



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

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21 **ABSTRACT**

22 We examined the effects of heat stress (HS) on production traits, somatic cell score (SCS),  
23 and conception rate at first insemination (CR) in Holsteins in Japan. We used a total of  
24 228 242 records of milk, fat, and protein yields and SCS for the first three lactations, as  
25 well as of CR in heifers and in first- and second-lactation cows that had calved for the  
26 first time between 2000 and 2012. Records from 47 prefectural weather stations  
27 throughout Japan were used to calculate the temperature–humidity index (THI); areas  
28 were categorized into three regional groups: no HS ( $\text{THI} < 72$ ), mild HS ( $72 \leq \text{THI} < 79$ ),  
29 and moderate HS ( $\text{THI} \geq 79$ ). Trait records from the three HS-region groups were treated  
30 as three different traits, and trivariate animal models were used. The genetic  
31 correlations between milk yields from different HS groups were very high (0.91 to 0.99).  
32 Summer calving caused the greatest increase in SCS, and in the first and second  
33 lactations this increase became greater as THI increased. In cows, CR was affected by  
34 the interaction between HS group and insemination month: with summer and early  
35 autumn insemination, there was a reduction in CR, and it was much larger in the mild-  
36 and moderate-HS groups than in the no-HS group.

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

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44 **INTRODUCTION**

45

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

60 Almost all dairy cattle in Japan are Holsteins, and the Japanese islands stretch from  
61  $45^{\circ}N$  to  $31^{\circ}N$ . Average yearly temperatures in the 47 prefectural regions of Japan vary  
62 from 9 to 23 °C. Wiersma developed formulas that expressed mild, moderate, and severe  
63 heat stress in dairy cattle as a function of THI in Armstrong (1994). In accordance with  
64 the categories devised by Wiersma, there are three HS regions in Japan: no HS  
65 ( $THI < 72$ ), mild HS ( $72 \leq THI < 79$ ), and moderate HS ( $79 \leq THI < 90$ ; hereafter referred to as  
66  $THI \geq 79$ ). Nagamine and Sasaki (2008) investigated the effects of environmental factors  
67 on fertility in dairy cows in Japan and found a highly significant effect of temperature in  
68 the southern regions. However, to our knowledge, no published report has yet used

69 THI-categorized regions to investigate the effects of HS on production, health, and  
70 reproductive traits in dairy cows in Japan or northeast Asia.  
71 Our objectives were to use HS groups to estimate the effects of HS and season on milk  
72 yield, somatic cell score (SCS), and conception rate at first service (CR) in Holstein cows  
73 in Japan. In addition, we used trivariate animal models to investigate the genetic  
74 correlations among HS groups in terms of milk yield, SCS, and CR.

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76

## 77 **MATERIALS AND METHODS**

78

### 79 **Data**

80 Records of yield and somatic cell count (SCC) in the first three lactations in Holstein  
81 cows, and of CR in heifers and first- and second-lactation cows that had calved for the  
82 first time between 2000 and 2012, were provided by the Livestock Improvement  
83 Association of Japan (Tokyo, Japan). Records were collected through the Dairy Herd  
84 Improvement Program. Records of 305-day milk yield (MY), 305-day fat yield (FY), and  
85 305-day protein yield (PY) were estimated by using a multiple-trait prediction (Schaeffer  
86 & Jamrozik 1996) according to Wilmink's function (Wilmink 1987). Lactation records  
87 that had fewer than eight test-day yields during the lactation period were eliminated.  
88 Average SCCs were log-transformed into SCSs by using the formula  $SCS =$   
89  $\log_2(SCC/100\ 000) + 3$  (Ali & Shook 1980). Three subsets (for first, second, and third  
90 lactations) were analyzed separately in the cases of yield and SCS. In addition, records  
91 of CR were assigned separately as three subsets (heifers, and first- and second-lactation  
92 cows). CR in heifers referred to the CR at first insemination (for first calving); CR in  
93 cows referred to the CR at first insemination during the first and second lactation

94 periods (for the second and third calvings, respectively). Records of CR were defined as  
95 binary traits of 0 or 1, where 1 indicated that the first insemination attempt successfully  
96 achieved pregnancy, and 0 indicated otherwise.

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

$$103 \quad THI = 1.8 \times t + 32 - (0.55 - 0.0055 \times rh) \times (1.8 \times t - 26),$$

104 where  $t$  is temperature in degrees Celsius and  $rh$  is relative humidity as a percentage.

105 THI was adjusted as follows (Mader *et al.* 2006):

$$106 \quad THI_{adj} = 4.51 + THI - 1.992 \times ws + 0.0068 \times sr,$$

107 where  $ws$  is wind speed measured in meters per second and  $sr$  is solar radiation  
108 measured in watts per square meter. Hereafter, we refer to  $THI_{adj}$  as THI. The  
109 distributions of the no-HS, mild-HS, and moderate-HS (Armstrong 1994; Smith *et al.*  
110 2013) groups in our dataset by prefecture are shown in Figure 1. Smith *et al.* (2013) also  
111 used severe HS ( $THI \geq 90$ ), but none of the regions studied here fell into that category.  
112 (The maximum THI was 81.) Areas were categorized into three regional groups: no HS  
113 ( $THI < 72$ ), mild HS ( $72 \leq THI < 79$ ), and moderate HS ( $THI \geq 79$ ). Our data contained  
114 782 710 records in the no-HS group, 162 909 for mild HS, and 133 070 for moderate HS.  
115 About 75,000 records in each HS group were chosen randomly by herd. Pedigree records  
116 obtained from the Holstein Cattle Association of Japan (Tokyo, Japan) were traced back  
117 three generations. A total of 228 242 records were used, with 407 274 animals in  
118 pedigree records.

119

120 **Model**

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

$$124 \quad Y_{ijklm} = HY_i + HS_j \times MC_k + AC_l + u_{jm} + e_{ijklm} \dots (1)$$

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

$$126 \quad Y_{ijklm} = HY_i + HS_j \times MI_k + AI_l + u_{jm} + e_{ijklm} \dots (2)$$

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

137 The variances were defined as

$$138 \quad \text{var} \begin{bmatrix} u \\ e \end{bmatrix} = \begin{bmatrix} G \otimes A & 0 \\ 0 & R \otimes I \end{bmatrix}, \quad G = \begin{bmatrix} \sigma_{u1}^2 & \sigma_{u1u2} & \sigma_{u1u3} \\ \sigma_{u1u2} & \sigma_{u2}^2 & \sigma_{u2u3} \\ \sigma_{u1u3} & \sigma_{u2u3} & \sigma_{u3}^2 \end{bmatrix}, \quad R = \begin{bmatrix} \sigma_{e1}^2 & 0 & 0 \\ 0 & \sigma_{e2}^2 & 0 \\ 0 & 0 & \sigma_{e3}^2 \end{bmatrix}$$

139 where  $G$  is a  $3 \times 3$  covariance matrix for additive genetics;  $R$  is a  $3 \times 3$  diagonal matrix of  
 140 residual variance corresponding to each trait (HS group);  $A$  is the matrix of additive  
 141 genetics among animals;  $I$  is the identity matrix for records; subscripts 1, 2, and 3 are

142 traits in the No-HS, Mild-HS, and Moderate-HS groups, respectively; and  $\otimes$  is the  
143 Kronecker product.

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

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

154

155

## 156 **RESULTS**

157

### 158 **Summary statistics**

159 Mean MY ranged from 8 080 kg to 10 041 kg, mean FY from 321 kg to 390 kg, and mean  
160 PY from 265 kg to 324 kg in the first three lactations (Table 1). SCS increased from the  
161 first lactation (range 2.3 to 2.5) to the third lactation (range 2.7 to 3.0). CR ranged from  
162 62% to 73% in heifers and from 39% to 45% in cows (Table 2). There were fewer CR  
163 records for mild- and moderate-HS heifers than for no-HS heifers.

164

### 165 **Heritability estimates**

166 Heritability estimates of MY declined with increasing parity, from 0.40 to 0.46 (first



167 lactation) to 0.27 to 0.29 (third lactation) (Table 3), in all HS groups. Heritability  
168 estimates also decreased steadily with increasing parity, from 0.39 to 0.41 (first  
169 lactation) to 0.27 to 0.28 (third lactation) for FY and from 0.34 to 0.36 (first lactation) to  
170 0.23 to 0.26 (third lactation) for PY. In contrast, the patterns of change in the  
171 heritabilities of SCS with increasing parity were not clear: the values ranged from 0.14  
172 (third lactation in the no-HS group) to 0.20 (first lactation in the moderate-HS group  
173 and second lactation in the moderate-HS group). Heritability estimates for CR were  
174 very low, ranging from 0.01 to 0.03 (Table 4), with no large differences between heifers  
175 and cows.

176

#### 177 **Genetic correlations**

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

189

#### 190 **Estimated effects of HS group and season**

191 The combined effect of HS group and season (HS-MC) on MY in cows was positive for

192 winter–spring calvings (first lactation: from +93 kg to 123 kg for January calvings and  
193 from 134 kg to 159 kg for February calvings; second lactation: from +96 kg to +174 kg for  
194 January to April calvings; third lactation: from +144 kg to +278 kg for January to March  
195 calvings) (Fig. 2). In contrast, this effect was negative in the case of summer and early  
196 autumn calvings (first lactation: from –120 kg to –162 kg for September calvings; second  
197 lactation: from –213 kg to –249 kg for September calvings; third lactation: from –215 kg  
198 to –301 kg for July–September calvings), but it did not differ among HS groups (Fig. 2).  
199 The differences in the estimated effects between spring and summer calvings increased  
200 in later lactations.

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

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

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

215

216

217 **DISCUSSION**

218

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

229 Our posterior means of heritabilities for MY (ranging from 0.27 to 0.46), FY (ranging  
230 from 0.27 to 0.41), and PY (ranging from 0.23 to 0.36) (Table 3) were similar to those  
231 reported before for Holstein cows in Japan (Kawahara *et al.* 2006; Hagiya *et al.* 2013;  
232 Yamazaki *et al.* 2013). Our heritability estimates for SCS (ranging from 0.14 to 0.20;  
233 Table 3) were in agreement with those in recent studies of Holstein cows (Pritchard *et al.*  
234 2013; Yamazaki *et al.* 2013). Our heritability estimates for reproductive traits were  
235 generally low. Using a linear model, Bastin *et al.* (2010) estimated that the heritability of  
236 the non-return rate at first lactation in Canadian Holstein cows was 0.026. Liu *et al.*  
237 (2008) also used a linear model; they reported that the heritabilities of the non-return  
238 rate in three European countries were 0.012 in heifers and 0.015 in dairy cows. Hagiya  
239 *et al.* (2013), using a threshold animal model, reported that the heritabilities of CR were  
240 0.031 in heifers, 0.034 in first-lactation cows, and 0.028 in second-lactation cows  
241 (Japanese Holsteins). Our heritability estimates for CR (ranging from 0.01 to 0.03) were

242 in the general range of these reports but lower than those obtained by using the  
243 threshold model (Table 4). For analysis of binary traits, theoretically, the threshold  
244 model is more accurate than the linear model (Gianola 1982), and heritability estimates  
245 obtained by using a threshold model are usually higher than those obtained by using a  
246 linear model (Weller & Ron 1992). However, the correlations between the estimated  
247 breeding values obtained from the threshold and linear models are very high ( $>0.99$ ;  
248 Weller & Ron 1992). As described in detail by Jamrozik *et al.* (2005), routine genetic  
249 evaluation of binary fertility traits is performed mostly by using a linear model, because  
250 with the threshold animal model there is a problem with convergence. Therefore, our  
251 results obtained by using a linear model should be useful for routine genetic evaluation.  
252 The genetic correlations of MY among the different HS groups declined slightly with  
253 increasing parity, whereas the genetic correlations of SCS and CR did not differ among  
254 lactations (Tables 5, 6). All posterior means of the genetic correlations were significantly  
255 ( $P < 0.001$ ) smaller than 1.0. These results suggest the existence of interactions between  
256 HS group and breeding value for MY, FY, PY, SCS, and CR under Japanese climatic  
257 conditions.

258 HS-MC had the greatest negative effect on MY when cows calved from July to  
259 September, but this effect did not differ among HS groups. The differences among HS  
260 groups in the seasonal effects on SCS in third-lactation cows were not clear, because the  
261 95% confidence interval was expanded (Fig. 3c). However, in the first two lactations the  
262 seasonal effects of increasing THI on SCS were highest with summer calving (Fig. 3a,  
263 3b). In contrast, the effects of month at first insemination on CR in heifers were similar  
264 throughout the year in all HS groups (Fig. 4a). However, among cows inseminated in  
265 summer and early autumn (July to September), those in the mild- and moderate-HS  
266 groups experienced a more negative effect on CR than did those in the no-HS group (Fig.

267 4b, 4c). Therefore, interactions with HS group affected the health and reproductive  
268 traits of cows, rather than the yield traits. In cows inseminated in August—especially  
269 during second lactation—there were large differences among HS groups in terms of the  
270 negative effect on CR (Fig. 4c). Aguilar *et al.* (2009) considered later-parity cows to be  
271 more susceptible than first-parity cows to HS. Boonkum *et al.* (2011) also reported that  
272 response to HS is strongly affected by parity. The differences we found in the effects on  
273 CR among HS groups were in agreement with these findings. Nishiura *et al.* (2015)  
274 found negative genetic correlations between test-day milk yield and fat-to-protein ratio  
275 (as an index of energy balance) in Japanese cows; they suggested that a negative energy  
276 balance in mid- to late lactation was associated with a reduction in milk yield. Negative  
277 energy balance in milking cows likely affects the health and reproductive traits of  
278 different HS groups to different degrees.

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

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288

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376 **Figure legends**

377

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

379 HS = heat stress; THI = temperature-humidity index; No HS =  $THI < 72$ ; Mild HS =  
380  $72 \leq THI < 79$ ; Moderate HS =  $THI \geq 79$

381

382 Figure 2 Effects and 95% confidence intervals (with bars) of calendar month at calving

383 on milk yield in cows in (a) first lactation, (b) second lactation, and (c) third lactation, by

384 HS group

385 HS = heat stress; THI = temperature-humidity index; No HS =  $THI < 72$ ; Mild HS =  
386  $72 \leq THI < 79$ ; Moderate HS =  $THI \geq 79$

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

388

389 Figure 3 Effects and 95% confidence intervals (with bars) of calendar month at calving

390 on somatic cell score in cows in (a) first lactation, (b) second lactation, and (c) third

391 lactation, by HS group

392 HS = heat stress; SCS = somatic cell score; THI = temperature-humidity index; No HS =  
393  $THI < 72$ ; Mild HS =  $72 \leq THI < 79$ ; Moderate HS =  $THI \geq 79$

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

395

396 Figure 4 Effects and 95% confidence intervals (with bars) of calendar month of

397 insemination on conception rate at first insemination in (a) heifers, (b) cows inseminated

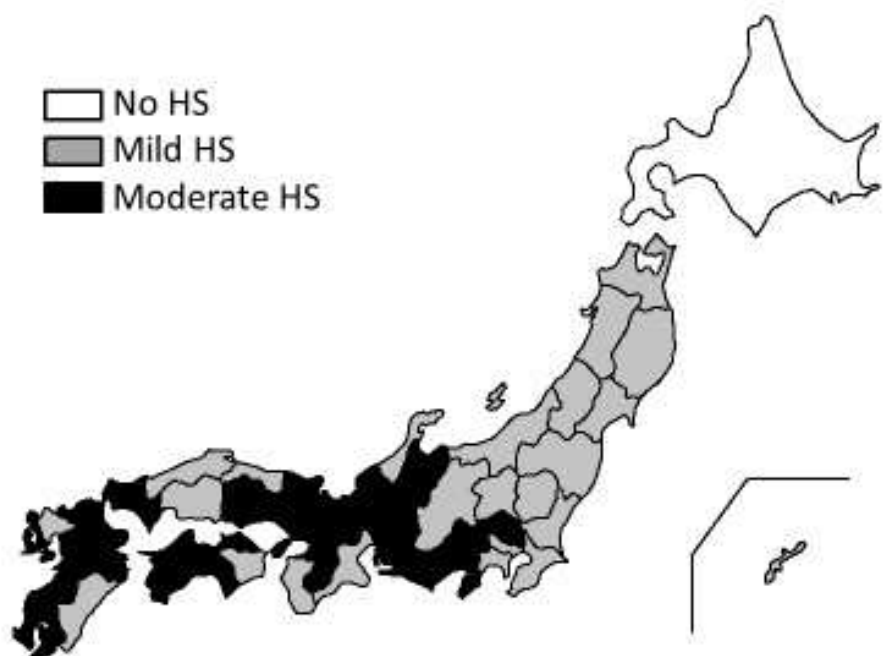
398 during first lactation period and (c) cows inseminated during second lactation period, by

399 HS group

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

- 401  $72 \leq \text{THI} < 79$ ; Moderate HS =  $\text{THI} \geq 79$
- 402 Average of effects was set to zero for each HS group.
- 403

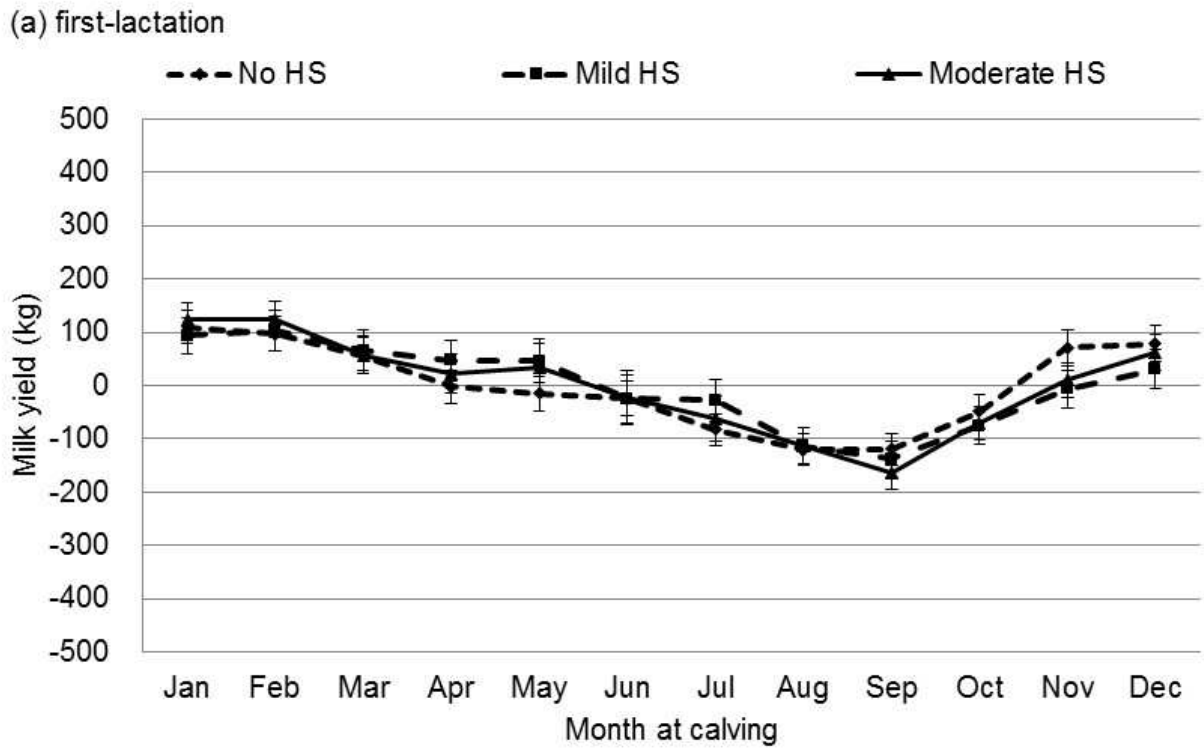
404 Fig. 1



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407 Fig. 2a

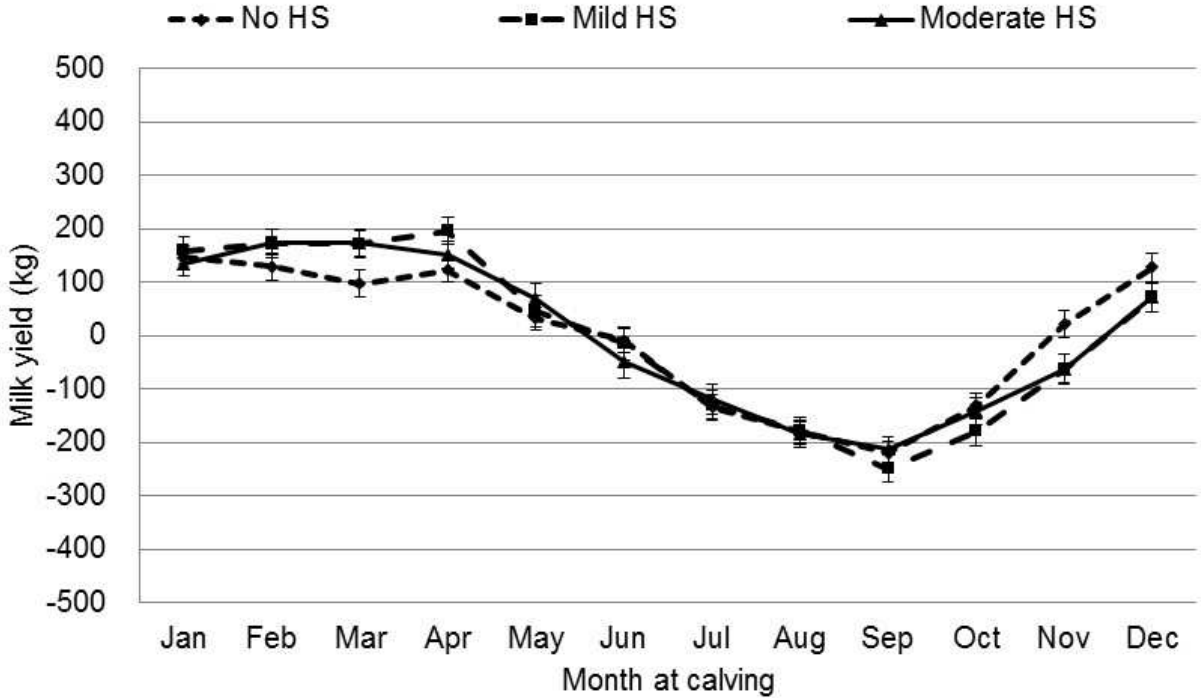


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410 Fig. 2b

(b) second-lactation

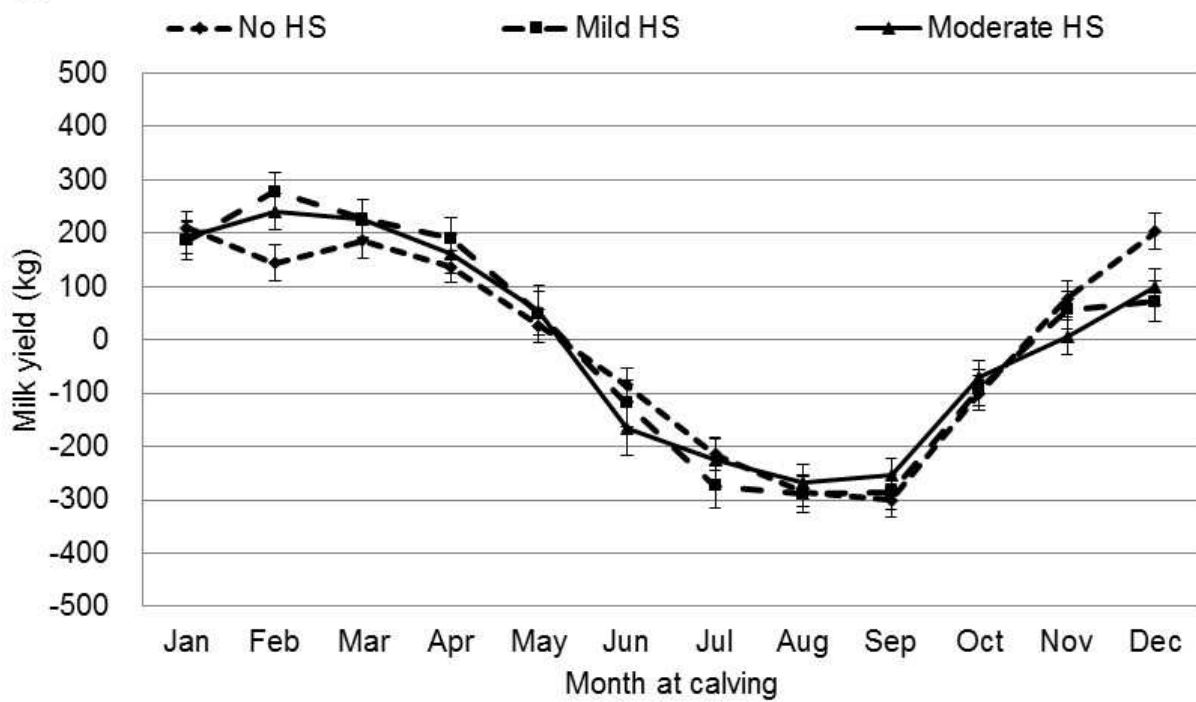


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413 Fig. 2c

(c) third-lactation

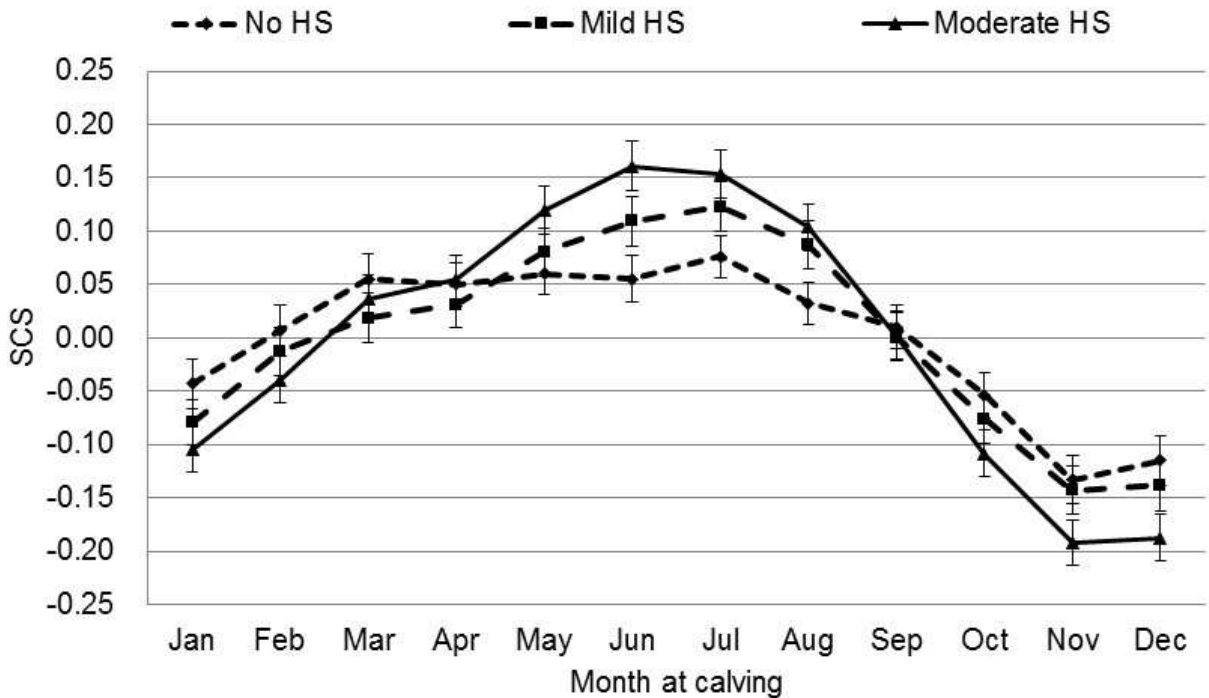


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416 Fig. 3a

(a) first-lactation



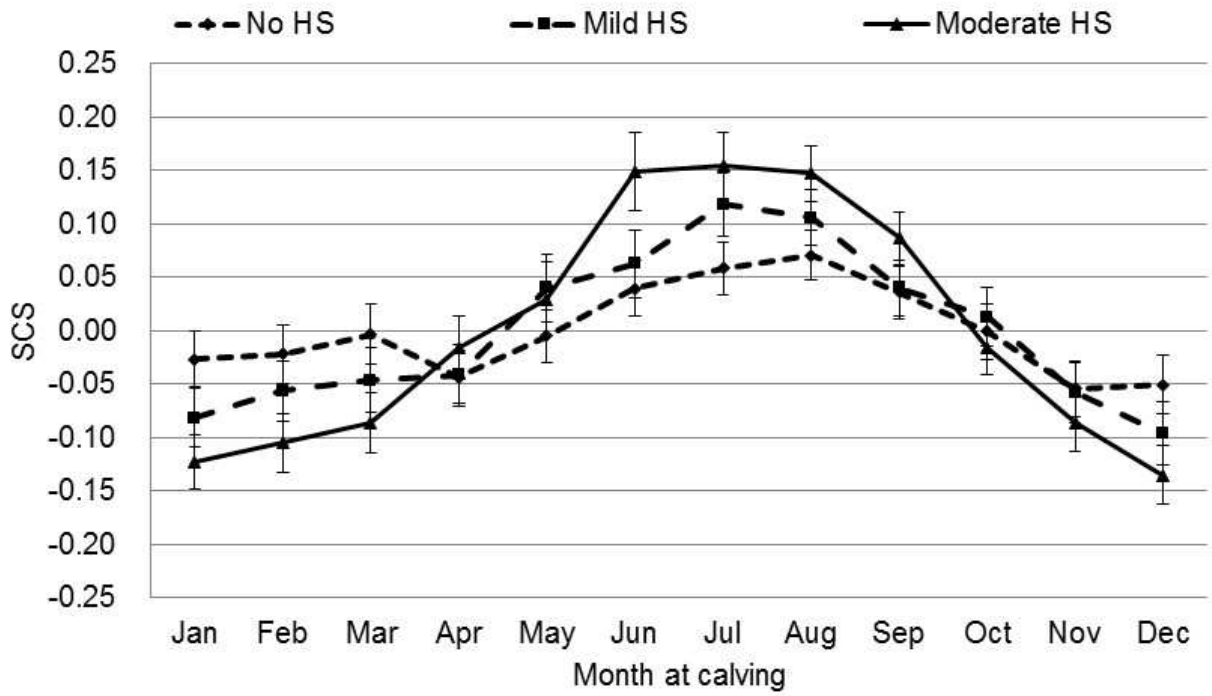
417

418



419 Fig. 3b

(b) second-lactation

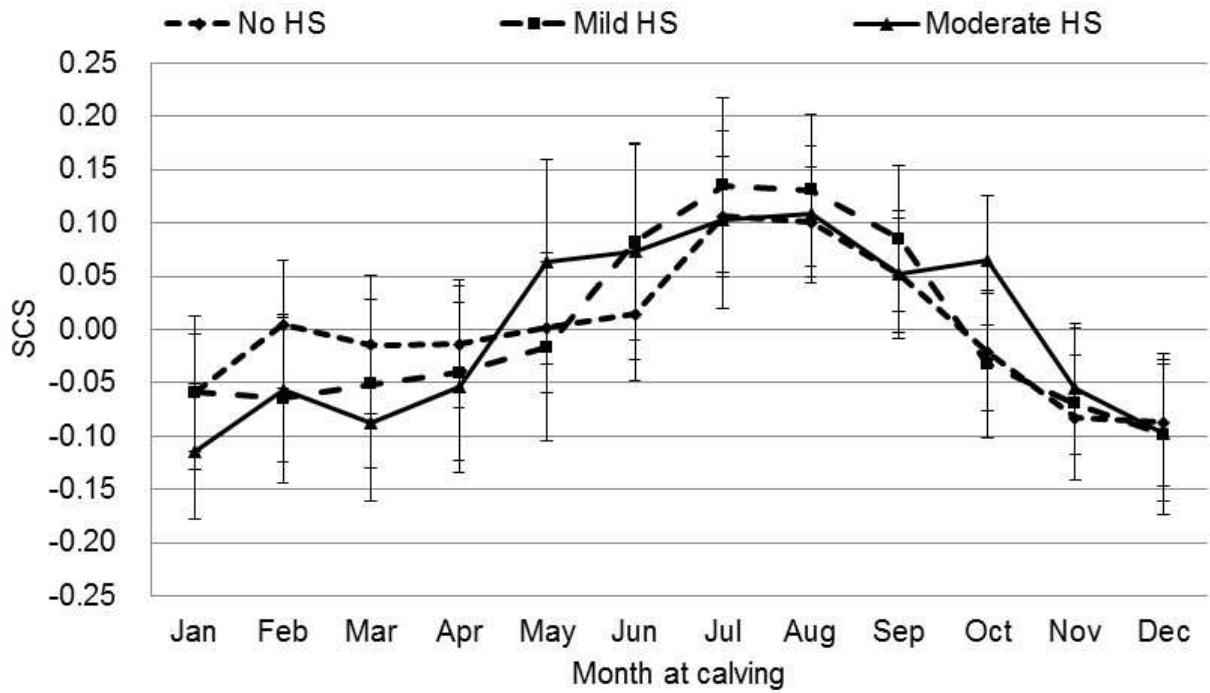


420

421

422 Fig. 3c

(c) third-lactation

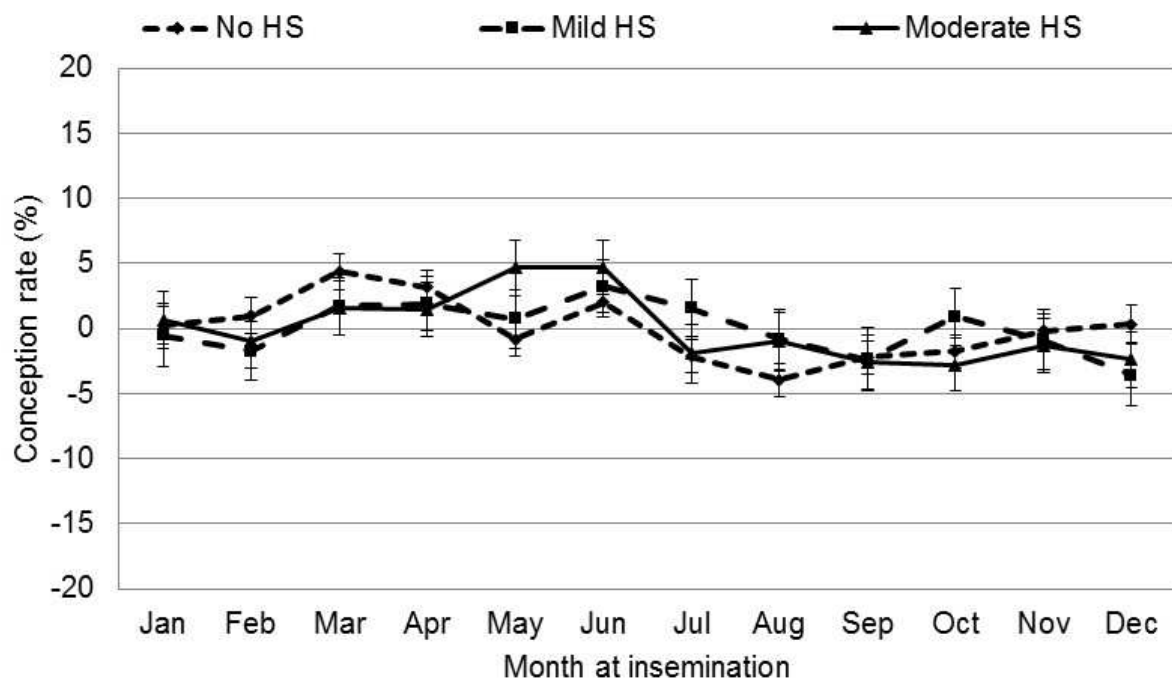


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425 Fig. 4a

(a) heifers

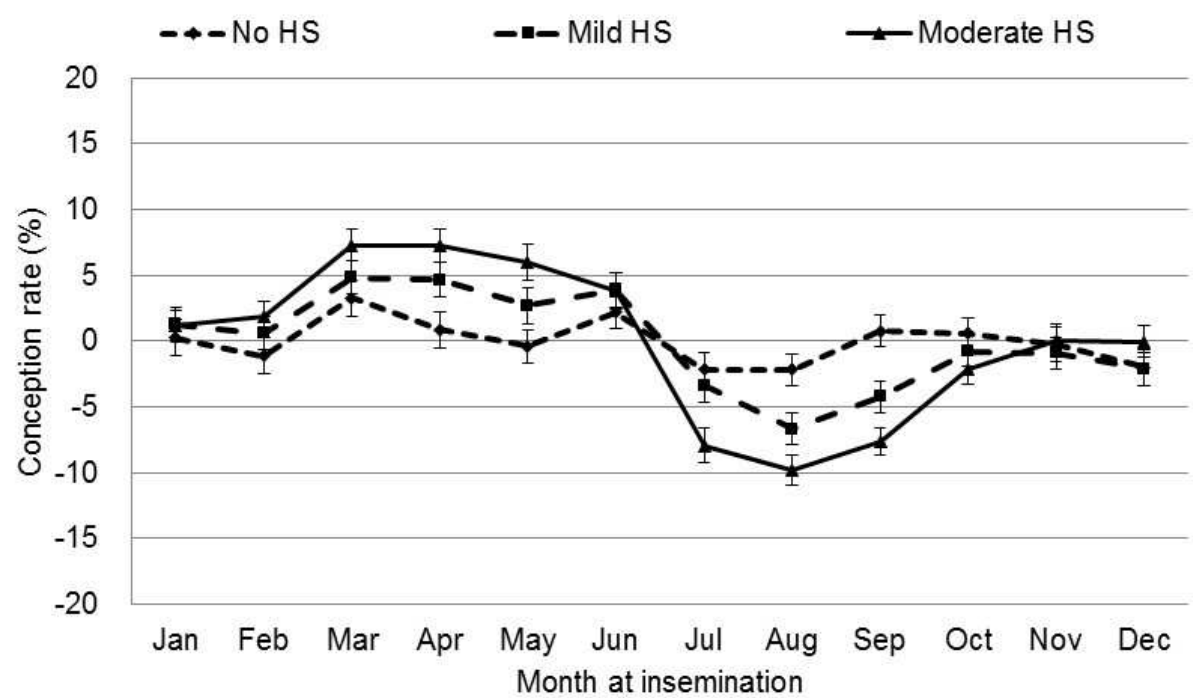


426

427

428 Fig. 4b

(b) cows during first-lactation period

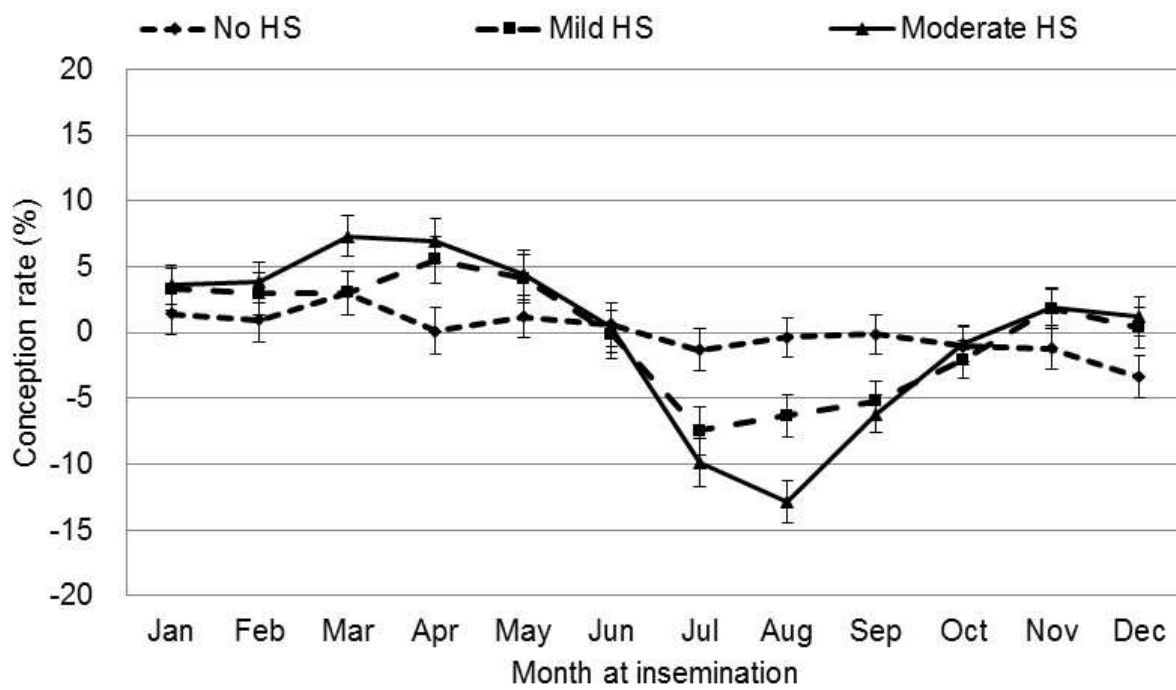


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431 Fig. 4c

(c) cows during second-lactation period



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

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

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**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 =  $72 \leq \text{THI} < 79$ ; Moderate HS =  $\text{THI} \geq 79$

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**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 =

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

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

Trait HS group	First lactation		Second lactation		Third lactation	
	$r_G$	(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 =  $72 \leq THI < 79$ ; Moderate HS =  $THI \geq 79$

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**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	
	$r_G$	(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 =  $72 \leq \text{THI} < 79$ ; Moderate HS = THI  $\geq 79$

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1 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  
2 る暑熱ストレスの影響

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13 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  
14 (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  
15 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  
16 ンパク質量および体細胞スコア，未經産から2産分娩次までの初回授精に関す  
17 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  
18 (THI) を計算し，47各都道府県をno HS (THI < 72)，mild HS (72 ≤  
19 THI < 79) およびmoderate HS (79 ≥ THI) の3区分に割り当てた。分析  
20 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  
21 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  
22 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  
23 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  
24 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  
25 mild HSとmoderate HSで顕著であった。