconditionally associated with multiple udder health outcomes. For freestall and tiestall herds, as the depth of bedding in stalls increased, udder health measures improved (lower avg. SCS, *P* = 0.10; BTSCC, *P* = 0.17; elevSCS, *P* = 0.01; and newSCS, *P* = 0.02). Similarly, comparing farms where cows were on deep bedding (i.e., grouping all herds reporting deeply-bedded stalls plus bedded pack herds) to herds that had stalls with a smaller amount of bedding on top of a mattress or concrete, farms with deep bedding had a numerically lower BTSCC (*P* = 0.17).

Udder hygiene measures were associated with several udder health outcomes. Higher mean hygiene scores and proportion of udders scored ≥3 were associated with higher chronSCS (*P* = 0.05 and 0.05, respectively), elevSCS (*P* = 0.09 and 0.13, respectively), and average SCS (*P =* 0.11 and 0.12, respectively; Table 4). A few specific management practices were also found to be unconditionally associated with udder health outcomes: consistent glove use was associated with lower newSCS (*P* = 0.11), clipping or flaming udders was associated with fewer chronSCS (*P* = 0.16), and both parenteral supplementation of a vit. E/selenium product and use of a non-antibiotic intramammary product at dry-off were associated with lower average SCS (*P* = 0.15 and *P* = 0.18, respectively; Table 4).

Both udder hygiene outcomes were unconditionally associated with the same predictors, most of which were related to the depth of bedding for cows. For herds using a bedded pack, deeper bedding was associated with lower average hygiene scores (*P* = 0.008) and lower proportion of dirty udders (*P* = 0.004; Table 4). Farms with cows housed on some type of deep bedding (i.e., grouping all herds reporting deeply-bedded stalls plus bedded pack herds) had numerically lower average hygiene scores (*P* = 0.06) and proportion of dirty udders (*P* = 0.06), compared to herds housing cows on stalls with bedding on a mattress or concrete surface (Table 4). For the fifteen farms reporting bedding depth in stalls, increased bedding depth was associated with lower mean udder hygiene score (*P* = 0.07) and a numerically lower proportion of dirty udders (*P* = 0.13; Table 4).

**Discussion**

The current work presents the results of our observational study exploring the relationship between facility type and udder health and hygiene metrics, BTM quality (SCC and microbiology), and milk production on small to midsize organic dairy farms in Vermont. The major objective was to identify whether these outcomes were associated with facility type, and whether bedded pack systems are a viable option for housing in Vermont during the non-grazing season when compared to the two most common indoor housing systems in the state (freestalls, tiestalls). As BTM bacteriology, udder health and hygiene metrics, and milk yield did not differ for BP herds compared to tiestall and freestall herds included in the current study, there was insufficient evidence to reject our hypothesis that these metrics would vary by facility type. We therefore feel that bedded pack systems can be considered a viable loose-housing option for organic dairy cattle during the non-grazing season in the Northeast.

**Objective 1: Comparison of bulk tank milk quality, udder health, milk production, and udder hygiene measures by facility type**

Previous work describing bulk tank milk aerobic culture data for farms using a bedded pack system has primarily been limited to descriptive studies enrolling only composting bedded pack herds (Barberg et al., 2007b, Shane et al., 2010), with only one study directly comparing bacterial counts between composting bedded packs and freestall barns (Lobeck et al., 2012). The current study is the first the authors are aware of directly comparing bacterial counts of bulk tank milk between bedded packs (both composting and static) and tiestall barns, and the first one to describe a population of exclusively organic dairies. The six farms included in Lobeck et al. (2012) used mainly wood sawdust as bedding material (with one using wheat straw by‐product) as did the 12 farms in Barberg et al. (2007). This is similar to the current study, where three of five bedded packs used a combination of woodchips/shavings and straw/hay, and two used exclusively sawdust/shavings. The six farms included in Shane et al. (2010) bedded with a variety of “alternative” organic materials, including straw by-products, soybean stubble, and oat hulls. In contrast to previous work, which evaluated milk culture results across the summer months (Barberg et al., 2007b) and year-round (Lobeck et al., 2012), the current study focused solely on sampling during the period when animals are primarily housed inside in Vermont. The authors were most interested in studying bulk tank milk bacteriology for these organic herds during the non-grazing season, as this is when these pastured-based farms need to house their animals inside. All herds included had excellent bulk tank milk quality; most (19/21) fell into the “low BTSCC” category as defined by Jayarao et al. 2004, with the remaining 2 in the “medium BTSCC” category.

The *Staph.* spp. count for the five bedded pack farms included in this study (53 cfu/mL, 95% CI: 10-96) was comparable to previous work describing bulk tank milk quality for CBP in Minnesota during the winter months. Lobeck et al. 2012 found a mean of 26.1 cfu/mL (95% CI: 2-443) and Shane et al. (2010) found a range of 0-108 cfu/mL for *Staph.* spp. from BTM collected just over the winter months from six composting bedded pack farms. “*Staph.* spp.” is comprised of a diverse group of different species, with 23 (Condas et al., 2017) or 25 (De Visscher et al., 2017) different species isolated from intramammary infections in dairy cattle. Within this highly heterogenous group, some species are considered primarily host-adapted (colonizing the skin or udder), while others are primarily found in the cow’s environment (reviewed in De Buck et al., 2021). Certain species have been associated with stall surfaces, air, and unused sawdust bedding material (Piessens et al., 2011), some with different facility types (Condas et al., 2017), and others with environmental contamination and poor teat hygiene at milking time (De Visscher et al., 2016, De Visscher et al., 2017). Although the specific source and routes of transmission for many *Staph.* spp. are still being elucidated, the importance of teat-dipping to control this group of bacteria is well-established (Hogan et al., 1987); in general, the use of pre- and post- milking teat dip decreases contamination of bulk tank milk both by commensal skin organisms and environmental contamination at milking time (Pankey et al., 1985, Pankey et al., 1987, Quirk et al., 2012). All but one farm in the current study would fall into the “low” category for *Staph.* spp. counts in the BTM (Jayarao et al., 2004), which is consistent with all 21 herds using both pre- and post-dip consistently at milking time. There was no difference in *Staph.* spp. count between the three facility types included in the current study.

Streptococci and strep-like organisms (SSLO) counts in BTM for bedded packs in the current study were much lower than those from Minnesota composting bedded packs in the winter. Shane et al. 2010 reported a range ofSSLOcounts of 98-48,400 cfu/mL for six farms, and Lobeck et al. 2012 reported a mean of 911 cfu/mL (95% CI: 138-6,011). The mean SSLO counts for bedded pack farms included in the current study was 39 cfu/mL (95% CI: 17-61). Work from Barberg et al. (2007) describing milk quality on composting bedded packs in Minnesota noted that 6 of 12 farms sampled had “high” levels of SSLO. SSLO count did not differ between tiestalls, freestalls, and bedded packs in the current study. The overall SSLO count for all 21 farms included in the current study (156 cfu/mL, 95% CI: 42-271) was much lower than that for the overall *Strep.* count for all three facility types studied in Lobeck et al. 2012 (445 cfu/mL, 95% CI: 116-1704). As the overall SSLO counts for all farm types included in the Minnesota studies are higher than that found for all 21 farms in the current study, better milking and bedding hygiene amongst herds included in the current study may best explain this difference in BTM pathogen profiles (Jayarao and Wolfgang, 2003).

All farms had low levels of coliforms in bulk tank milk (1.2 cfu/mL, 95% CI: 0.3-2.1), indicating excellent hygiene practices at milking time (Jayarao and Wolfgang, 2003). Coliform counts did not differ between the three facility types. Bedded pack farms in the current study had very low coliform counts in BTM (1 cfu/mL, 95% CI: 0-3), similar to those found for three compost bedded pack farms in a Brazilian study (2.8 cfu/mL; Fávero et al. 2015). These low coliform counts are in contrast with previous work describing BTM quality for this kind of facility in the United States. Coliform counts for bedded packs in Minnesota in the winter ranged from 15-1,128 cfu/mL (Shane et al., 2010), and the six bedded packs included in Lobeck et al. 2012. had a mean of 63.7 cfu/mL (95% CI: 6-735). However, direct comparison of coliform counts between studies may be potentially problematic due to variation in duration of freezer storage (Schukken et al., 1989). Although sampled during summer months, Barberg et al. 2007 found that 5 of 12 bedded packs sampled had “high” levels of coliforms in BTM, contributing to their conclusion that “special attention to cow preparation procedures at milking time are a must for achieving satisfactory milk quality when cows are housed in compost dairy barns.”

Prevalence of *Staph. aureus* was similar between the five VT bedded pack farms in the current study (9 cfu/mL, 95% CI: 0-21) and the six bedded packs described in Lobeck et al. 2012 (6.2 cfu/mL, 95% CI: 1.3-30.1). Farm-level prevalence of *Staph. aureus* was also fairly low for bedded packs studied in Shane et al. 2010 (3 of 6 farms BTM negative) and Barberg et al. 2007 (only 1 of 12 farms with a “high” level of *Staph. aureus*). Overall, the population of all 21 farms in the current study had a higher amount of *Staph. aureus* in BTM than the 18 Minnesota farms described in Shane et al. 2010 (43.6 cfu/mL, 95% CI 14-73; vs. 17.3 cfu/mL, 95% CI: 3.3-91.2). Although it is not clear how many herds included in previous work on bedded packs were certified organic, the higher prevalence of *Staph. aureus* amongst farms in the current study is consistent with work comparing organic and conventional dairy systems (Pol and Ruegg, 2007). There was no difference in *Staph. aureus* cfu count between bedded packs, tiestalls, and freestalls.

Analysis of a single bulk tank milk sample from a farm is a simple, convenient, and relatively inexpensive way to capture a snapshot of current milk quality and animal health on a farm, and can be a highly specific (albeit poorly sensitive) screening test for major contagious mastitis pathogens (*Staph. aureus* and *Strep. agalactiae;* Godkin and Leslie 1993). Our bulk tank sampling strategy (collecting a single sample) differed from previous work describing the bacteriology of milk from bedded pack farms, where four or five consecutive bulk tank milk pickups were collected and then pooled for analysis (Barberg et al., 2007b, Shane et al., 2010, Lobeck et al., 2012). We acknowledge that analysis of a single BTM sample in the current study comes with limitations. Bacterial groups traditionally considered to be primarily environmental in origin (non-*ag. Strep., Staph* spp*.,* coliforms), may enter BTM from cows with an intramammary infection, but also may originate from non-specific contamination (teat and udder skin, bedding, manure, or other environmental sources; Elmoslemany et al., 2009). Furthermore, a single bulk tank sample does not give insight into long-term, consistent patterns of a particular farm’s milk quality as is possible from repeated BTM samplings (Jayarao and Wolfgang, 2003). With the financial constraints of research on commercial dairy farms, the limitations inherent in performing analysis of a single bulk tank milk sample from each farm were a trade-off for the ability to get a picture of milk quality on a larger number of farms included in the study.

Udder health outcomes included in the current study (percent cows with elevSCS, percent cows with chronSCS, percent cows with newSCS, BTSCC, and average SCS) did not differ significantly between facility types. Although some previous work has found BTSCC to be elevated for CBP farms (425,000 cells/mL over all four seasons, Black et. al 2013; 325,000 cells/mL during summer, Barberg et. al 2007b), other groups have also found udder health and milk quality measures on bedded pack farms are similar to farms using more traditional facility types. Specifically, subclinical mastitis prevalence levels did not differ between compost bedded packs and two types of freestall housing in Minnesota and South Dakota, where the percent of cows in a herd with an SCC on test day ≥200,000 cells/mL was 33.4, 26.8, and 26.8% for compost bedded packs, cross-ventilated freestalls, and naturally-vented freestalls (Lobeck et al., 2011). Eckelkamp et. al 2016a found no significant difference in subclinical mastitis prevalence in CBP vs. sand-bedded freestalls in Kentucky with a history of low BTSCC (21.8 and 19.4%, respectively), as well as no difference in BTSCC between the two facility types (229,582 and 205,131 cells/mL, respectively). Subclinical mastitis prevalence was 27.7% for 12 CBP farms in Minnesota (Barberg et. al 2007b), which may be more representative of the general population of bedded pack farms in that state as there were no inclusion criteria around maintaining a low SCC previous to the start of the study. The prevalence of subclinical mastitis for herds in the current study is similar to previous work in the US (26% for bedded packs, 23.7% for freestall barns). In contrast, Fávero et. al (2015) found a much higher prevalence of subclinical mastitis (43.8%) and percent new infections (20.9%) for three bedded pack farms in Brazil than the current study (26 and 7% respectively, for the three bedded packs with available data).

STD 150-day milk production did not differ between facility type in the current study. This aligns with previous research which found no significant differences in various production metrics of cows housed on bedded packs vs. in freestall barns (Lobeck et al., 2011, Eckelkamp et al., 2016a, Costa et al., 2018). Varying production metrics for cows housed on bedded packs have been reported previously (kg/cow/day, fat-corrected milk/cow/day, average L/cow/day, ME-305, rolling herd average, energy-corrected milk), preventing direct comparisons of milk production between the bedded packs in the current study and other work. Additionally, many variables play a role in determining milk production (nutrition, breed, seasonality, DIM), so teasing out the effect of facility type alone on production in an observational study is difficult. However, as Leso et. al (2020) point out, the “results in the literature indicate that high levels of milk production are possible in CBP.” As bedded packs potentially improve cow comfort, one may even expect greater milk production than in more traditional housing systems (Calamari et al., 2009, Ruud et al., 2010).

There was no difference in the two udder hygiene measures between the three facility types included in the study. This finding is in accordance with previous work, which found that cow hygiene on bedded pack systems is comparable to traditional facility types in the Upper Midwestern U.S., Southeastern U.S., and Brazil (Barberg et al., 2007b, Shane et al., 2010, Lobeck et al., 2011, Black et al., 2013, Eckelkamp et al., 2016b, a, Costa et al., 2018, Adkins et al., 2022, Andrade et al., 2022). Black (2013) and Eckelkamp (2016a) reported that increased pack moisture allows wet bedding material and manure to adhere more easily to animals, meaning that cow hygiene is highly dependent on conditions of the bedded pack. This sentiment was echoed by the bedded pack producers in the current study, who shared that keeping their cows clean during periods of wet or humid weather could be a challenge. However, all bedded packs in the current study had an average udder hygiene score of less than 2.5, and the farm with the lowest mean average udder hygiene score overall was a bedded pack farm. Although Cook (2002) has pointed out the challenges of comparing dairy cattle hygiene between different facility types, we chose to focus on gathering observations of udder hygiene. The relationship between udder hygiene and health is well-studied, and was a tractable observation to make during non-grazing season farm visits where individual animals were often roaming freely in a pen, or confined in a tiestall barn.

**Objective 2: Analysis of farm management factors (non-facility) associated with bulk tank milk quality, udder health, milk production, and udder hygiene scores for all farms combined**

As results from the multivariable models exploring the relationship between facility type and outcomes of interest suffered from limited statistical power due to small sample sizes, the focus of the discussion will be on trends that emerged from the univariate analysis which combined all 21 farms.

One finding emerging from this work is that farms with deeper bedding had more favorable udder hygiene metrics (deeper bedding begets cleaner cows). When comparing farms that housed cows with a deep bedding system (deeply-bedded stalls or a bedded pack) to those that housed cows on stalls with a smaller amount of bedding (over a mattress or concrete surface), the deeply-bedded systems tended to have better hygiene scores. This agrees with previous observational field studies of freestall barns, including: Cook et al.. 2016 (prevalence of dirty udders was 13% lower for farms using deep bedding vs. stalls with mats), de Vries et al. 2015 (deep-bedding vs. mat/mattress reduced the likelihood of a cow having a dirty hindquarter by half), and Robles et al. 2020 (farms with mattress-based stalls had a higher prevalence of cows with dirty upper legs/flanks vs. those using a deep bedding system, often inorganic sand). In contrast, an experimental study looking at the effect of bedding depth in tiestalls over 28-day periods found no difference between leg, flank, and udder hygiene of cows using deeply-bedded stalls (14 cm) and the control treatment (2-3 cm; Wolfe et al., 2018).

Beyond comparing udder hygiene of cows housed on a deep-bedding system to cows that were not, there was a linear association between bedding depth (depth of bedded pack, depth of bedding in freestalls and tiestalls) and hygiene score. As the measured height of bedding got deeper (height of bedded pack, or amount of bedding material in stall), cows tended to have cleaner udders. To the best of our knowledge, work exploring this direct relationship between measured bedding depth and hygiene is limited to a single study by de Vries et al. 2015, who found no relationship between prevalence of dirty hindquarters and three different freestall bedding height groups (<0.56 cm, 0.56–1.75 cm, >1.75 cm). In our study, this relationship between bedding depth and udder hygiene was especially strong for bedded packs, despite the limited sample size of five herds. To the best of our knowledge, this specific association has not previously been explored for bedded pack herds. There is clearly opportunity for future research looking at this relationship between increased amount of bedding used in deep-bedded systems (or more deeply-bedded stalls) and the benefit of improved udder hygiene and milk quality.

Multiple measures of udder health in this study were associated with udder hygiene, in accordance with the well-supported tenet that better cow hygiene is associated with better milk quality (cleaner cows beget better milk). The association between hygiene and udder health has been well-documented, both at the cow level (for IMI presence: de Pinho et al. 2012; for SCS/SCC: Reneau et al. 2005, Dohmen et al. 2010, and Sant’anna et al. 2011; for both SCS and IMI: Schreiner and Ruegg, 2003) and at the herd-level (BTSCC: Barkema et al. 1998; new IMI rate: Cook et al. 2002; average herd SCC, incidence clinical mastitis, and % new high SCC: Dohmen et al. 2010). Of particular relevance to the current work, a study carried out on three bedded pack farms in Brazil found the odds of a new case of subclinical mastitis (SCC ≥200,000 cells/mL) and of a cow having subclinical mastitis on test day increased 32% and 16% for each one-unit increase in leg cleanliness score, respectively (Fávero et al., 2015). Curiously, although leg cleanliness score was associated with both mastitis outcomes on Brazilian bedded packs, udder hygiene score was not.

A third interesting finding to emerge from the univariate regression results is that farms using deeper bedding had better milk quality outcomes (deeper bedding begets better milk). Although there is an established recommendation of 15 cm for deep bedding of freestalls (Bickert, 2000; Cook, 2002), this depth appears to be based on optimizing cow comfort in deep-bedded freestalls with no reference to udder hygiene or health. There is very limited work exploring ideal bedding material depth for tiestall barns (Tucker and Weary, 2004, Tucker et al., 2009), and this is again solely focused on the important concern of cow comfort. As is the experience of the authors, and is stated elsewhere in a literature review by McPherson (2020), “…very little research has investigated the effect of bedding depth on cow cleanliness” or considerations around udder health outcomes. It is likely that the effect seen in the current work of deeper bedding and better udder health outcomes is mediated through the presumed casual pathway of (1) deeper bedding leading to improved hygiene, and (2) improved hygiene resulting in better udder health. Even still, the opportunity exists for research exploring optimal stall bedding depths of different organic materials in tiestall barns with a focus on mastitis and udder health outcomes. It may be that recommending a particular depth of bedding to use for different types of organic material would not prove feasible, as the ideal amount would vary with many factors particular to a producer’s barn and bedding source (type of stall surface, presence/type of stall mat used, type of organic material, particle size, compressibility, percent dry matter, etc.).

---------------- conclusion paragraphs---------------- (add strengths, limitations, future directions)

Recent previous work has exclusively focused on describing bedded packs that are actively managed for aerobic composting (Leso et al., 2020). Leso et al. contrasted composting bedded packs managed with daily cultivation with conventional bedded packs, such as straw yards, noting the reduced cow cleanliness and increased risk of mastitis associated with the latter. While bedded pack systems are not common for housing lactating cows in Vermont, both composting and static systems are used (Andrews et al., 2021). This infrequent use of bedded packs in our state created a challenge for enrolling ten herds using this kind of system in our observational study. Despite this limitation, by including bedded pack farms managed in a variety of ways, the current work sheds light on a broader spectrum of options used within this loose-housing system. Our current study shows that farms can achieve excellent milk quality using either a static or aerobically composting bedded pack system for indoor housing; e.g., three of the five bedded pack farms had a BTSCC ≤ 99,000 cells/mL, and the remaining two were ≤ 160,000 cells/mL. Furthermore, the lowest BTSCC in the study (54,000 cells/mL) was a bedded pack farm using woodchips and straw which was not actively managing the pack to compost. This low BTSCC was not just from selectively dumping milk from high-SCC cows; the same farm also had the lowest overall percent of cows with an elevated SCS on DHIA test day (8.6%; data not shown).

As udder health and udder hygiene metrics for bedded packs did not differ compared to tiestall and freestall herds included in the current study, we feel that bedded pack systems can be considered a viable loose-housing option for organic herds during the non-grazing season in the Northeast. These systems have a number of advantages for producers considering updating their facilities, including a smaller initial investment when compared to a new freestall or tiestall barn (Barberg et al., 2007a, Janni et al., 2007, Black et al., 2013), although the cost year-over-year for bedding is substantial (Shane et al., 2010). From the perspective of animal welfare, bedded packs provide a housing option that does not restrict animal movement, which is an issue of growing concern for both producers and the general public (Barkema et al., 2015). Additionally, bedded packs are designed for cow comfort (Barberg et al., 2007b, Bewley et al., 2012), and prevalence of lameness, foot, and leg injuries in these systems has been found to be less than tiestall and freestall barns (Barberg et al., 2007b, Lobeck et al., 2011, Burgstaller et al., 2016). The relationship between decreased milk production and lameness is well documented (Warnick et al., 2001, Green et al., 2002), leading to an additional incentive for producers to minimize lameness in their herd. Lastly, manure management and environmental stewardship is a top concern for both dairy producers and the general public (Holly et al., 2018). Anecdotally, the five bedded pack producers enrolled in the study were pleased with their systems of manure management, viewing their used bedding material and manure as a valuable soil amendment and an integral part of their nutrient management plan. Bedded pack systems decrease the amount of liquid manure waste when compared to conventional barns, and the used bedding with manure is more easily composted before use as a soil amendment. As composted bedded pack material is drier before it is spread on fields, it poses less of a risk for run-off into waterways, increases soil infiltration of nutrients, and creates flexibility around timing of manure application to fields (Rushmann). With no obvious disadvantages for udder health or hygiene when properly managed on farms with excellent milking hygiene practices already in place, bedded packs may be an especially good housing option for small, pasture-based farms in the Northeast both now and in the future.

**Conclusion**

The current study is to the authors’ knowledge the first direct comparison of milk quality and udder hygiene on bedded pack farms to both tiestall and freestall herds of similar size and management styles, for a population of entirely small to midsize organic dairy farms. It is also the first to describe udder health and hygiene on bedded packs in the Northeast US, which is significant as the performance of these systems can be greatly influenced by climatic factors. Bedded pack systems did not differ significantly in their milk quality, udder health, udder hygiene measures, or milk production, as compared to the more commonly used indoor housing systems (freestall or tiestall) for organic cows in Vermont. Bedded packs can therefore be considered as a viable option for pasture-based herds looking for a loose-housing system.

**Acknowledgements**

This project was funded by the USDA NIFA OREI project 2018-51300-28561. We would like to thank all the organic dairy producers who agreed to participate in this study, for giving us their time and allowing us to collect samples from their farms. We would also like to thank Jennifer Timmerman and the Laboratory for Udder Health at Veterinary Diagnostic Lab (University of Minnesota), as well as the laboratory staff at St. Alban’s Cooperative/Dairy Farmers of America, for their advice and analyses of bulk tank milk samples collected in the study.

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**Tables**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Table 1. Objective 1: Univariable bulk tank milk aerobic culture outcomes by facility type for 21 Vermont organic dairy herds [median (95%CI); *range*]. | | | | | |
| Bacteria group (cfu/mL) | Overall (n = 21) | Bedded packs (n = 5) | Tiestalls (n = 10) | Freestalls (n = 6) | *P-*value |
| *Staph.* spp. (cfu/mL) | 65 (36-155); *0-665* | 40 (10-96); *0-130* | 85 (14-255); *15-665* | 67.5 (28-104); *5-125* | 0.62 |
| *Strep.* and strep-like organisms (cfu/mL) | 45 (42-271); *10-1250* | 35 (17-61); *10-80* | 167.5 (30-481); *20-1250* | 32.5 (11-167); *25-260* | 0.10 |
| *Staph. aureus* (cfu/mL) | 30 (14-73); *0-320* | 0 (0-21); *0-30* | 47.5 (5-121); *0-320* | 42.5 (10-70); *0-100* | 0.19 |
| Coliforms (cfu/mL) | 0 (0.3-2.1); *0-5* | 0 (0-3); *0-5* | 0 (.003-3); *0-5* | (0-2.5); *0-5* | 0.82 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Table 2. Objective 1: Univariable udder health and production outcomes by facility type for 21 Vermont organic dairy herds. [mean (95%CI); *range*]. | | | | | | |
|  |  |  |  | | |  |
| Outcome | | Overall | Bedded packs | Tiestalls | Freestalls | *P-*value |
| Bulk tank milk somatic cell count (cells/mL) | |  |  |  |  |  |
|  | Count | 21 | 5 | 10 | 6 |  |
|  | Mean (95% CI); *Range* | 144,286 (121,218-167,353); *54,000-250,000* | 107,600 (70,275-144,925); *54,000-160,000* | 146,400 (114,136-178,664); *97,000-250,000* | 171,333 (126,965-215,702); *98,000-250,000* | 0.15 |
| Percent of cows with newly elevated SCS (%)1 | |  |  |  |  |  |
|  | Count | 19 | 3 | 10 | 6 |  |
|  | Mean (95% CI); *Range* | 5.7 (4.2-7.3); *0-12.3* | 7.0 (2.8-11.2); *2.9-12.3* | 5.4 (3.0-7.8); *0-10.5* | 5.6 (3.0-8.3); *0-9.8* | 0.81 |
| Percent of cows with chronically elevated SCS (%)1 | |  |  |  |  |  |
|  | Count | 19 | 3 | 10 | 6 |  |
|  | Mean (95% CI); *Range* | 13.6 (11.2-16.1); *2.9-23.1* | 14.5 (5.4-23.7); *2.9-23.1* | 14.3 (11.9-16.7); *7.8-20.8* | 12.0 (6.7-17.3); *5.7-23.1* | 0.74 |
| Percent of cows with SCS ≥ 4.0 cells/mL on current test date (%)1 | |  |  |  |  |  |
|  | Count | 19 | 3 | 10 | 6 |  |
|  | Mean (95% CI); *Range* | 24.9 (21.6-28.3); *8.6-36.9* | 26.0 (12.6-39.3); *8.6-36.9* | 25.4 (22.1-28.6); *17.6-32.8* | 23.7 (16.9-30.5); *11.6-36.5* | 0.90 |
| Avg. SCS of cows on farm2 | |  |  |  |  |  |
|  | Count | 20 | 4 | 10 | 6 |  |
|  | Mean (95% CI); *Range* | 2.44 (2.26-2.62); *1.7-3.3* | 2.38 (1.84-2.91); *1.7-3.1* | 2.45 (2.31-2.59); *2.2-2.8* | 2.50 (2.00-2.93); *1.9-3.3* | 0.97 |
| Standardized 150-day milk (pounds)3 | |  |  |  |  |  |
|  | Count | 18 | 4 | 8 | 6 |  |
|  | Mean (95% CI); *Range* | 50.0 (45.7-54.3); *33.5-68.0* | 46.9 (39.8-53.9); *38.5-56.3* | 49.4 (43.1-55.7); *33.5-68.0* | 53.0 (43.5-62.5); *38.7-67.7* | 0.65 |
| 1 DHIA data not available for 2 bedded pack farms | | | | | |  |
| 2 DHIA data not available for 1 bedded pack farm | | | | | |  |
| 3 DHIA data not available for 1 bedded pack farms and 2 tiestall farms | | | | | |  |

|  |  |  |  |
| --- | --- | --- | --- |
| Table 3. Predictors, level of predictor, and group size offered to multivariable models for each of the eight different outcomes of interest along with facility type. | | | |
| Outcome | Predictor | Level of parameter | Group size |
| Bulk tank milk somatic cell count (cells/mL) | |  | 21 |
|  | Predominant breed | Holstein | 8 |
|  |  | Jersey/Other | 13 |
|  | Herd size |  | 21 |
| Percent of cows with newly elevated SCS (%) | |  | 19 |
|  | Herd size category | 30-55 lactating cows | 5 |
|  |  | 56-69 lactating cows | 6 |
|  |  | 70-100 lactating cows | 8 |
|  | Use of bedding amendment | Yes | 5 |
|  |  | No | 14 |
|  | Subjective assessment of air quality by researcher | Fair | 5 |
|  |  | Good | 14 |
|  | Glove use at milking time1 | Always | 9 |
|  |  | Never/Inconsistently | 9 |
|  | Clinical mastitis record keeping practices | Always kept records of clinical mastitis events | 7 |
|  |  | Never kept record of clinical mastitis events | 6 |
|  |  | Sometimes kept record/Temporarily kept record of clinical mastitis events | 6 |
| Percent of cows with chronically-elevated SCS (%) | |  | 19 |
|  | Feeding additional supplemental selenium2 | Yes | 11 |
|  |  | No | 7 |
|  | Use of bedding amendment | Yes | 5 |
|  |  | No | 14 |
|  | Clip udder hair | Yes | 5 |
|  |  | No | 14 |
|  | Proportion of dirty udders |  | 19 |
| Percent of cows with SCS ≥ 4.0 cells/mL on current test date (%) | |  | 19 |
|  | Use of bedding amendment | Yes | 5 |
|  |  | No | 14 |
|  | Mean hygiene |  | 19 |
| Avg. SCS of cows on farm | |  | 20 |
|  | Feeding additional supplemental selenium1 | Yes | 11 |
|  |  | No | 8 |
|  | Use of bedding amendment | Yes | 5 |
|  |  | No | 15 |
|  | Use of injectable selenium and vitamin E product | Never | 11 |
|  |  | Regularly/Occasionally | 9 |
|  | Mean hygiene |  | 20 |
| Standardized 150-day milk (pounds) | |  | 18 |
|  | Use of injectable selenium and vitamin E product | Never | 11 |
|  |  | Regularly/Occasionally | 7 |
|  | Culture high SCC cows | Always/Sometimes | 8 |
|  |  | Never | 10 |
|  | Herd size category | 30-55 lactating cows | 5 |
|  |  | 56-69 lactating cows | 5 |
|  |  | 70-100 lactating cows | 8 |
| Proportion of cows with udder hygiene scores ≥3 | |  | 21 |
|  | Subjective assessment of air quality by researcher | Fair | 5 |
|  |  | Good | 16 |
| Average hygiene score | |  | 21 |
|  | Culture milk samples ever | Sometimes/Regularly | 14 |
|  |  | Never | 7 |
|  | Producer generally follows recommended practices for mastitis control | Yes | 8 |
|  |  | No | 13 |
| 1 One farm used automatic milking system | | | |
| 2 One farm unable to provide response | | | |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Table 4. Objective 2. Selected models of univariate analysis identifying factors unconditionally associated with milk quality, udder health and udder hygiene outcomes at *P* <0.20 for 21 Vermont organic dairy herds | | | | |
| Outcome Parameter Explanatory Variable | | Group (sample size) | Coefficient estimate (SE) | *P-*value |
| Bulk tank milk somatic cell count (cells/mL) | |  |  |  |
| Model 1 | Lying surface | Mattress or concrete (n = 13) | 36,000 (23,454) | 0.14 |
|  |  | Deep bedding (n = 8) | Ref. | Ref. |
| Model 2 | Depth of bedding in stalls (cm)1 | Tiestalls and freestalls (n = 15) | -5,797 (3,970) | 0.17 |
| Percent cows with newly elevated SCS (%)2 | |  |  |  |
| Model 3 | Glove use | Inconsistent glove (n = 9) | 2.83% (1.7) | 0.11 |
|  |  | All milkers consistently use gloves (n = 9) | Ref. | Ref. |
|  | Depth of bedding in stalls (cm)1 | Tiestalls and freestalls (n = 15) | -0.62% (0.24) | 0.02 |
| Percent cows with chronically elevated SCS (%)2 | |  |  |  |
|  | Herds that clip or flame udders one or more times per lactation | Yes (n = 5) | -4.31% (2.9) | 0.16 |
|  |  | No (n = 14) | Ref. | Ref. |
|  | Proportion of cows with udder hygiene scores ≥3 | All herds with available test data (n = 19) | 12.7% (6) | 0.05 |
|  | Average hygiene score | All herds with available test data (n = 19) | 6.39% (3.1) | 0.05 |
| Percent cows with SCS ≥ 4.0 on current test date (%)2 | |  |  |  |
|  | Depth of bedding in stalls (cm)1 | Tiestalls and freestalls (n = 15) | -1.2% (0.42) | 0.01 |
|  | Proportion of cows with udder hygiene scores ≥3 | All herds with available test data (n = 19) | 13.6% (8.5) | 0.13 |
|  | Average hygiene score | All herds with available test data (n = 19) | 7.7% (4.3) | 0.09 |
| Average SCS of cows on farm3 | |  |  |  |
|  | Herds that regularly do parenteral supplementation of dry cows with vit. E and selenium | Regular or occasional supplementation (n = 9) | -0.27 (0.18) | 0.15 |
|  |  | No parenteral supplementation (n = 11) | Ref. | Ref. |
|  | Herds that use any sort of approved organic intramammary product at dry-off | Yes (n = 5) | -0.29 (0.21) | 0.18 |
|  |  | No (n = 15) | Ref. | Ref. |
|  | Depth of bedding in stalls (cm)1 | Tiestalls and freestalls (n = 15) | -0.05 (0.03) | 0.1 |
|  | Proportion of cows with udder hygiene scores ≥3 | All herds with available test data (n = 20) | 0.75 (0.45) | 0.12 |
|  | Average hygiene score | All herds with available test data (n = 20) | 0.39 (0.23) | 0.11 |
| Proportion of cows with udder hygiene scores ≥3 | |  |  |  |
|  | Depth of bedded pack (m) | Bedded pack herds (n = 5) | -0.5 (0.06) | 0.004 |
|  | Lying surface | Mattress or concrete (n = 13) | 0.17 (0.08) | 0.06 |
|  |  | Deep bedding (n = 8) | Ref. | Ref. |
|  | Depth of bedding in stalls (cm)1 | Tiestalls and freestalls (n = 15) | -0.02 (0.02) | 0.13 |
| Average hygiene score | |  |  |  |
|  | Depth of bedded pack (m) | Bedded pack herds (n = 5) | -0.96 (0.15) | 0.008 |
|  | Lying surface | Mattress or concrete (n = 13) | 0.33 (0.16) | 0.06 |
|  |  | Deep bedding (n = 8) | Ref. | Ref. |
|  | Depth of bedding in stalls (cm)1 | Tiestalls and freestalls (n = 15) | -0.06 (0.03) | 0.07 |
| 1 Stall bedding depth for freestalls and tiestalls bedded with wood shavings or sawdust | | | | |
| 2 DHIA data available for n = 19 herds. One herd included in average linear score analyses is seasonal and had no recent test data. | | | | |
| 3 DHIA data available for n = 20 herds. | | | | |

Example table format for Tables 1 and 2 – can landscape if you like  
Table reports mean log10 cfu/mL (95% CI)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Pathogen group | Bedded Pack | Tie stall | Free stall | P value |
| Count | 5 | 10 | 6 | 21 |
| Staph. spp. | Mean log value (95% CI) | Mean log value (95% CI) | Mean log value (95% CI) | X |
| Strep SLO spp. | Mean log value (95% CI) | Mean log value (95% CI) | Mean log value (95% CI) | X |
| Staph. aureus | Mean log value (95% CI) | Mean log value (95% CI) | Mean log value (95% CI) | X |
| coliforms | Mean log value (95% CI) | Mean log value (95% CI) | Mean log value (95% CI) | X |