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# Increased Photoperiod and Temperature-Humidity Index during the Dry Period increased Colostrum Volume and decreased Brix Score in Holstein and Jersey Cattle

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## Abstract

Milk production is unfavorably affected by heat stress which is associated with seasonality. Therefore, it is possible that colostrogenesis is also impacted by photoperiod and temperature-humidity index (THI). This study evaluated the effects of photoperiod and THI during the dry period on colostrum production in Holstein and Jersey cows. We hypothesized that photoperiod during the dry period differentially affects Holstein and Jersey colostrum production independent of THI conditions. Jersey (n = 89) and Holstein (n = 137) cows were enrolled at calving. Calf birth weight, colostrum volume and Brix score were recorded. For Jersey cows, colostrum was assayed for fat, protein, lactose, solids-not-fat (SNF) and somatic cell score (SCS) via infrared spectroscopy. Daily photoperiod (PHOTO) exposure and maximum THI (mTHI) were collected from weather stations within 5 km of each farm and averaged for the far-off and close-up period. Cows were into thirds based on close-up PHOTO exposure. PHOTO 1 (< 708 mins) cows produced less colostrum than PHOTO 2 (709–824 mins) or PHOTO 3 (> 825 mins) cows, however, Brix score, colostral components and calf birth weight did not differ by PHOTO interval. Age at calving, percentage of days where mTHI > 68, and dry period length all impacted colostrum volume and components. Overall, PHOTO exposure impacted colostrum volume and Brix percentage, however, colostrum components were not impacted in Jersey cows. PHOTO and THI during the close-up period had a greater impact on colostrogenesis than during the far-off period, indicating sensitivity to environmental conditions may change throughout the dry period.

## INRODUCTION

Colostrum production in dairy cattle is influenced by several management and physiological factors, such as age of dam, diet, breed, dry period length, vaccination status and overall health (McGrath et al., 2016). These factors can affect both colostrum volume and colostrum quality (i.e., immunoglobulin, protein and fat content) (Morin et al., 2021; Conneely et al., 2013; Wells et al., 1996). Immunoglobulin G (IgG) concentration of 50 g/L has widely been accepted as the minimum industry standard for adequate quality colostrum (Geiger, 2020). Despite close management of factors known to affect colostrum, producers still note differences among cows for colostral volume ranging from 2.8 to 26.5 L as well as for immunoglobulin content, ranging from 13 to 256 g/L of IgG (Morin et al., 2001; Conneely et al., 2013). Approximately 30% of cows produce inadequate quality colostrum with less than 50 g/L, which accounts for 8 to 25% of calf deaths each year (Morrill et al., 2012; Raboisson et al., 2016). Therefore, identification of additional factors contributing to colostrum production in dairy cattle is critical to improve calf survival and health.

Environmental factors such as ambient photoperiod, temperature, and humidity may account for differences in colostrum production (Gavin et al., 2018; Cabral et al., 2016). In controlled temperature and humidity studies, eight hours of daylight during the dry period resulted in an increase of 4.6 kg per day for up to 16 wks in Holstein cows compared to cows exposed to longer daylengths (Auchtung et al., 2005; Miller et al., 1999; Miller et al., 2000; Lacasse et al., 2014; Crawford et al., 2015). Additionally, multiparous Jersey cows calving in the summer and exposed to temperature-humidity index (THI) values > 80, produced 5.3 kg more colostrum compared to those calving in the winter (Gavin et al., 2018). Moderate and positive correlations between colostrum volume with photoperiod (r = 0.48 to 0.91) and THI (r = 0.60 to 0.79 ± 0.14) during winter months further support previous evidence of the impact of environmental conditions on colostrum production in dairy cows (Gavin et al., 2018). Despite colostrum volume being positively correlated with temperature during the close-up period, IgG was antagonistic with elevated temperature (Cabral et al., 2016). However, Morin et al. (2001) found no differences in colostrum volume or Ig content in Holstein cows after shortened or lengthened photoperiod exposure when temperature and humidity was controlled. Collectively, previous research has demonstrated a strong positive correlation between photoperiod and THI. Therefore, to determine the impact of photoperiod on colostrum and milk production, it is critical to account for the interaction of THI with cow performance.

To date, there is little information on the concordant effects of altered photoperiod and ambient THI during the dry period on colostrum production. Nor is it known what management factors during the dry period impact colostrogenesis in dairy cattle breeds. Additionally, very few studies have evaluated the environmental impact of photoperiod and THI on dairy breed. Therefore, the objective of this research was to determine the impact of photoperiod, ambient temperature and humidity exposure during the various stages of the dry period on subsequent colostrum quantity and quality in Holstein and Jersey cows. We hypothesized that photoperiod during the dry period differentially affects Holstein and Jersey colostrum production post-calving depending on THI conditions, with increased daylength increasing colostrum production under moderate THI conditions to a greater degree in Jersey than Holstein cattle.

## MATERIALS AND METHODS

**Animal Management** - All animal procedures were approved by the Virginia Polytechnic Institute and State University Animal Care and Use Committee (#17–249 and #18–071). Holstein (n = 137; 4.0 ± 0.1 y of age at calving) and Jersey (n = 89; 4.0 ± 0.1 y of age at calving) cows were enrolled from two commercial farms in Virginia from February 2018 through June 2019. Both farms had similar dry off procedures and housed dry cows on pasture. The dry period began the day that cows were treated with dry cow treatment and daily milking was stopped and ended on the day that the cow calved. The far-off dry period began the day of dry-off and ended at 22 days prior to estimated due date for calving. The close-up dry period began 21 days prior to expected due date and ended the day of calving. Diet and management differed between the far-off and close-up period based on physiological differences in nutrient requirements and industry recommendations. Both farms exposed cows to ambient photoperiod for the entire dry period. The average dry period length for Farm 1 was 55 ± 1 d and 57 ± 0 d for Farm 2. Both farms fed separate diets for far-off and close-up cows formulated to meet NRC requirements (Nutrient Requirements of Dairy Cattle, 2021), with cows switching to the close-up ration approximately 21 days before

expected calving date. The far-off period ration was comprised of corn silage and free-choice grass hay and pasture. The close-up period ration consisted of corn-silage and pelleted feed.

**Experiment 1 -** The specific objectives of experiment 1 were to 1) determine the relationship of photoperiod exposure and temperature-humidity index (THI) with colostrum volume and Brix score and 2) determine the impact of breed on the relationship of photoperiod and THI with colostrum production. After parturition, calves were immediately separated from the dam prior to suckling and weights were recorded. Within one h of calving, colostrum was collected into an individual bucket milker and weighed. A calibrated Brix Refractometer (Vee Gee Scientific, Vernon Hills) was used to determine Brix score. Variables recorded for cows included age of dam, dry off date, length of far off and close up period, calving difficulty and calving date. Birth weight and sex were recorded for calves. Additional data were collected from each farm's animal recording system (PC DART; Dairy Records Management Systems, Raleigh, NC) and the Council on Dairy Cattle Breeding that included inbreeding coefficient (F) and predicted transmitting abilities for test day milk, fat and protein percentage.

Environmental measures were collected for each day that a cow was dry from a local weather station located less than 5 km from each farm (Virtual Weather Crossing). These measures included: sunrise, sunset, temperature and humidity. Sunrise and sunset data were used to determine total daily light exposure in minutes. Daily average humidity and maximum daily average temperature were used to calculate average daily THI using the formula (NRC, 1971):

$$THI = (1.8 \times [MAT] + 32) - [(0.55 - 0.0055 \times RH) \times (1.8 \times [MAT] - 26)]$$

where, MAT is the daily maximum ambient temperature and RH is the daily average relative humidity. Average daily photoperiod (PHOTO) and maximum THI (mTHI) exposure for the entire dry period, the far-off (FO) period (d -70 to -22 before calving) and the close-up (CU) dry period (d -21 to d 0 of calving) were calculated for analyses. The percentage of days during the entire dry period, the FO dry period and the CU dry period that cows were exposed to mTHI greater than 68 was determined.

**Experiment 2 –** The objective of experiment 2 was to determine the relationship of PHOTO and THI on colostrum components in Jersey cows. In addition to collecting cow, calf and weather data described in experiment 1, colostrum samples were also collected from Jersey cows into 50 mL conical centrifuge tubes containing a preservative, put on ice, and shipped to DHIA (Radford, VA) for component analyses (i.e., fat percentage, protein percentage, lactose percentage solids-not-fat (SNF) percentage, somatic cell score (SCS)) via infrared spectroscopy.

**Statistical Analysis** – Dry off dates and calving dates were used to determine dry period length. Only data from animals having a dry period length of 45 to 70 days were included in the study (removing n = 75 animals). Jersey cows from Farm 1 (n = 43), Holstein cows from Farm 2 (n = 137) and Jersey cows from Farm 2 (n = 46) were used. After all data collection, cows were subdivided into three class intervals based on CU average daylength into approximate thirds to allow for even distribution of animal numbers by breed among groups. The three class intervals were: Holstein (n = 54) and Jersey (n = 22) cows exposed to < 708 mins of daylength (PHOTO 1), Holstein (n = 43) and Jersey (n = 31) exposed to 709 to 824 mins of daylength (PHOTO 2) and Holstein (n = 40) and Jersey (n = 36) exposed to > 825 mins of daylength (PHOTO 3) during the CU period. All statistical analyses were completed with SAS 9.4 (SAS; Cary, NC) with animal as the experimental unit. The MEANS procedure was used to determine summary statistics and PROC UNIVARIATE was used to identify any outliers prior to analysis. Transformations were applied to outcome variables as needed to achieve residual normality using the Box Cox procedure in SAS.

A backwards stepwise elimination was used within the GLM procedure to determine the effect of average daily daylength, maximum temperature and humidity index (mTHI) exposure and percent of days mTHI > 68 on colostrum volume, Brix score and colostrum components for both the CU and FO periods. Fixed effects were farm, breed, dam age at calving (yr), inbreeding percentage, PTA for protein production (kg) and dry period length (d). The CORR procedure was also used to determine Pearson correlations among variables.

The MIXED procedure was used to determine the effect of breed and PHOTO interval with colostrum volume, Brix score, fat percentage, protein percentage, SNF percentage, lactose percentage, SCS and calf birth weight. Random effects included animal, farm, dam age at calving (yr), inbreeding percentage, protein (kg) PTA and CU mTHI. Values are reported as the means and standard errors. Significance was determined at $P < 0.05$ and tendencies at $P < 0.10$. Post-hoc power analyses were performed using the POWER procedure to determine if there was sufficient power for sample size.

## RESULTS

**Descriptive Statistics** – Descriptive statistics for each breed are displayed in Table 1. Holstein and Jersey cows both averaged 4.0 ± 0.1 y of age at calving and averaged 57 ± 1 and 56 ± 1 for length of days dry, respectively. Colostrum volume averaged 3.2 kg more and Brix score averaged 2% more for Holsteins compared to Jersey cows.

Table 1
Descriptive statistics by breed.

| Item | Jersey (n = 89) | | | Holstein (n = 137) | | |
|---|---|---|---|---|---|---|
| | Mean ± SE | Min | Max | Mean ± SE | Min | Max |
| Age at Calving (yr) | 4.0 ± 0.1 | 2.6 | 9.1 | 4.0 ± 0.1 | 2.0 | 9.0 |
| Dry Period Length (d) | 56 ± 1 | 45 | 70 | 57 ± 1 | 45 | 70 |
| Colostrum (kg)[1] | 5.5 ± 0.4 | 0.7 | 14.5 | 8.7 ± 0.4 | 0.9 | 20.9 |
| Brix (%)[2] | 23 ± 0 | 11 | 31 | 25 ± 0 | 10 | 32 |
| Calf Wt. (kg)[3] | 28.3 ± 1.3 | 23.1 | 46.3 | 41.3 ± 0.6 | 29.9 | 49.0 |
| Total Photo (min)[4] | 773 ± 10 | 585 | 876 | 735 ± 8 | 582 | 877 |
| Total mTHI[5] | 57 ± 1 | 47 | 67 | 57 ± 1 | 48 | 68 |
| % Total days mTHI > 68[6] | 7.3 ± 1.3 | 0 | 44.1 | 7.8 ± 1.3 | 0 | 47.8 |
| Descriptive statistics were determined using the MEANS procedure of SAS 9.4 (SAS Institute, Inc., Cary, NC) | | | | | | |
| [1]Colostrum volume determined at first milking post-calving (within one h of calving). | | | | | | |
| [2]Brix score was determined with an optical Brix refractometer at the first milking post-calving (within one h of calving). | | | | | | |
| [3]Calf birth weight was determined with a scale by farm staff. | | | | | | |
| [4]Total Photo in minutes corresponds to the average daily photoperiod exposure in minutes that cows were exposed to during the entire dry period. Calculated from sunrise and sunset data recovered from a local weather station. | | | | | | |
| [5]Total mTHI corresponds to the average daily maximum THI (mTHI) that cows were exposed to during the entire dry period. Calculated from maximum temperature and relative humidity data recovered from a local weather station. | | | | | | |
| [6]% Total days mTHI > 68 corresponds to the percentage of days that cows were exposed to a mTHI greater than 68 during the entire dry period. Calculated from maximum temperature and relative humidity data recovered from a local weather station. | | | | | | |

**Photoperiod –** For every one unit increase in CU daylength exposure and additional day dry, colostrum volume was expected to increase ($p < 0.001$, $p = 0.003$ respectively; Online Resource 1). Additionally, there was a weak but positive correlation between colostrum volume and CU PHOTO ($r_p = 0.18$; $p = 0.009$; Table 2). Whereas a one unit increase in average daily photoperiod exposure during the FO period was expected to decrease ($p = 0.076$) colostrum volume and increased dam age tended to decrease ($p = 0.076$) colostrum volume (Online Resource 1). Despite significance in regression modeling, coefficient values were negligible for colostrum volume.

Table 2
Correlation for colostrum parameters and environmental factors with Pearson correlation coefficient value and significance indicated: † $p \leq 0.10$; * $p \leq 0.05$; ** $p \leq 0.01$.

| Variable | Volume[1] | Brix Score[2] | Fat[3] | TP[3] | SNF[3] | Lactose[3] | SCS[3] | FO PHOTO[4] | CU PHOTO[4] | FO mTHI[5] | CU mTHI[5] | % FO Days of THI[6] | % CU Days of THI[6] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Volume** | | -0.12[7] | 0.33** | -0.23 | -0.08 | 0.36** | -0.01 | 0.07 | 0.18** | 0.06 | 0.22** | -0.03 | 0.08 |
| **Brix Score** | | | 0.00 | 0.91** | 0.94** | -0.24 | -0.12 | -0.17** | -0.22** | -0.19** | -0.18** | -0.07 | -0.18** |
| **Fat** | | | | -0.07 | -0.02 | 0.26† | 0.06 | 0.143 | 0.19 | 0.02 | 0.14 | 0.16 | 0.00 |
| **TP** | | | | | 0.98** | -0.47** | 0.00 | 0.09 | -0.04 | -0.02 | -0.08 | -0.05 | -0.26† |
| **SNF** | | | | | | -0.31* | -0.03 | 0.05 | -0.06 | -0.03 | -0.07 | -0.05 | -0.22 |
| **Lactose** | | | | | | | -0.19** | -0.24† | -0.06 | -0.02 | 0.11 | 0.04 | 0.29* |
| **SCS** | | | | | | | | 0.26† | 0.21 | 0.10 | -0.03 | 0.07 | -0.10 |
| **FO PHOTO** | | | | | | | | | 0.87** | 0.85** | 0.71** | 0.56** | 0.40** |
| **CU PHOTO** | | | | | | | | | | 0.71** | 0.80** | 0.57** | 0.51** |
| **FO mTHI** | | | | | | | | | | | 0.73** | 0.69** | 0.54** |
| **CU mTHI** | | | | | | | | | | | | 0.51** | 0.65** |
| **% FO Days of THI** | | | | | | | | | | | | | 0.61** |
| **% CU Days of THI** | | | | | | | | | | | | | |

Correlations and associated *P*-values were determined using the CORR procedure in SAS 9.4 (SAS Institute, INC., Cary, NC)

[1]Colostrum volume determined at first milking post-calving (within one h of calving).

[2]Brix score was determined with an optical Brix refractometer at the first milking post-calving (within one h of calving).

[3]Fat (%), protein (%), SNF (%), lactose (%) and SCS were determined by DHIA laboratory via infrared spectroscopy. Composite colostrum samples were collected at the first milking post-calving (within one h of calving) into collection tubes with additive. Samples were frozen within 6 h before being shipped on ice to DHIA.

[4]FO and CU PHOTO corresponds to the average daily photoperiod exposure in minutes that cows were exposed to during the far-off (FO), close-up (CU) dry period. Calculated from sunrise and sunset data recovered from a local weather station.

[5]FO and CU mTHI corresponds to the average daily maximum THI (mTHI) that cows were exposed to during the far-off (FO), close-up (CU) dry period. Calculated from maximum temperature and relative humidity data recovered from a local weather station.

[6]FO and CU % days of THI corresponds to the percentage of days that cows were exposed to a mTHI greater than 68 during the far-off (FO), close-up (CU) dry period. Calculated from maximum temperature and relative humidity data recovered from a local weather station.

[7]Value depicts Pearson correlation coefficient

Holstein cows were predicted to produce more colostrum and have heavier calves compared to Jersey cows ($p < 0.001$; Online Resource 1, Online Resource 2). By photoperiod interval, PHOTO 1 cows produced less ($p \leq 0.05$; Fig. 1) colostrum compared to PHOTO 2 and PHOTO 3 cows within breed. Volume differed by breed × photoperiod interval ($p < 0.001$), with Holstein cows producing more colostrum than Jersey cows for each photoperiod interval ($p < 0.001$; Fig. 1). Calf birthweight differed ($p < 0.001$) by breed × photoperiod interval. Holstein calves were heavier ($p < 0.001$; PHOTO 1 = 41.9 ± 0.9 kg, PHOTO 2 = 40.8 ± 1.0 kg, PHOTO 3 = 40.0 ± 2.2 kg) than Jersey calves (PHOTO 1 = 27.3 ± 1.3, PHOTO 2 = 30.6 ± 3.2, PHOTO 3 = 26.5 ± 0.8) for each photoperiod interval.

Brix Score differed by farm × PHOTO ($p = 0.021$). Specifically, farm 1 cows in PHOTO 3 had the least Brix score (21.0 ± 0.6%) compared to PHOTO 1 ($p = 0.009$; 25.3 + 0.5%) and 2 ($p = 0.047$; 24.7 ± 0.5%) cows at farm 2. However, within farm, Brix score did not differ ($p > 0.10$) by PHOTO. There was no predicted relationship between Brix score and photoperiod, but for every one unit increase in age of dam (yr), Brix score was predicted to increase ($p < 0.001$) by 6%. Additionally, farm 1 was predicted to have a decrease ($p < 0.001$) in Brix score by 12% for cows compared to farm 2 (Online Resource 3).

Despite no predicted relationship, Brix score was weakly and negatively correlated with FO PHOTO ($r_p$ = -0.17; $p$ = 0.010), CU PHOTO ($r_p$ = -0.22; $p$ = 0.002) and overall PHOTO ($r_p$ = -0.21; $p$ < 0.001)

Colostral protein did not differ ($p$ = 0.709) by PHOTO interval (Table 3) but tended to increase ($p$ = 0.058) by 1.80% for each additional day dry and increase ($p$ = 0.038) by 0.49% for each minute increase in average photoperiod exposure during the far-off dry period. There appeared to be a quadratic effect of colostral lactose with PHOTO interval ($p$ = 0.007). Specifically, PHOTO 2 lactose decreased by 0.40% and 0.31% compared to PHOTO 1 ($p$ = 0.042) and PHOTO 3 ($p$ = 0.008), respectively. For every yearly increase in dam age, lactose percentage was predicted to decrease ($p$ < 0.001) by 0.52% during the FO period. This was also reflected by a tendency for a weak but negative correlation ($r_p$ = -0.24; $p$ = 0.078) between lactose percentage and FO PHOTO. Additionally, lactose was predicted to increase ($p$ < 0.001) by 0.51% for each minute increase in average daylength exposure during the CU period (Online Resource 4). Colostral SCS did not differ ($p$ = 0.317) by PHOTO interval (Table 3) but was predicted to increases ($p$ < 0.001) by 1.69 for cows calving at farm 1 compared to farm 2 and tended to increase ($p$ = 0.07) by 0.31 for each year increase in dam age (Online Resource 5). SCS tended to be weakly, but positively correlated with both FO PHOTO ($r_p$ = 0.26; $p$ = 0.060) and overall PHOTO ($r_p$ = 0.24; $p$ = 0.075).

Table 3
Average, standard error and $p$-values by photoperiod interval for colostrum variables. Different superscripts indicate significant differences ($p$ < 0.05).

| | **Photoperiod Interval** | | | ***p*-value** |
|---|---|---|---|---|
| | **PHOTO 1** | **PHOTO 2** | **PHOTO 3** | **PHOTO** |
| | **(< 708 min)** | **(709–824 min)** | **(> 825 min)** | |
| Colostral Fat[1] (%) | 2.90 ± 0.39[a] | 4.07 ± 0.38[a] | 3.53 ± 0.28[a] | 0.159 |
| Colsotral Protein[1] (%) | 13.68 ± 0.49[a] | 14.89 ± 0.93[a] | 13.81 ± 0.56[a] | 0.709 |
| Colostral Solids-not-fat[1] (%) | 17.53 ± 0.56[a] | 18.34 ± 0.87[a] | 17.58 ± 0.51[a] | 0.787 |
| Colostral Lactose[1] (%) | 2.99 ± 0.16[a] | 2.59 ± 0.11[b] | 2.91 ± 0.07[a] | 0.007 |
| Colostral SCS[2] | 4.17 ± 0.55[a] | 5.29 ± 0.46[a] | 5.49 ± 0.30[a] | 0.317 |

[1]Colostral fat, protein, solids-not-fat and lactose percentage were determined from a colostrum sample collected within one h of calving and refrigerated within 30 min of collection. Samples were then frozen and shipped to Dairy Herd Information Association (DHIA) for infrared spectroscopy laboratory testing.

[2]Colostral SCS was determined from a colostrum sample collected within one h of calving and refrigerated within 30 min of collection. Samples were then tested for SCC using a Cell Counter (DeLaval, Tumba, Sweden). Data were transformed from SCC to SCS using the formula: SCS = $\log_2$(SCC/100,000) + 3

**THI –** There was a strong and positive correlation between overall photoperiod and mTHI ($r_p$ = 0.85; $p$ < 0.001). As the percentage of days in the CU period with mThI > 68 increased, colostrum volume was also predicted to increases ($p$ < 0.007). This was further supported by Pearson correlations with weak to moderate positive relationships between colostrum volume with CU mTHI ($r_p$ = 0.22; $p$ = 0.001) and overall mTHI ($r_p$ = 0.14; $p$ = 0.050). Conversely, Brix score was weakly and negatively correlated with FO mTHI ($r_p$ = -0.19; $p$ = 0.004), CU mTHI ($r_p$ = -0.18; $p$ = 0.007), % CU days of mTHI > 68 ($r_p$ = -0.18; $p$ = 0.007) and overall % days of mTHI > 68 ($r_p$ = -0.13; $p$ = 0.055).

Protein was predicted to decrease ($p$ = 0.014) by 2.86 for each percentage increase in the number of days of mTHI > 68 during the close-up period (Online Resource 6). This was supported by a weak and negative correlation ($r_p$ = -0.26; $p$ = 0.059) with % CU days of mTHI > 68. Like colostral protein percentage, colostral SNF percentage was predicted to decrease ($p$ = 0.058) by 2.49% for each percentage increase in the number of days of mTHI > 68 during the close-up period (Online Resource 7). Finally, colostral lactose percentage was weakly and positively correlated ($r_p$ = 0.29; $p$ = 0.030) with % CU days of mTHI > 68.

## DISCUSSION

This study tracks ambient photoperiod and THI exposure in dry Holstein and Jersey cows to determine the effect on subsequent colostrum production post-calving. Average colostrum volume in this study for Holstein (8.7 kg) and Jersey (5.5 kg) cows are slightly greater than the averages reported in literature for Holstein (6.1 to 7.0 kg) and Jersey (4.0 to 4.3 kg) cows, however, values are well within the reported range (Kehoe et al., 2011; Silva-del-Rio et al., 2017; Zarei et al., 2017; Gavin et al., 2018; Soufleri et al., 2021; Valldecabres and Silva-del-Rio, 2022). Increases observed in our study may be attributable to genetic selection pressure on milk production, which would, in turn, increase colostrum production, as early lactation milk production is moderately correlated ($r_p$ = 0.37 to 0.47; $p \leq 0.05$) with colostrum yield (Kessler et al., 2014). Brix score for Holstein (25%) and Jersey (23%) cows were typical based on averages reported in literature for Holstein (24.70% to 27.60%) and Jersey (19.26% to 25.40%) cow Brix scores (Morrill et al., 2012; Borchardt et al., 2022). Based on these values, we determined that both herds are representative of the broader population of Holstein and Jersey cows at farms that are managed similarly. In addition, photoperiod exposure was similar on both farms, with less than an hour difference in average daily photoperiod exposure during the close-up period.

Based on previous literature showing that Holstein and Jersey cows produce decreased amounts of colostrum during winter months (Gavin et al., 2018; Borchardt et al., 2022) and that colostrum volume is positively associated with elevated THI and increased light intensity during the prepartum period (Cabral et al., 2016; Westhoff et al., 2023), we expected that colostrum volume would be greatest for cows in the PHOTO 3 interval compared to PHOTO 1. This was reflected in both breeds with PHOTO 1 cows producing less colostrum volume than PHOTO 2 and PHOTO 3 cows. Continuous linear regression modeling showed slightly different results, with increased far-off photoperiod predicted to decrease colostrum volume while increased close-up photoperiod was predicted to increase colostrum volume. While the impact of both variables was minimal, the impact of close-up photoperiod exposure was 24,000 × greater than the magnitude of impact of far-off photoperiod exposure. This likely indicates that the close-up period, rather than the far-off period is the critical time point for photoperiod to impact colostrum volume, which coincides with endocrine changes associated with colostrogenesis (Brandon et al., 1971). This datum corroborates Westhoff et al. (2023), who showed that increased average light intensity during the 14 days pre-partum was associated with an increase in colostrum yield. In this study, the far-off period varied in length from 24 to 49 d due to the range in total dry period of 45 to 70 d. Therefore, more variation within the far-off period is present and could mask potential effects of far-off photoperiod on colostrum volume.

Differences in colostrum volume and Brix score were detected between PHOTO groups 1, 2 and 3, which indicates appropriate stratification of animals into the groups. In addition, breaking animals at the cut point of less than 708 minutes of CU PHOTO exposure for PHOTO 1, 709 to 824 minutes for PHOTO 2 and greater than 825 for PHOTO 3 allowed for equal distribution of each breed across the groups. PHOTO 1 animal's average CU PHOTO exposure was greater than – 0.5 standard deviations from the mean while PHOTO 3 included animals greater than 0.7 standard deviations from the mean for average CU PHOTO exposure.

Incidences of mastitis and pasture forage quality were not available for this study and these factors may have contributed to colostrum quality. Within farm, Brix score was lowest for cows exposed to more daylength and highest for cows exposed to decreased daylength. This suggests an inverse relationship between Brix score and photoperiod. In linear regression modeling, Brix score was not associated with THI or photoperiod exposure but differed by farm. Therefore, it is likely that the difference observed is partially due to differences in management or genetics of the animals between farms. The inverse relationship between Brix score and colostrum volume and Brix score and THI was expected based on previous findings (Westhoff et al., 2023; Zentrich et al., 2019). Westhoff et al. (2023) found that increased average daily light intensity was associated with decreased Brix score (Westhoff et al., 2023). Because colostrum volume and Brix score are inversely related, it is difficult to determine the degree to which these values are impacted by the environment and the degree to which they are impacted by each other. Previous production information for these cows could have assisted in determining the degree to which colostrum volume is impacted by factors other than the environment, however these data were not available. The mechanism by which photoperiod impacts colostrum volume has not been described and research is needed to understand this relationship before associations with Brix score can be described.

Differences in colostrum components for Jersey cows by photoperiod exposure were detected for lactose percentage, but not fat percentage, protein percentage, SNF percentage or SCS. Lactose percentage was increased for PHOTO interval 1 and 3. Lactose percentage is associated with increased total colostrum volume as it draws water into the mammary gland (Fox et al., 2015). Colostrum volume was also increased for PHOTO interval 3, but was lowest for PHOTO 1, which does not agree entirely with the lactose findings. In regression modeling, lactose was predicted to increase with increased close-up photoperiod but decrease with increased far-off photoperiod. The confounding photoperiod and lactose relationship remains unexplained, however, there are other significant factors affecting lactose not accounted for in the models, such as the factors previously mentioned. This is reflected by the low (0.27) regression coefficient for the lactose prediction model.

Percent of FO dry period days mTHI > 68 predicted a decrease in colostrum volume, which is inconsistent with previous literature that demonstrated increased THI was associated with increased colostrum volume (Gavin et al., 2018; Cabral et al., 2016; Westhoff et al., 2023). However, these three studies were conducted during the 30 days prior to parturition. Therefore, this is the first known study to show an association between THI during only the early dry period and colostrum volume. As previously mentioned, endocrine changes during the 21-day pre-partum period could explain how the observation of decreased light during the far-off period, yet increased light during the close-up period resulted in increased colostrum volume. It is possible that interaction of the environment with the cascade of hormonal events during the close-up period may impact colostrogenesis differently than the far-off period, but with both periods being important to colostrum production.

In addition, it is important to note that cows on this study were exposed to very mild and infrequent heat stress. Only 6.6% of cows had an average close-up mTHI greater than 68 and 62.4% of cows did not have a single day during their dry period where the mTHI was greater than 68. The highest average mTHI for the close-up period was below 72. Heat stress and reductions in performance are not seen at THI values below 68 and generally do not become abundant until a THI of 72 is reached (do Amaral et al., 2009; Bernabucci et al., 2010). Therefore, interpretation and application of these results is most appropriate for cows experiencing mild to no heat-stress. Based on these data, we suggest that colostrum volume increases with increasing photoperiod exposure during the close-up period. Data from cows where average THI for the entire close-up period was above 72 may show slightly different results or a median threshold where colostrum volume is highest between certain THI values.

Colostral fat percentage (Online Resource 8), nor SCS were predicted to be affected by any of the THI or photoperiod variables. However, colostral protein was predicted to increase with increased far-off photoperiod exposure and decrease with increased percentage of days of THI > 68 during the close-up period, with the degree of change being over 5 times greater for the close-up period variable. Solids-not-fat percentage was also predicted to be affected by a close-up period parameter, predicting a decrease with increased percentage of days of THI > 68 during the close-up period. This further indicates the importance and increased impact of the close-up period on colostrum rather than the far-off period.

Overall, regression models for the colostrum parameters have weak correlations ($r^2$ = 0.07 to 0.29) indicating that other factors not accounted for here are impacting colostrum volume and quality. Because variables such as previous protein production were found to be correlated with colostrum parameters in the previous research study, it is likely that inclusion of this data and other parameters would improve the reliability of the models.

## CONCLUSION

This study evaluated the impact of both photoperiod and THI during the dry period on Holstein and Jersey cow colostrum production. Colostrum volume increased with increased photoperiod exposure, specifically during the close-up period. Brix score decreased with photoperiod exposure, showing an inverse relationship with colostrum volume. Fat percentage followed the same trend as colostrum volume, but only for animals located at one farm. Lactose and protein were inversely related, being decreased and increased, respectively for the intermediary photoperiod interval. Lactose was the only colostrum component that differed by photoperiod interval and was highest for both the lowest and highest photoperiod categories. Based on these data, we suggest that while Brix and colostrum volume differ by photoperiod exposure for Holstein and Jersey cows, colostrum components for Jersey cows do not differ by photoperiod exposure. However, protein percentage, SNF percentage and lactose percentage may be affected by both photoperiod and THI according to predictive modeling. The objective of this study, to determine the impact of photoperiod and THI on colostrum in Holstein and Jersey cows confirms previous findings and contributes new findings. To improve colostrum production, future studies are needed to uncover any potential differences in physiological responses between breeds to THI and photoperiod during the dry period.

### Declarations

## FUNDING

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## CONSENT TO PARTICIPATE

Consent to Participate declaration: not applicable.

## ETHICS DECLARATION

All animal procedures were approved by the Virginia Polytechnic Institute and State University Institutional Animal Care and Use Committee (IACUC Protocol Nos. 17–249 and 18–071).

## COMPETING INTERESTS

The authors declare that they have no competing interests.

## Author Contribution

Conceptualization, K.J.A., A.N.V. and R.R.C; Data curation, K.J.A., A.N.V. and R.R.C. ; Formal analysis, K.J.A., C.S.P.W. and R.R.C. ; Funding acquisition, R.R.C. ; Investigation, K.J.A., A.N.V and A.J.D.; Methodology, K.J.A., A.N.V., A.J.D., C.S.P.W. and R.R.C. ; Project administration, R.R.C. ; Resources, A.N.V., A.J.D. and R.R.C. ; Software, K.J.A., C.S.P.W, and R.R.C. ; Supervision, R.R.C. ; Validation K.J.A., A.J.D. and R.R.C. ; Visualization, K.J.A., A.D.E., G.E.D., C.S.P.W. and R.R.C. ; Writing - original draft, K.J.A. ; Writing - review & editing, A.J.D., A.D.E, G.E.D, C.S.P.W and R.R.C.

## Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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## Figures

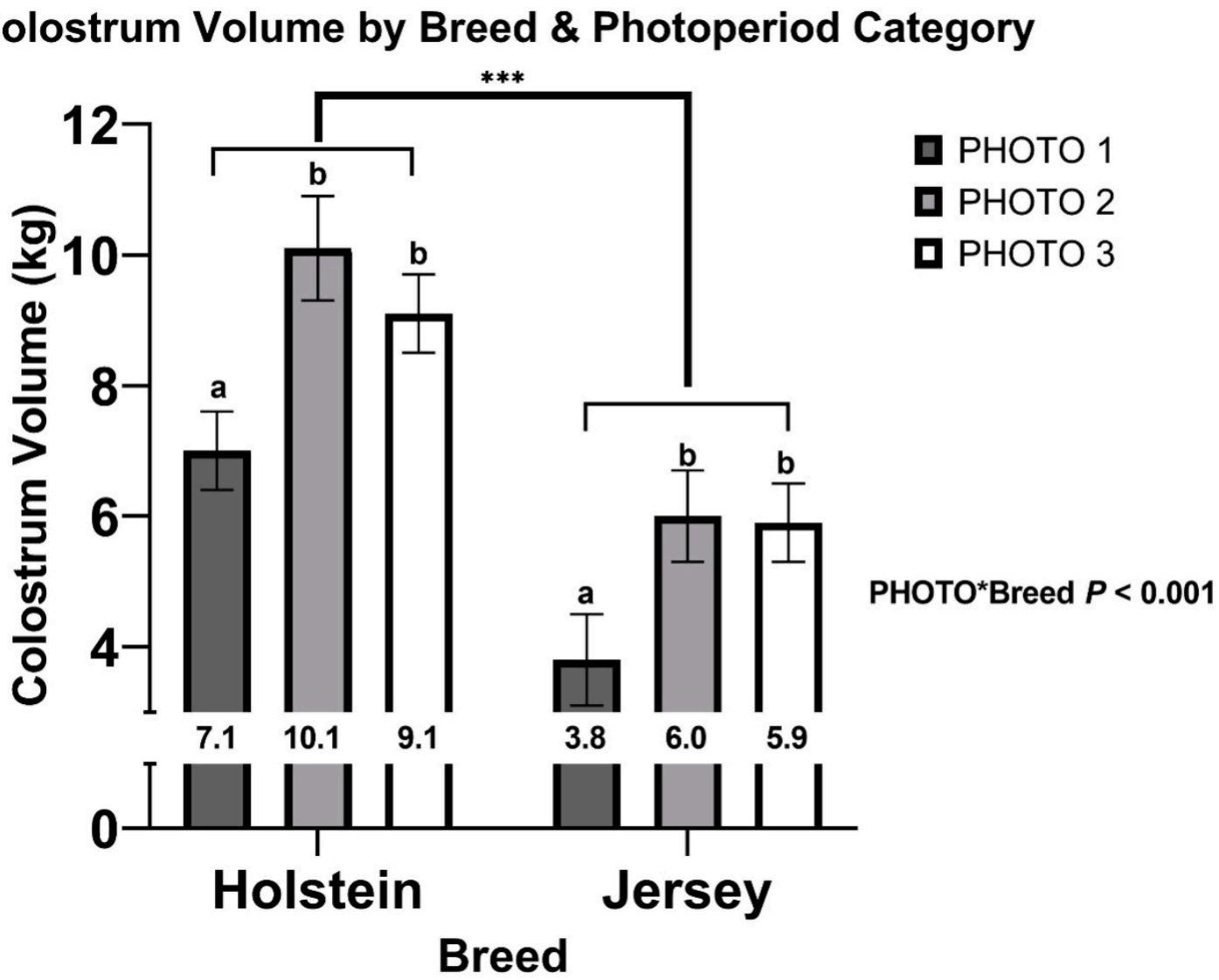



**Figure 1**

Colostrum volume by breed and photoperiod interval. Colostrum volume was measured from the first milking within one h of calving. Volume differed by photoperiod interval × breed ($p < 0.001$), with Holstein cows producing more colostrum than Jersey cows for each photoperiod interval ($p < 0.001$). Within breed, PHOTO 1 (<708 mins) cows produced less colostrum ($p \leq 0.05$) compared to PHOTO 2 (709-824 mins) and PHOTO 3 (>825 mins) cows for both breeds.

## Supplementary Files

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- SupplementaryTables.docx