Effects of heat stress on production, somatic cell score, and conception rate in Holsteins

Authors: Koichi HAGIYA[1], Kiyoshi HAYASAKA[2], Takeshi YAMAZAKI[3], Tatsuo SHIRAI[4], Takefumi OSAWA[4], Yoshinori TERAWAKI[5], Yoshitaka NAGAMINE[6], Yutaka MASUDA[7] and Mitsuyoshi SUZUKI[1]

Institute, address, country: *[1]Obihiro University of Agriculture and Veterinary Medicine, Obihiro 080–8555, Japan, [2]NARO Institute of Livestock and Grassland Science, Nasushiobara, Tochigi 329-2793, Japan, [3]NARO Hokkaido Agricultural Research Center, Sapporo 062–8555, Japan; [4]National Livestock Breeding Center, Nishigo, Fukushima 961-8511, Japan; [5]Rakuno Gakuen University, Ebetsu 069-8501, Japan; [6]Nihon University, Fujisawa 252-8510, Japan; [7]University of Georgia, Athens 30602, USA*

Running head: HEAT STRESS IN HOLSTEINS

Corresponding author: Koichi Hagiya, Obihiro University of Agriculture and Veterinary Medicine, Obihiro 080-8555, Japan

E-mail: hagiya@obihiro.ac.jp

ABSTRACT

We examined the effects of heat stress (HS) on production traits, somatic cell score (SCS), and conception rate at first insemination (CR) in Holsteins in Japan. We used a total of 228 242 records of milk, fat, and protein yields and SCS for the first three lactations, as well as of CR in heifers and in first- and second-lactation cows that had calved for the first time between 2000 and 2012. Records from 47 prefectural weather stations throughout Japan were used to calculate the temperature–humidity index (THI); areas were categorized into three regional groups: no HS (THI<72), mild HS (72≤THI<79), and moderate HS (THI≥79). Trait records from the three HS-region groups were treated as three different traits, and trivariate animal models were used. The genetic correlations between milk yields from different HS groups were very high (0.91 to 0.99). Summer calving caused the greatest increase in SCS, and in the first and second lactations this increase became greater as THI increased. In cows, CR was affected by the interaction between HS group and insemination month: with summer and early autumn insemination, there was a reduction in CR, and it was much larger in the mild- and moderate-HS groups than in the no-HS group.

Keywords: genetic correlation, heat-stress, Holsteins, temperature–humidity index (THI).

INTRODUCTION

Heat stress (HS) negatively affects production, health, and reproductive traits in dairy cows (Kadzere *et al.* 2002; Ravagnolo & Misztal 2002; West 2003; Aguilar *et al.* 2009; Boonkum *et al.* 2011). Although Holsteins are affected by HS more than are some other dairy breeds (Garcia-Peniche *et al.* 2005), Holstein cows still produce larger volumes of milk under severe HS than do Jersey cows (Smith *et al.* 2013). The magnitude of HS is determined by the combined effects of temperature, relative humidity, solar radiation, and wind speed (Dikmen & Hansen 2009), and the most common index of the degree of HS affecting dairy cows is the temperature–humidity index (THI). Armstrong (1994), for example, reported that HS begins to affect reproductive traits in dairy cows when THI>72. Daily milk yield decreases at about 0.2 kg per unit increase in THI (Ravagnolo *et al.* 2000). Aguilar *et al.* (2009) investigated the effect of HS on yield traits in the first three lactations and found that susceptibility to HS increased from the first to the third lactation. Ravagnolo and Misztal (2002) reported that reproductive performance (non-return rate at 45 days) in Holsteins decreases with increasing THI.

Almost all dairy cattle in Japan are Holsteins, and the Japanese islands stretch from 45°N to 31°N. Average yearly temperatures in the 47 prefectural regions of Japan vary from 9 to 23 °C. Wiersma developed formulas that expressed mild, moderate, and severe heat stress in dairy cattle as a function of THI in Armstrong (1994). In accordance with the categories devised by Wiersma, there are three HS regions in Japan: no HS (THI<72), mild HS (72≤THI<79), and moderate HS (79≤THI<90; hereafter referred to as THI≥79). Nagamine and Sasaki (2008) investigated the effects of environmental factors on fertility in dairy cows in Japan and found a highly significant effect of temperature in the southern regions. However, to our knowledge, no published report has yet used

THI-categorized regions to investigate the effects of HS on production, health, and reproductive traits in dairy cows in Japan or northeast Asia.

Our objectives were to use HS groups to estimate the effects of HS and season on milk yield, somatic cell score (SCS), and conception rate at first service (CR) in Holstein cows in Japan. In addition, we used trivariate animal models to investigate the genetic correlations among HS groups in terms of milk yield, SCS, and CR.

MATERIALS AND METHODS

Data

Records of yield and somatic cell count (SCC) in the first three lactations in Holstein cows, and of CR in heifers and first- and second-lactation cows that had calved for the first time between 2000 and 2012, were provided by the Livestock Improvement Association of Japan (Tokyo, Japan). Records were collected through the Dairy Herd Improvement Program. Records of 305-day milk yield (MY), 305-day fat yield (FY), and 305-day protein yield (PY) were estimated by using a multiple-trait prediction (Schaeffer & Jamrozik 1996) according to Wilmink's function (Wilmink 1987). Lactation records that had fewer than eight test-day yields during the lactation period were eliminated. Average SCCs were log-transformed into SCSs by using the formula SCS = $\log_2(\mathrm{SCC}/100\,000) + 3$ (Ali & Shook 1980). Three subsets (for first, second, and third lactations) were analyzed separately in the cases of yield and SCS. In addition, records of CR were assigned separately as three subsets (heifers, and first- and second-lactation cows). CR in heifers referred to the CR at first insemination (for first calving); CR in cows referred to the CR at first insemination during the first and second lactation periods (for the second and third calvings, respectively). Records of CR were defined as binary traits of 0 or 1, where 1 indicated that the first insemination attempt successfully achieved pregnancy, and 0 indicated otherwise.

Weather records from 47 prefectural weather stations were obtained from the website of the Japan Meteorological Agency (2015; Tokyo, Japan). THI values were estimated from average temperature, relative humidity, wind speed, and solar radiation in August over the 5 years from 2008 to 2012. Adjusted THI (THI_{adj}) values were calculated according to the steps of Hammami *et al.* (2013). First, THI was estimated by using the following formula (NRC 1971):

$$THI = 1.8 \times t + 32 - (0.55 - 0.0055 \times rh) \times (1.8 \times t - 26),$$

where t is temperature in degrees Celsius and rh is relative humidity as a percentage. THI was adjusted as follows (Mader *et al.* 2006):

$$THI_{adj} = 4.51 + THI - 1.992 \times ws + 0.0068 \times sr,$$

where ws is wind speed measured in meters per second and sr is solar radiation measured in watts per square meter. Hereafter, we refer to THI_{adj} as THI. The distributions of the no-HS, mild-HS, and moderate-HS (Armstrong 1994; Smith *et al.* 2013) groups in our dataset by prefecture are shown in Figure 1. Smith *et al.* (2013) also used severe HS ($THI \geq 90$), but none of the regions studied here fell into that category. (The maximum THI was 81.) Areas were categorized into three regional groups: no HS ($THI < 72$), mild HS ($72 \leq THI < 79$), and moderate HS ($THI \geq 79$). Our data contained 782 710 records in the no-HS group, 162 909 for mild HS, and 133 070 for moderate HS. About 75,000 records in each HS group were chosen randomly by herd. Pedigree records obtained from the Holstein Cattle Association of Japan (Tokyo, Japan) were traced back three generations. A total of 228 242 records were used, with 407 274 animals in pedigree records.

Model

Genetic correlations among the three HS groups were estimated by using a trivariate animal model that took into account the genetic covariance among records for HS groups. The following linear model (1) was applied to MY, FY, PY, and SCS for cows:

$$Y_{ijklm} = HY_i + HS_j \times MC_k + AC_l + u_{jm} + e_{ijklm} \ldots (1)$$

and model (2) applied to CR for heifers and cows:

$$Y_{ijklm} = HY_i + HS_j \times MI_k + AI_l + u_{jm} + e_{ijklm} \ldots (2)$$

where Y_{ijklm} is MY, FY, PY, SCS, or CR; HY_i is the fixed effect of herd year i; u_{jm} is HS group j × the random additive genetic effect of animal m; and e_{ijklm} is the random residual in both equations (1) and (2). $HS_j \times MC_k$ is the combined effect of HS group j × month at calving k (three HS-region groups and 12 calendar months); AC_l is the fixed effect of age group at calving l (18–20, 21–22, 23, 24, … 33, 34, and 35 months for first lactation; ≤35, 36–37, 38–39, 40–41, 42–43, 44–45, 46–47, and 48–49 months for second lactation; and ≤45, 46–50, 51–55, 56–60, 61–65, and 66–83 months for third lactation) in equation (1); $HS_j \times MI_k$ is the combined effect of HS group j × month at insemination k (three HS groups and 12 calendar months); and AI_l is the fixed effect of age group at first insemination l (≤ 13, 14, 15, … 19, 20, 21–25, 26–30, 31–40, ≥41 months) in equation (2).

The variances were defined as

$$\mathrm{var}\begin{bmatrix} u \\ e \end{bmatrix} = \begin{bmatrix} G \otimes A & 0 \\ 0 & R \otimes I \end{bmatrix}, \quad G = \begin{bmatrix} \sigma^2_{u1} & \sigma_{u1u2} & \sigma_{u1u3} \\ \sigma_{u1u2} & \sigma^2_{u2} & \sigma_{u2u3} \\ \sigma_{u1u2} & \sigma_{u2u3} & \sigma^2_{u3} \end{bmatrix}, \quad R = \begin{bmatrix} \sigma^2_{e1} & 0 & 0 \\ 0 & \sigma^2_{e2} & 0 \\ 0 & 0 & \sigma^2_{e3} \end{bmatrix}$$

where G is a 3 × 3 covariance matrix for additive genetics; R is a 3 × 3 diagonal matrix of residual variance corresponding to each trait (HS group); A is the matrix of additive genetics among animals; I is the identity matrix for records; subscripts 1, 2, and 3 are traits in the No-HS, Mild-HS, and Moderate-HS groups, respectively; and $\otimes$ is the Kronecker product.

The GIBBS3F90 program (Misztal *et al.* 2002) was used for Gibbs sampling to estimate the genetic parameters of the linear models. A flat prior was used for fixed effects, and an inverted Wishart distribution was used as the prior on the random effects. For each analysis, 50 000 samples after a burn-in of 50 000 iterations were used to calculate the posterior means and standard deviations of the covariance components. Convergence was determined from a visual inspection of the plotting of Gibbs samples.

Solutions for the fixed effects of HS × month at calving or HS × month at insemination were obtained iteratively by using a preconditioned conjugate gradient algorithm with iteration on data (Tsuruta *et al.* 2001) in a program developed for national evaluation in Japan by the National Livestock Breeding Center (Nishigo-mura, Japan)

RESULTS

Summary statistics

Mean MY ranged from 8 080 kg to 10 041 kg, mean FY from 321 kg to 390 kg, and mean PY from 265 kg to 324 kg in the first three lactations (Table 1). SCS increased from the first lactation (range 2.3 to 2.5) to the third lactation (range 2.7 to 3.0). CR ranged from 62% to 73% in heifers and from 39% to 45% in cows (Table 2). There were fewer CR records for mild- and moderate-HS heifers than for no-HS heifers.

Heritability estimates

Heritability estimates of MY declined with increasing parity, from 0.40 to 0.46 (first lactation) to 0.27 to 0.29 (third lactation) (Table 3), in all HS groups. Heritability estimates also decreased steadily with increasing parity, from 0.39 to 0.41 (first lactation) to 0.27 to 0.28 (third lactation) for FY and from 0.34 to 0.36 (first lactation) to 0.23 to 0.26 (third lactation) for PY. In contrast, the patterns of change in the heritabilities of SCS with increasing parity were not clear: the values ranged from 0.14 (third lactation in the no-HS group) to 0.20 (first lactation in the moderate-HS group and second lactation in the moderate-HS group). Heritability estimates for CR were very low, ranging from 0.01 to 0.03 (Table 4), with no large differences between heifers and cows.

Genetic correlations

The posterior means of the genetic correlations among HS groups for yield traits and SCS were high (Table 5). The maximum was 0.99 and the minimum 0.90 through all combinations. In general, slightly higher correlations were found for yields in first lactation: the correlations ranged from 0.97 to 0.99 for MY, from 0.94 to 0.99 for FY, and from 0.95 to 0.99 for PY. The correlations for MY gradually decreased in later lactations. The genetic correlations between pairs of HS groups for SCS ranged from 0.90 (between mild HS and moderate HS in third lactation) to 0.98 (between mild HS and moderate HS in second lactation) and did not differ greatly over the first three lactations. Those for CR ranged from 0.92 (between no HS and mild HS in first lactation) to 0.98 (between mild HS and moderate HS in second lactation); the correlations did not differ markedly between heifers and cows (Table 6).

Estimated effects of HS group and season

The combined effect of HS group and season (HS-MC) on MY in cows was positive for winter–spring calvings (first lactation: from +93 kg to 123 kg for January calvings and from 134 kg to 159 kg for February calvings; second lactation: from +96 kg to +174 kg for January to April calvings; third lactation: from +144 kg to +278 kg for January to March calvings) (Fig. 2). In contrast, this effect was negative in the case of summer and early autumn calvings (first lactation: from –120 kg to –162 kg for September calvings; second lactation: from –213 kg to –249 kg for September calvings; third lactation: from –215 kg to –301 kg for July–September calvings), but it did not differ among HS groups (Fig. 2). The differences in the estimated effects between spring and summer calvings increased in later lactations.

HS-MC had positive effects on SCS in the case of summer calvings and negative effects in the case of winter calvings (Fig. 3). The effects of summer calving increased with increasing THI in the first and second lactations, whereas the effects of HS-MC on SCS in the third lactation did not differ among HS groups.

The combined effects of HS group and month at insemination (HS-MI) on CR in heifers were slightly positive with spring insemination and negative with summer insemination (Fig. 4a); however, the seasonal differences were very small and there were no marked differences among HS groups.

In contrast, the seasonal effects of HS-MI on CR in first- and second-lactation cows were very clear and were negative with summer (August) insemination and positive with spring (March) insemination (Fig. 4b, 4c). The differences in effects between HS groups were clear in first- and second-lactation cows, ranging from a 0% effect on CR in the no-HS group to a –13% effect in the moderate-HS group in second lactation with insemination in August (Fig. 4c).

DISCUSSION

We assigned HS groups by using the adjusted THI of Mader *et al.* (2006), who indicated that adjustments for wind speed and solar radiation were useful for assessing heat stress. Nagamine and Sasaki (2008) investigated the environmental factors affecting CR in Holsteins in Japan. They assigned two HS groups based on latitude and suggested that CR was affected more by temperature than by humidity. Although the effects of temperature, humidity, wind speed, and solar radiation on HS under Japanese climatic conditions have not been clarified, we considered the adjusted THI useful because it included various environmental factors affecting HS. Ravagnolo and Misztal (2002) proposed using information from local weather stations to predict heat tolerance in dairy cows.

Our posterior means of heritabilities for MY (ranging from 0.27 to 0.46), FY (ranging from 0.27 to 0.41), and PY (ranging from 0.23 to 0.36) (Table 3) were similar to those reported before for Holstein cows in Japan (Kawahara *et al.* 2006; Hagiya *et al.* 2013; Yamazaki *et al.* 2013). Our heritability estimates for SCS (ranging from 0.14 to 0.20; Table 3) were in agreement with those in recent studies of Holstein cows (Pritchard *et al.* 2013; Yamazaki *et al.* 2013). Our heritability estimates for reproductive traits were generally low. Using a linear model, Bastin *et al.* (2010) estimated that the heritability of the non-return rate at first lactation in Canadian Holstein cows was 0.026. Liu *et al.* (2008) also used a linear model; they reported that the heritabilities of the non-return rate in three European countries were 0.012 in heifers and 0.015 in dairy cows. Hagiya *et al.* (2013), using a threshold animal model, reported that the heritabilities of CR were 0.031 in heifers, 0.034 in first-lactation cows, and 0.028 in second-lactation cows (Japanese Holsteins). Our heritability estimates for CR (ranging from 0.01 to 0.03) were in the general range of these reports but lower than those obtained by using the threshold model (Table 4). For analysis of binary traits, theoretically, the threshold model is more accurate than the linear model (Gianola 1982), and heritability estimates obtained by using a threshold model are usually higher than those obtained by using a linear model (Weller & Ron 1992). However, the correlations between the estimated breeding values obtained from the threshold and linear models are very high (>0.99; Weller & Ron 1992). As described in detail by Jamrozik *et al.* (2005), routine genetic evaluation of binary fertility traits is performed mostly by using a linear model, because with the threshold animal model there is a problem with convergence. Therefore, our results obtained by using a linear model should be useful for routine genetic evaluation.

The genetic correlations of MY among the different HS groups declined slightly with increasing parity, whereas the genetic correlations of SCS and CR did not differ among lactations (Tables 5, 6). All posterior means of the genetic correlations were significantly ($P < 0.001$) smaller than 1.0. These results suggest the existence of interactions between HS group and breeding value for MY, FY, PY, SCS, and CR under Japanese climatic conditions.

HS-MC had the greatest negative effect on MY when cows calved from July to September, but this effect did not differ among HS groups. The differences among HS groups in the seasonal effects on SCS in third-lactation cows were not clear, because the 95% confidence interval was expanded (Fig. 3c). However, in the first two lactations the seasonal effects of increasing THI on SCS were highest with summer calving (Fig. 3a, 3b). In contrast, the effects of month at first insemination on CR in heifers were similar throughout the year in all HS groups (Fig. 4a). However, among cows inseminated in summer and early autumn (July to September), those in the mild- and moderate-HS groups experienced a more negative effect on CR than did those in the no-HS group (Fig.

4b, 4c). Therefore, interactions with HS group affected the health and reproductive traits of cows, rather than the yield traits. In cows inseminated in August—especially during second lactation—there were large differences among HS groups in terms of the negative effect on CR (Fig. 4c). Aguilar *et al.* (2009) considered later-parity cows to be more susceptible than first-parity cows to HS. Boonkum *et al.* (2011) also reported that response to HS is strongly affected by parity. The differences we found in the effects on CR among HS groups were in agreement with these findings. Nishiura *et al.* (2015) found negative genetic correlations between test-day milk yield and fat-to-protein ratio (as an index of energy balance) in Japanese cows; they suggested that a negative energy balance in mid- to late lactation was associated with a reduction in milk yield. Negative energy balance in milking cows likely affects the health and reproductive traits of different HS groups to different degrees.

In conclusion, the effects of HS on CR in heifers were not very clear through the seasons. However, there was an interaction between HS group and insemination season in cows: the reduction in CR in cows—especially those inseminated in August—was much larger in the mild- and moderate-HS groups than in the no-HS group. This finding should be considered in statistical modeling in evaluations of the reproductive traits of cows from various THI regions.

ACKNOWLEDGMENTS

The authors thank S. Inoue from NARO Hokkaido Agricultural Research Center (Sapporo, Japan) for providing advice on the weather data. This work was supported by a grant from the Ministry of Agriculture, Forestry, and Fisheries of Japan (Development of Breeding Technology for Animal Life Production).

REFERENCES

Aguilar I, Misztal I, Tsuruta S. 2009. Genetic components of heat stress in dairy cattle with multiple lactations. *Journal of Dairy Science* **92**, 5702–5711.

Ali AKA , Shook GE. 1980. An optimum transformation for somatic cell concentration in milk. *Journal of Dairy Science* **63**, 487–490.

Armstrong DV. 1994. Heat stress interaction with shade and cooling. *Journal of Dairy Science* **77**, 2044–2050.

Bastin C, Loker S, Gengler N, Sewalem A, Miglior F. 2010. Genetic relationships between body condition score and reproductive traits in Canadian Holstein and Ayrshire first-parity cows. *Journal of Dairy Science* **93**, 2215–2228.

Boonkum W, Misztal I, Duangjinda M, Pattarajinda V, Tumwasorn S, Sanpote J. 2011. Genetic effects of heat stress on milk yield of Thai Holstein crossbreds. *Journal of Dairy Science* **94**, 487–492.

Dikmen S, Hansen PJ. 2009. Is the temperature-humidity index the best indicator of heat stress in lactating dairy cows in a subtropical environment? *Journal of Dairy Science* **92**, 109–116.

Garcia-Peniche TB, Cassell BG Pearson RE, Misztal I. 2005. Comparisons of Holsteins with Brown Swiss and Jersey Cows on the same farm for age at first calving and first calving interval. *Journal of Dairy Science* **88**, 790–796.

Gianola D. 1982. Theory and analysis of threshold characters. *Journal of Animal Science* **54**, 1079–1096.

Hagiya K, Terawaki Y, Yamazaki T, Nagamine Y, Itoh F, Yamaguchi S, Abe H, Gotoh Y, Kawahara T, Masuda Y, Suzuki M. 2013. Relationships between conception rate in Holstein heifers and cows and milk yield at various stages of lactation. *Animal* **7**, 1423–1428.

Hammami H, Bormann J, M’hamdi N, Montalda MM, Gengler N. 2013. Evaluation of heat stress effects on production traits and somatic cell score of Holsteins in temperate environment. *Journal of Dairy Science* **96**, 1844–1855.

Jamrozik J, Fatehi J, Kistemaker GJ, Schaeffer LR. 2005. Estimates of genetic parameters for Canadian Holstein female reproduction traits. *Journal of Dairy Science* **88**, 2199–2208.

Japan Meteorological Agency. 2015. *Japan Meteorological Agency Climate Statistics, Historic Monthly Values* [homepage on the Internet]. Weather, Climate & Earthquake Information ; [cited 4 August 2015]. Available from URL: http://www.data.jma.go.jp/obd/stats/data/en/index.html.

Kadzere CT, Murphy MR, Silanikove N, Maltz E. 2002. Heat stress in lactating dairy cows: a review. *Livestock Production Science* **77**, 59–91.

Kawahara T, Gotoh Y, Yamaguchi S, Suzuki M. 2006. Variance component estimates with dominance models for milk production in Holsteins of Japan using Method R. *Asian-Australian Journal of Animal Science* **19**, 769–774.

Liu A, Jaltner J, Relnhardt F, Pasman E, Rensing S, Reents R. 2008. Genetic Evaluation of Fertility Traits of Dairy Cattle Using a Multiple-Trait Animal Model. *Journal of Dairy Science* **91**, 4333–4343.

Mader TL, Davis MS, Brown-Brandl T. 2006. Environmental factors influencing heat stress in feedlot cattle. *Journal of Animal Science* **84**, 712–719.

Misztal I, Tsuruta S, Strabel T, Auvray B, Druet T, Lee DH. 2002. BLUPF90 and Related Programs (BGF90). *Proceedings of the 7th World Congress on Genetic Applied to Livestock*

Production, CD-ROM Communication no. **28**, 07, Montpellier, France.

Nagamine Y, Sasaki O. 2008. Effect of environmental factors on fertility of Holstein–Friesian cattle in Japan. *Livestock Science* **115**, 89–93.

Nishiura A, Sasaki O, Aihara M, Takeda H, Satoh M. 2015. Genetic analysis of fat-to-protein ratio, milk yield and somatic cell score of Holstein cows in Japan in the first three lactations by using a random regression model. *Animal Science Journal.* **86**, 961-969.

NRC. 1971. *A guide to environmental research on animals.* National Academy of Science, Washington, DC.

Pritchard T, Coffey M, Mrode R, Wall E. 2013. Genetic parameters for production, health, fertility and longevity traits in dairy cows. *Animal* **7**, 34–46.

Ravagnolo O, Misztal I. 2002. Effect of heat stress on nonreturn rate in Holstein cows: Genetic analyses. *Journal of Dairy Science* **85**, 3092–3100.

Ravagnolo O, Misztal I, Hoogenboom G. 2000. Genetic Component of Heat Stress in Dairy Cattle, Development of Heat Index Function. *Journal of Dairy Science* **83**, 2120–2125.

Schaeffer LR, Jamrozik J. 1996. Multiple-trait prediction of lactation yields for dairy cows. *Journal of Dairy Science* **80**, 3015–3022.

Smith DL, Smith T, Rude JB, Ward SH. 2013. Comparison of the effects of heat stress on milk and component yields and somatic cell score in Holstein and Jersey cows. *Journal of Dairy Science* **96**, 3028–3033.

Tsuruta S, Misztal I, Strandén I. 2001. Use of the preconditioned conjugate gradient algorithm as a generic solver for mixed-model equations in animal breeding applications. *Journal of Animal Science* **79**, 1166–1172.

Weller JI, Ron M. 1992. Genetic analysis of fertility traits in Israeli Holsteins by linear and threshold models. *Journal of Dairy Science* **75**, 2541–2548.

West JW. 2003. Effects of Heat-Stress on Production in Dairy Cattle. *Journal of Dairy Science* **86**, 2131–2144.

Wilmink JBM. 1987. Adjustment of test-day milk, fat, and protein yield for age, season and stage of lactation. *Livestock Production Science* **16**, 335–348.

Yamazaki T, Hagiya K, Takeda H, Sasaki O, Yamaguchi S, Sogabe M, Saito Y, Nakagawa S, Togashi K, Suzuki K, Nagamine Y. 2013. Genetic correlations between lactation persistency and somatic cell scores on test day within and across first and second lactations in Holstein cows. *Livestock Science* **152**, 120–126.

Figure legends

Figure 1 Distribution of HS groups in the Japanese dataset, by prefecture

HS = heat stress; THI = temperature-humidity index; No HS = THI<72; Mild HS = 72≤THI<79; Moderate HS = THI≥79

Figure 2 Effects and 95% confidence intervals (with bars) of calendar month at calving on milk yield in cows in (a) first lactation, (b) second lactation, and (c) third lactation, by HS group

HS = heat stress; THI = temperature-humidity index; No HS = THI<72; Mild HS = 72≤THI<79; Moderate HS = THI≥79

Average of effects was set to zero for each HS group.

Figure 3 Effects and 95% confidence intervals (with bars) of calendar month at calving on somatic cell score in cows in (a) first lactation, (b) second lactation, and (c) third lactation, by HS group

HS = heat stress; SCS = somatic cell score; THI = temperature-humidity index; No HS = THI<72; Mild HS = 72≤THI<79; Moderate HS = THI≥79

Average of effects was set to zero for each HS group.

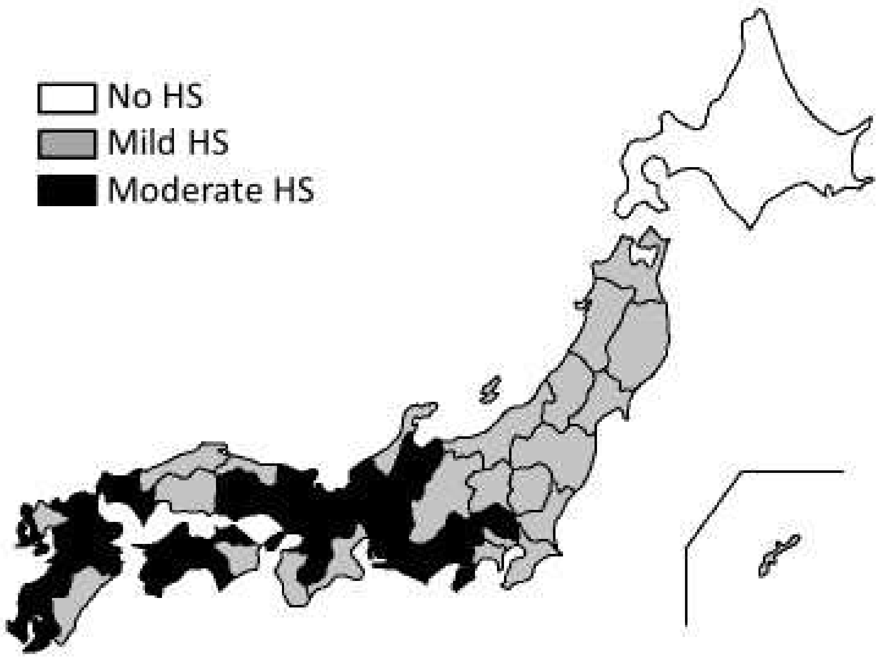
Figure 4 Effects and 95% confidence intervals (with bars) of calendar month of insemination on conception rate at first insemination in (a) heifers, (b) cows inseminated during first lactation period and (c) cows inseminated during second lactation period, by HS group

HS = heat stress; THI = temperature-humidity index; No HS = THI<72; Mild HS =

$72 \leq THI < 79$; Moderate HS = $THI \geq 79$

Average of effects was set to zero for each HS group.

404 Fig. 1



405

406

Fig. 2a

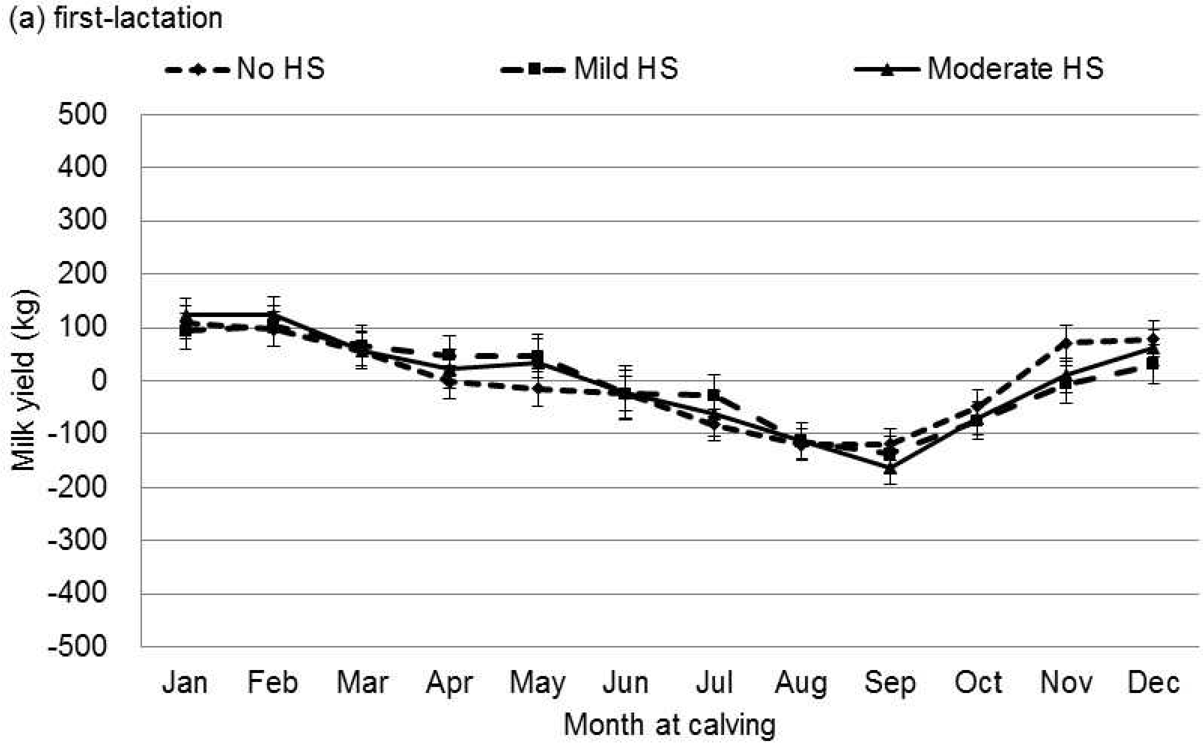

(a) first-lactation
No HS
Mild HS
Moderate HS
500
400
300
200
100
0
-100
-200
-300
-400
-500
Milk yield (kg)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month at calving

Fig. 2b

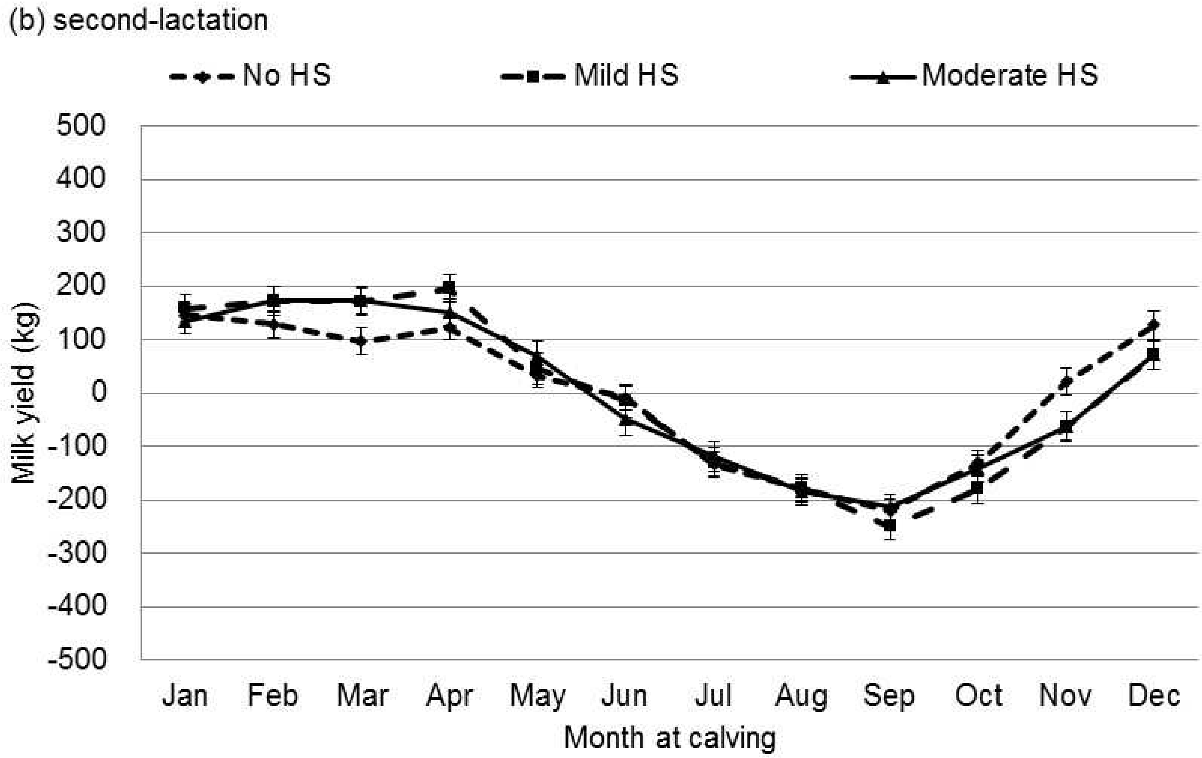

(b) second-lactation
No HS
Mild HS
Moderate HS
500
400
300
200
100
0
-100
-200
-300
-400
-500
Milk yield (kg)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month at calving

Fig. 2c

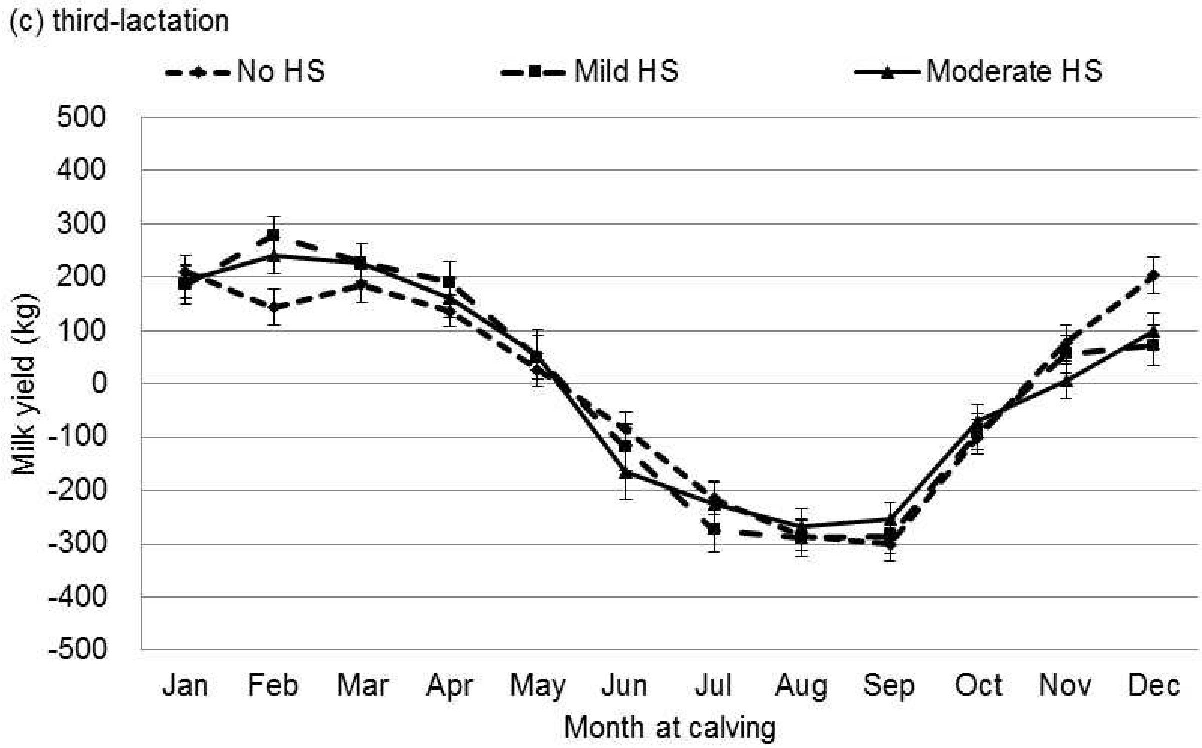

(c) third-lactation
No HS
Mild HS
Moderate HS
500
400
300
200
100
0
-100
-200
-300
-400
-500
Milk yield (kg)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month at calving

Fig. 3a

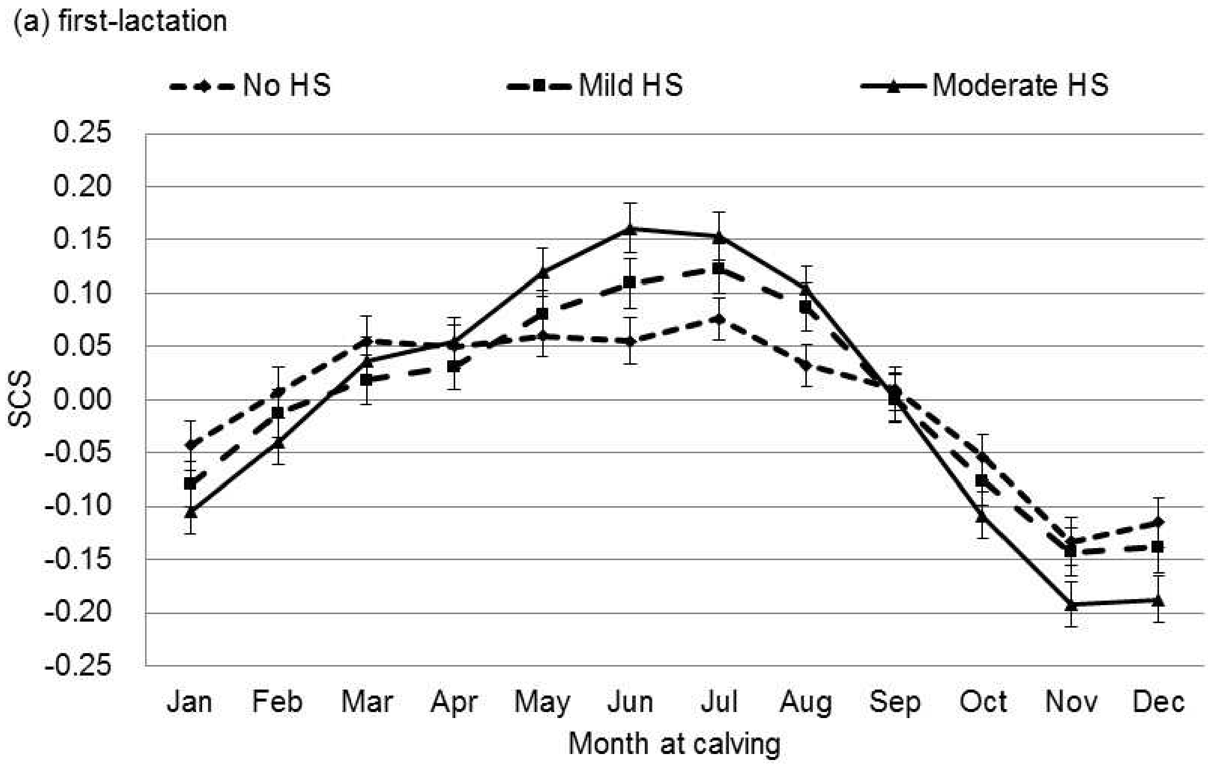

(a) first-lactation
No HS
Mild HS
Moderate HS
SCS
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month at calving

Fig. 3b

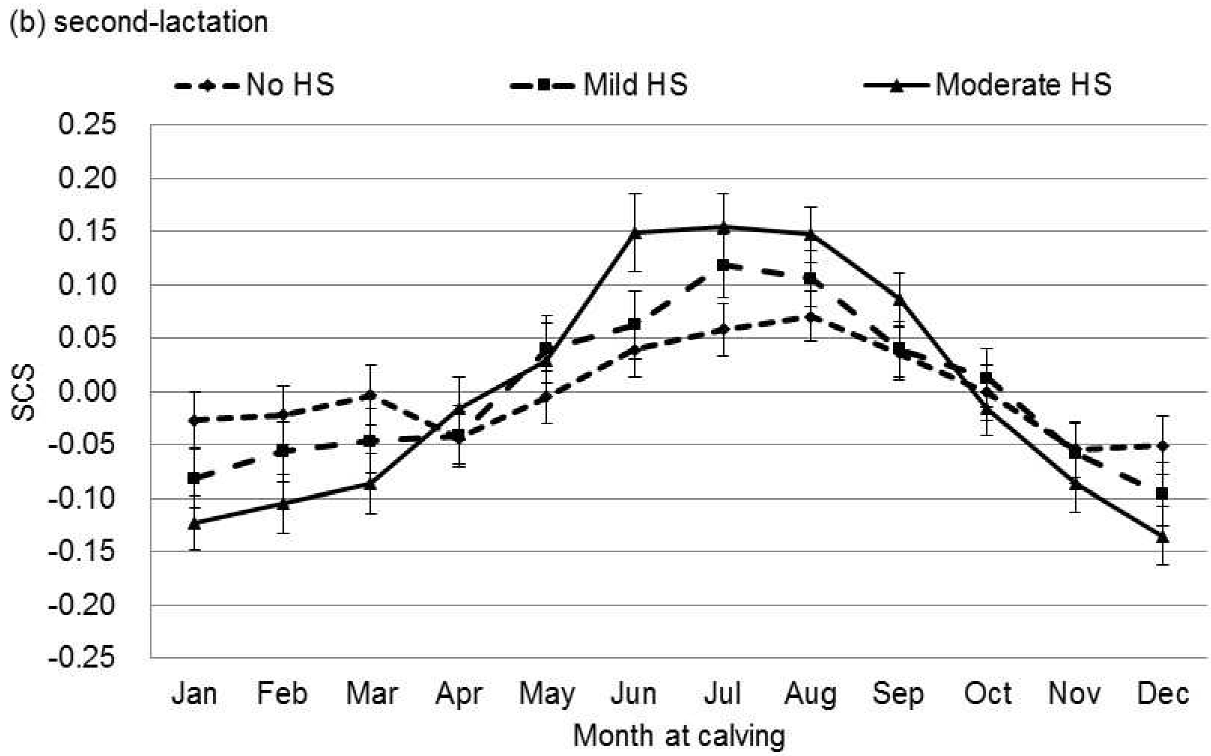

(b) second-lactation
No HS
Mild HS
Moderate HS
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
SCS
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month at calving

Fig. 3c

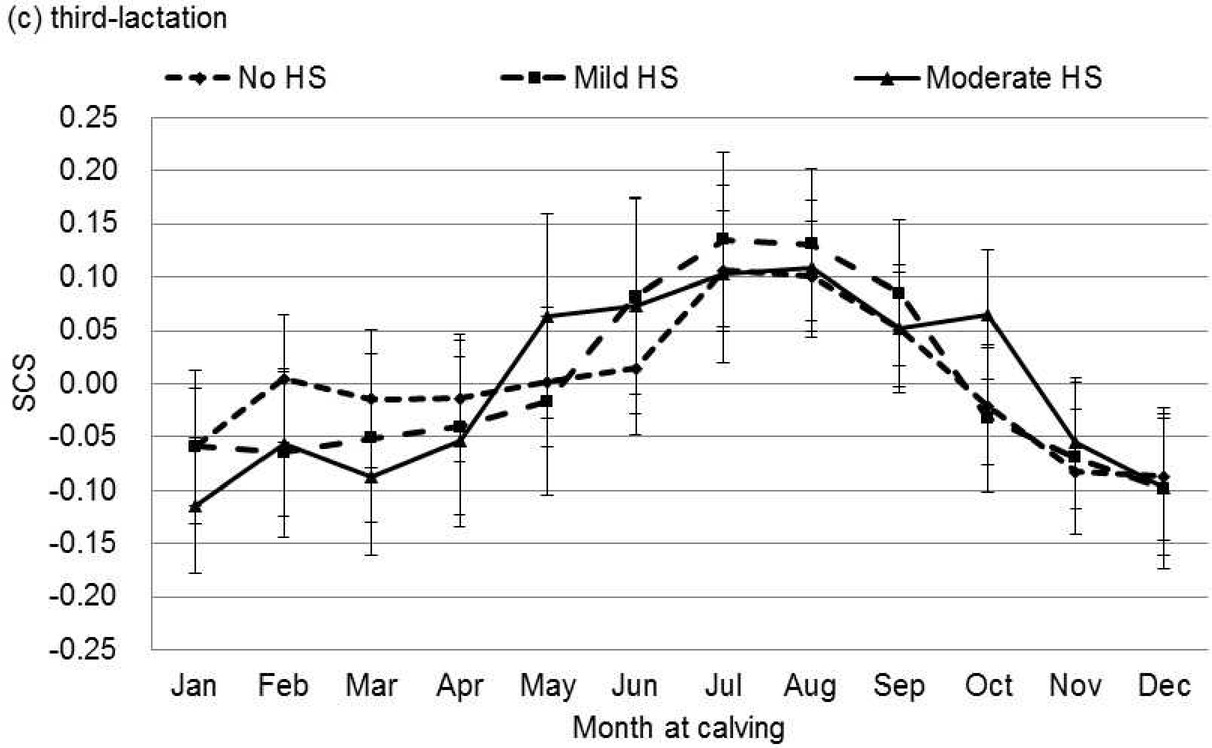

(c) third-lactation
No HS
Mild HS
Moderate HS
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
SCS
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month at calving

Fig. 4a

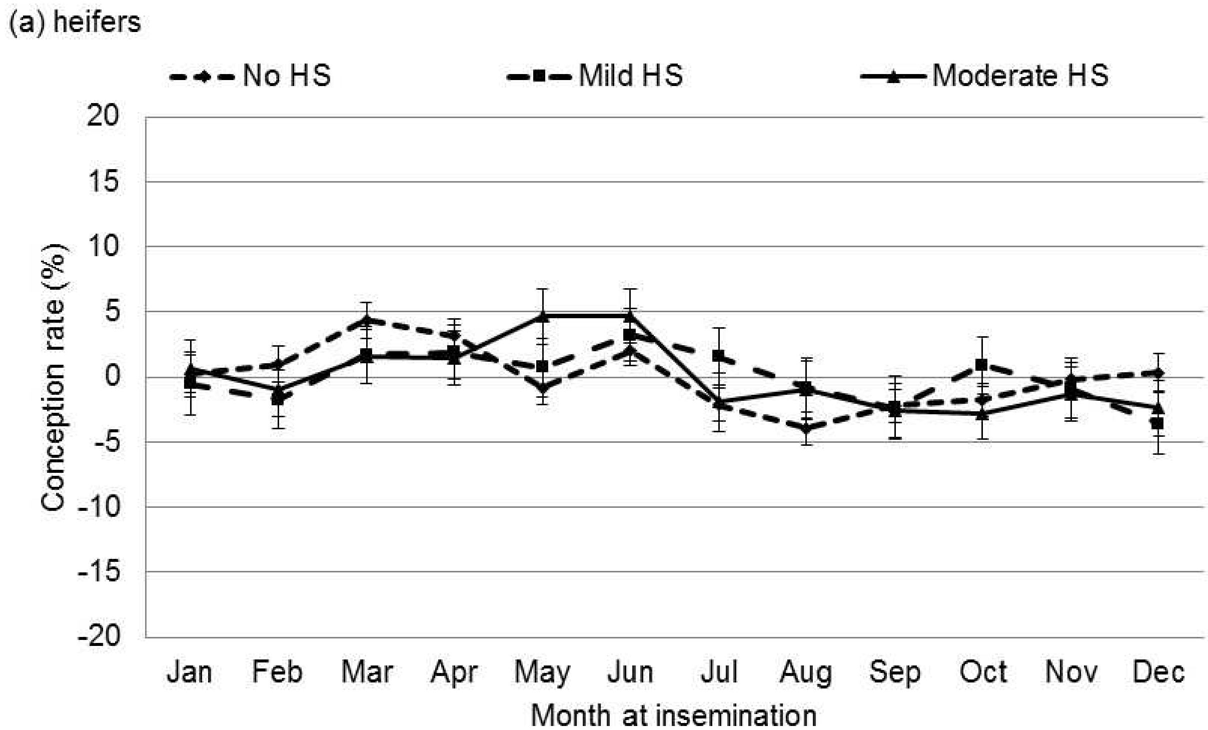

(a) heifers
No HS
Mild HS
Moderate HS
Conception rate (%)
20
15
10
5
0
-5
-10
-15
-20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month at insemination

Fig. 4b

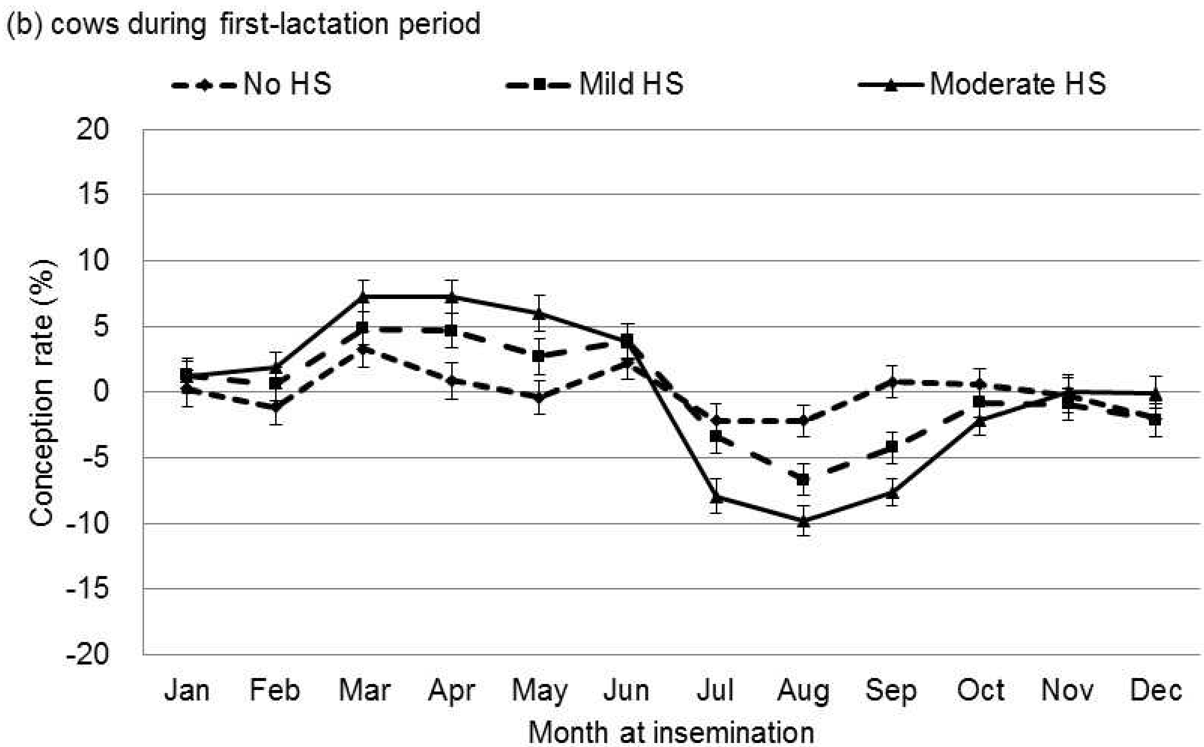

(b) cows during first-lactation period
No HS
Mild HS
Moderate HS
Conception rate (%)
20
15
10
5
0
-5
-10
-15
-20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month at insemination

Fig. 4c

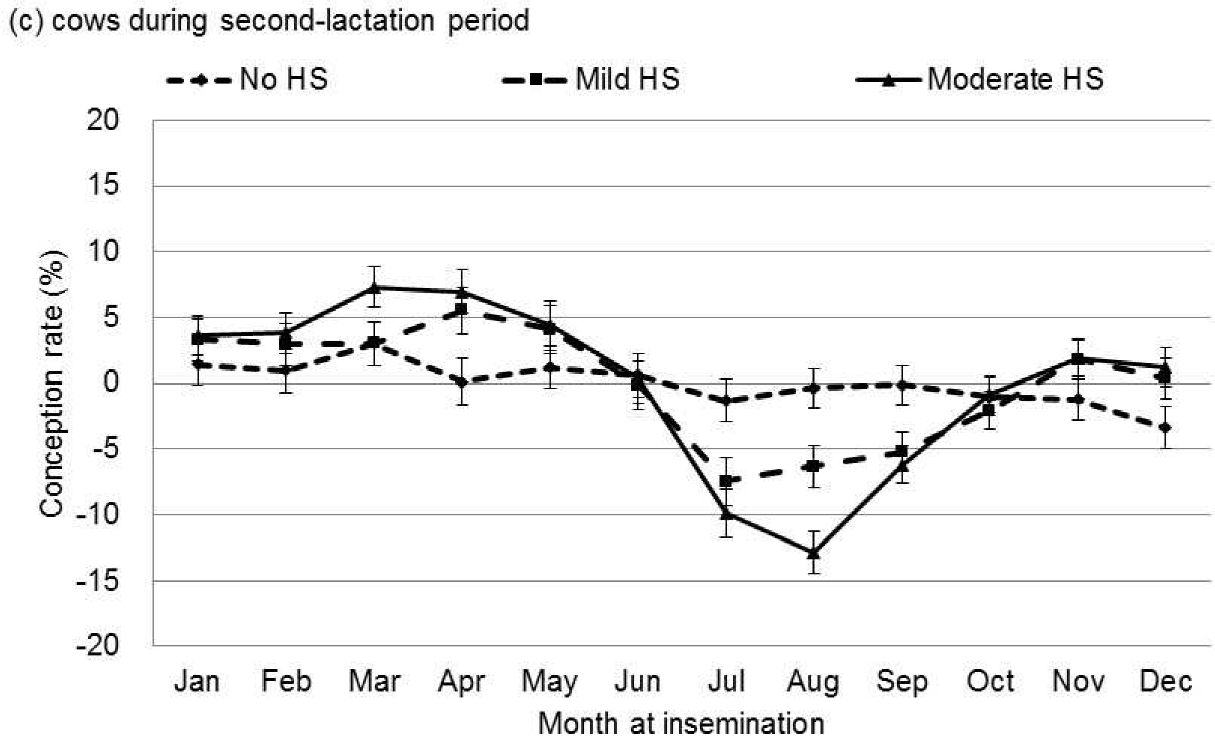

(c) cows during second-lactation period
No HS
Mild HS
Moderate HS
Conception rate (%)
20
15
10
5
0
-5
-10
-15
-20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month at insemination

Table 1 Means (s.d.) of milk, fat, and protein yields and SCS in cows in different HS groups

Trait	No. of records [SCS]	Milk, kg/305 days		Fat, kg/305 days		Protein, kg/305 days		SCS	
First lactation									
No HS	79 389 [79 217]	8080	(1493)	321	(58)	265	(48)	2.3	(1.1)
Mild HS	72 949 [72 668]	8608	(1484)	330	(56)	281	(46)	2.4	(1.2)
Moderate HS	75 904 [75 739]	8440	(1389)	323	(54)	274	(43)	2.5	(1.2)
Second lactation									
No HS	65 829 [65 504]	9371	(1798)	373	(70)	307	(56)	2.5	(1.3)
Mild HS	57 606 [57 238]	9709	(1803)	371	(69)	316	(55)	2.7	(1.4)
Moderate HS	61 376 [61 198]	9483	(1726)	363	(69)	309	(53)	2.8	(1.4)
Third lactation									
No HS	43 069 [42 889]	9743	(1874)	390	(75)	317	(58)	2.7	(1.4)
Mild HS	34 058 [33 934]	10041	(1858)	384	(72)	324	(57)	2.9	(1.5)
Moderate HS	36 759 [36 659]	9863	(1798)	379	(73)	317	(55)	3.0	(1.5)

HS = heat stress; SCS = somatic cell score; THI = temperature–humidity index;

No HS = THI<72; Mild HS = 72≤THI<79; Moderate HS = THI≥79

Table 2 Means (s.d.) of conception rate at first insemination of heifers and cows in different HS groups

Trait	No. of records	Conception rate at first insemination, %
Heifers		
No HS	50 061	62 (49)
Mild HS	11 204	73 (44)
Moderate HS	14 618	70 (46)
Cows in first lactation period		
No HS	57 165	45 (50)
Mild HS	54 320	43 (49)
Moderate HS	56 684	41 (49)
Cows in second lactation period		
No HS	35 192	42 (49)
Mild HS	30 174	41 (49)
Moderate HS	31 900	39 (49)

HS = heat stress; THI = temperature–humidity index; No HS = THI < 72; Mild HS = 72 ≤ THI < 79; Moderate HS = THI ≥ 79

Table 3 Posterior means (s.d.) of heritabilities (h^2) for milk, fat, and protein yields and SCS of cows in different HS groups

Trait	Milk		Fat		Protein		SCS	
	h^2	(s.d.)	h^2	(s.d.)	h^2	(s.d.)	h^2	(s.d.)
First lactation								
No HS	0.46	(0.01)	0.39	(0.01)	0.35	(0.01)	0.15	(0.01)
Mild HS	0.40	(0.01)	0.39	(0.01)	0.34	(0.01)	0.19	(0.01)
Moderate HS	0.45	(0.01)	0.41	(0.01)	0.36	(0.01)	0.20	(0.01)
Second lactation								
No HS	0.34	(0.01)	0.31	(0.01)	0.26	(0.01)	0.18	(0.01)
Mild HS	0.32	(0.01)	0.32	(0.01)	0.29	(0.01)	0.18	(0.01)
Moderate HS	0.32	(0.01)	0.28	(0.01)	0.26	(0.01)	0.20	(0.01)
Third lactation								
No HS	0.27	(0.01)	0.28	(0.02)	0.23	(0.02)	0.14	(0.01)
Mild HS	0.29	(0.01)	0.28	(0.02)	0.25	(0.01)	0.18	(0.02)
Moderate HS	0.28	(0.01)	0.27	(0.02)	0.26	(0.02)	0.19	(0.01)

HS = heat stress; SCS = somatic cell score; THI = temperature–humidity index; No HS = THI<72; Mild HS = 72≤THI<79; Moderate HS = THI≥79

Table 4 Posterior means (s.d.) of heritabilities (h^2) for conception rate at first insemination of heifers and cows in different HS groups

Trait	Conception rate at first insemination	
	h^2	(s.d.)
Heifers		
No HS	0.01	(0.00)
Mild HS	0.02	(0.00)
Moderate HS	0.03	(0.01)
Cows in first lactation period		
No HS	0.01	(0.00)
Mild HS	0.01	(0.00)
Moderate HS	0.01	(0.00)
Cows in second lactation period		
No HS	0.01	(0.00)
Mild HS	0.02	(0.00)
Moderate HS	0.02	(0.00)

HS = heat stress; THI = temperature–humidity index; No HS = THI<72; Mild HS = 72≤THI<79; Moderate HS = THI≥79

446

Table 5 Posterior means (s.d.) of genetic correlations in HS groups for milk, fat, and protein yields and SCS of cows

Trait	First lactation		Second lactation		Third lactation	
HS group	r_G	(s.d.)	r_G	(s.d.)	r_G	(s.d.)
Milk						
No HS – Mild HS	0.98	(0.00)	0.97	(0.01)	0.96	(0.01)
No HS – Moderate HS	0.97	(0.00)	0.95	(0.01)	0.92	(0.01)
Mild HS – Moderate HS	0.99	(0.00)	0.97	(0.00)	0.91	(0.01)
Fat						
No HS – Mild HS	0.95	(0.01)	0.96	(0.00)	0.96	(0.00)
No HS – Moderate HS	0.94	(0.01)	0.93	(0.01)	0.95	(0.01)
Mild HS – Moderate HS	0.99	(0.00)	0.97	(0.00)	0.93	(0.02)
Protein						
No HS – Mild HS	0.97	(0.00)	0.97	(0.00)	0.95	(0.00)
No HS – Moderate HS	0.95	(0.01)	0.94	(0.01)	0.95	(0.01)
Mild HS – Moderate HS	0.99	(0.00)	0.96	(0.01)	0.91	(0.02)
SCS						
No HS – Mild HS	0.93	(0.02)	0.92	(0.01)	0.97	(0.01)
No HS – Moderate HS	0.94	(0.02)	0.95	(0.02)	0.93	(0.02)
Mild HS – Moderate HS	0.96	(0.01)	0.98	(0.00)	0.90	(0.02)

HS = heat stress; r_G = genetic correlation; SCS = somatic cell score; THI = temperature–humidity index; No HS = THI<72; Mild HS = 72≤THI<79; Moderate HS = THI≥79

447

Table 6 Posterior means (s.d.) of genetic correlations in HS groups for conception rate at first insemination of heifers and cows

Trait	Heifers		Cows in first lactation period		Cows in second lactation period	
HS group	r_G	(s.d.)	r_G	(s.d.)	r_G	(s.d.)
Conception rate at first insemination						
No HS – Mild HS	0.97	(0.01)	0.93	(0.02)	0.96	(0.01)
No HS – Moderate HS	0.92	(0.01)	0.94	(0.01)	0.95	(0.01)
Mild HS – Moderate HS	0.97	(0.01)	0.98	(0.00)	0.97	(0.00)

HS = heat stress; r_G = genetic correlation; THI = temperature–humidity index; No HS = THI<72; Mild HS = 72≤THI<79; Moderate HS = THI≥79

表題：　ホルスタイン種における生産量，体細胞スコアおよび受胎率に対する暑熱ストレスの影響

著者名：　萩谷功一[1]・早坂貴代史[2]・山崎武志[3]・白井達夫[4]・大澤剛史[4]・寺脇良悟[5]・長嶺慶隆[6]・増田豊[7]・鈴木三義[1]

所属：　[1]帯広畜産大学，帯広市 080-8555

[2]畜産草地研究所，那須塩原市 329-2793

[3]北海道農業研究センター，札幌市豊平区 062-8555

[4]家畜改良センター，福島県西白河郡西郷村 961-8511

[5]酪農学園大学，江別市 069-8501

[6]日本大学，藤沢市 252-8510

[7]ジョージア大学，Athens 30602, USA

日本のホルスタイン種における泌乳，体細胞スコアおよび初回授精受胎率（CR）に対する暑熱ストレス（HS）の影響を調査した．データは，2000年から2012年の間に初産分娩した雌牛の初産から３産次の乳量，乳脂量，乳タンパク質量および体細胞スコア，未経産から２産分娩次までの初回授精に関する228,242記録である．47都道府県の気象観測所のデータから温湿度指数（THI）を計算し，47各都道府県をno HS（THI＜72），mild HS（72≦THI＜79）およびmoderate HS（79≧THI）の３区分に割り当てた．分析には，各HS区分の記録を異なる形質とみなした３形質アニマルモデルを使用した．各HS区分間の遺伝相関は非常に高かった（0.91から0.99）．夏分娩はSCSの上昇をもたらすが，特に初産および２産次にTHIの増加とともに上昇した．経産牛において，CRはHS区分と授精月の相互作用に影響され，すなわち，夏季から初秋の授精においてCRが低下し，no HSとの比較においてmild HSとmoderate HSで顕著であった．