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1 **Original article**

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3 **Relationships between welfare and reproductive performance in French dairy herds**

4

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16

17 **Abstract**

18 This study aimed to investigate the relationship between cow reproductive performance
19 and welfare evaluated at the herd level using the Welfare Quality protocol. The 11 criteria, four
20 principles (good feeding, good housing, good health and appropriate behavior, scale 0 to 100)
21 and overall welfare category (excellent/enhanced/acceptable/not classified=poor welfare) were
22 included as risk factors for calving to first service interval (CFSI) and calving rate (CR). The
23 confounding factors cow breed, parity, season of calving and AI, calving to AI interval, rank of
24 AI (1 to 3) and milk production were taken into account. The sample included 3951 AIs (2172
25 AI1, 1182 AI2, 597 AI3) in 124 French commercial dairy herds.

26

27 Median CFSI was shorter for the cows bred in herds with a higher overall welfare
28 category (median 75 and 76 days in enhanced and acceptable herds vs. 86 in poor welfare ones,
29 $P = 0.02$). The scores for absence of injuries and expression of social behavior tended to be
30 associated with CFSI ($P < 0.10$). Calving rate (34.5%) was not related to the overall welfare
31 category. However, CR was positively related to the good housing score and a positive trend
32 was observed with the score for absence of prolonged hunger and absence of injuries scores. In
33 conclusion, this study confirms a positive relationship between CFSI and welfare in dairy cows
34 with no explicit links with specific aspects of animal welfare.

35

36 *Keywords:* Calving rate; Calving to first service interval; Dairy cow; Fertility; Welfare

37

38 **Introduction**

39 There is currently a serious concern about farm animal welfare in western countries: the
40 vegan and anti-species movements call into question rearing animals. Moreover, consumers
41 want to know how their food is produced. Identifying positive relationships between welfare
42 and productivity might reassure consumers and encourage producers to improve animal welfare
43 in their farms. Moreover, relationships between welfare and routinely recorded data (date of
44 birth, calving date, date of insemination, milk production, milk quality, date of culling...) might
45 help in selecting herds for welfare assessment (Sandgren et al., 2009; de Vries et al., 2014).
46 This has been extensively studied in dairy cows (for a review: (de Vries et al., 2011). For
47 example, in their meta-analysis, Lopez-Gatius et al. (2003) and Bedere et al. (2018) reported
48 significant associations between body condition score (BCS) at calving, BCS change between
49 calving and first service, BCS at nadir and number of days open. Days open were significantly
50 reduced in animals with high BCS at calving showed a significant reduction in days open vs.
51 animals with an intermediate or low BCS. A severe loss (>0.5 points on a 5 point scale) in BCS
52 during early lactation and a low BCS ($BCS \leq 2$) at nadir was related to an increase in days open
53 and to a reduction of conception rate compared to a slight BCS loss and $BCS \geq 2.5$ at nadir
54 (Chagas et al., 2007; Bedere et al., 2018). However, if days open is a good indicator of the
55 effects of BCS or change in score on reproductive performance, the measurement of conception
56 rate at first service produced variable results among studies. Likewise, lameness (Hernandez et
57 al., 2001; Hernandez et al., 2005) and disease (Fourichon et al., 2000; Raboisson et al., 2014)
58 were clearly related to reproductive performance: affected cows had longer calving to first
59 service interval and required more AIs to become pregnant than healthy cows. The response to
60 the approach of a human was positively associated with conception rate at first service
61 (Hemsworth et al., 2000). However, most studies have focused on only one specific aspect of
62 welfare rather than considering welfare as a whole.

63

64 A protocol allowing the overall assessment of animal welfare at the herd level was
65 developed in Europe in the Welfare Quality project (Botreau et al., 2007; Welfare Quality,
66 2009; de Vries et al., 2013). This protocol was used in the winter of 2010-2011 in 131 French
67 dairy farms and conducted to identify the main welfare problems and associations between
68 welfare and milk production (Coignard et al., 2013; Coignard et al., 2014; de Boyer des Roches
69 et al., 2014). Coignard et al. (2014) identified positive associations between milk yield and low
70 levels of aggression between cows and good emotional state of the herd. However, milk yield
71 was also associated with low welfare principle scores for Good health assessed by the
72 occurrence of diseases and injuries.

73

74 In dairy systems, production performance refers to milk yield and composition but is
75 also related to reproductive performance and longevity. Calving and insemination dates are
76 routinely recorded in most countries. Sangden et al. (2009) and De Vries et al. (2014) have
77 already explored the relationship between reproductive performance and welfare measured at
78 the herd level. However, they did not consider confounding factors in their models. Therefore,
79 the objective of this study was to investigate the relationship between cow reproductive
80 performance and welfare scores measured at the herd level through the Welfare Quality
81 Protocol, in French commercial dairy herds, taking into account confounding factors for
82 reproductive performance recorded in the national database.

83

84 **Materials and methods**

85 The study was carried out in 2010 and 2011 using only remote observations; ethical
86 review was not required for this kind of work in 2010 and animal studies were compliant with
87 all applicable provisions established by the European Directive 2010/63/EU. However,

88 approval was sought and granted by the VetAgro Sup Ethics Committee for Experiments on
89 Animals (France, agreement number CEEA18) on 5 March, 2019.

90

91 *Dairy farms and welfare assessment*

92 This investigation was conducted in the 131 French commercial dairy farms previously
93 studied by de Boyer des Roches et al. (2014). The farms were selected to be representative of
94 the diversity of French dairy systems. They were visited once during the winter, between
95 December 2010 and March 2011.

96

97 Animal welfare was estimated using the Welfare Quality (WQ) assessment protocol for
98 dairy cattle (Welfare Quality, 2009). Briefly, 11 welfare criteria were assessed using one to
99 seven measurements (Table 1). Each criterion was evaluated on a scale of 0 (lowest score) to
100 100 (highest score). These criterion scores were then grouped into four principle welfare scores
101 giving the highest importance to the worst criterion. The four principle scores (good feeding,
102 good housing, good health and appropriate behavior) were also expressed on a scale of 0 (lowest
103 score) to 100 (highest score). Finally, the farm was assigned to an overall welfare category
104 according to their principles scores. Overall welfare was considered to be excellent (at the
105 highest level), if all the scores were >55 with two principle welfare scores >80, enhanced
106 (good), if the principle welfare scores were all >20 with two principle scores >55, acceptable
107 (above or meets minimal requirements), if the four principle welfare scores were >10 with at
108 least three principle scores > 20. In the other situations, welfare was considered to be very low
109 and the term used to describe the herd was not classified (poor welfare).

110

111 *Data recorded and reproductive performance of the cows*

112 The following data were extracted from the national performance database (Système
113 National d'Information Génétique): cow breed, dates of calving, parity, milk production during
114 the first 3 months of lactation, insemination dates, breed of the bull used, type of semen (sex
115 sorted or not). Rank 1 to 3 artificial inseminations (AI) performed between the 1 December
116 2010 to the 31 March 2011 were selected. During this period, cows are housed in France and
117 welfare was considered to be unchanged. In April, most of the cows are put out to grass and
118 this might change their welfare situation. When first service occurred before 20 days post-
119 calving or >200 days post-calving, the cows were excluded from the study. When two AIs were
120 separated by an interval shorter than 5 days only the second AI was used and included in the
121 analysis. The use of these inclusion criteria meant that only the data from 124 herds of the 131
122 were used. The exclusion of the remaining seven herds was due to the fact that an eligible AI
123 was not observed during the period.

124

125 Two parameters were calculated to estimate reproductive performance: the calving to
126 first service interval (CFSI) and the calving rate after AI (CR). A cow was considered to be
127 pregnant if its subsequent calving occurred during an interval which was compatible with the
128 average length of pregnancy for the breed ± 2 standard deviations (SD; as evaluated by
129 Marceau et al. (2014). Cows culled between AI and the end of pregnancy were considered to
130 be non-pregnant as recommended by the International Committee for Animal Recording¹.

131

132 *Statistical analysis*

133 The statistical unit was the AI. The overall welfare category, each principle and each
134 criterion scores were taken into account in the analysis. As previously proposed by Coignard et

¹ See: International Committee for Animal Recording, 2016. International Recording Guidelines.
<https://www.icar.org/index.php/icar-recording-guidelines/> (Accessed 17 March 2019).

135 al. (2014), the quantitative evaluations of each principle and criterion welfare scores were split
136 into two categories: the first category corresponded to the lowest scores (i.e. scores lower than
137 or equal to the first quartile) observed at cow level and the second category corresponded to the
138 scores above the first quartile. This methodology was chosen to investigate the effects of high
139 welfare impairment rather than to compare the best half to the worst half of herds since in the
140 herds included in this study welfare variability was low (absence of enhanced and low number
141 of poor welfare scored herds).

142

143 The relationships between CFSI and the welfare indicators (i.e. overall welfare category,
144 principles and criteria scores) were evaluated using multivariate Cox proportional hazard
145 models. Models were adjusted to take into account the factors likely to influence CFSI: cow
146 breed (Prim'Holstein vs. Montbéliarde and other breeds), parity (primiparous vs. multiparous),
147 season of calving (spring and summer, autumn, winter), mean milk production during the 3
148 months after calving, season of insemination (autumn vs. winter) and two interactions:
149 parity*milk production and breed*milk production. These factors were selected because they
150 have already been associated with CFSI in the literature (Crowe et al., 2014).

151 The following model was used:

$$152 \quad h_{ij}(t|X_{ij}, \alpha_j) = h_0(t) * \exp(X_{ij}\beta + \alpha_j)$$

$$153 \quad \alpha_j \sim Normal(0, \sigma_\alpha^2)$$

154 where h_{ij} is the hazard function at time t for the probability of AI after a calving for the i^{th} cows
155 of the j^{th} herd, $h_0(t)$ is the unspecified hazard function, X_{ij} is a matrix containing all adjustment
156 variables previously cited, β is the vector of coefficients associated with these variables and α_j
157 and α_j is a herd random effect. It was assumed to be normally distributed with a mean of 0 and
158 a variance of σ_α^2 .

159

160 Mixed logistic regression was used to analyze the relationships between CR and welfare
161 indicators. As previously described, the models were adjusted for factors likely to influence CR
162 (Walsh et al., 2011) : cow breed, parity, season of calving, mean milk production during the 3
163 months after calving, season of insemination, rank of AI (1, 2 or 3), interval between calving
164 and AI, type of semen (sex-sorted vs. not sorted) and crossbreeding (bull breed different from
165 the cow breed), parity*milk production and breed*milk production. The model used was:

$$166 Y_{ij} \sim \text{Bernoulli}(p_{ij})$$

$$167 \ln\left(\frac{p_{ij}}{1-p_{ij}}\right) = X_{ij}\beta + u_{ij} + \alpha_j$$

$$168 u_{ij} \sim \text{Normal}(0, \sigma_u^2)$$

$$169 \alpha_j \sim \text{Normal}(0, \sigma_\alpha^2)$$

170 where the outcome Y_{ij} is the binary variable representing the occurrence of a calving for the cow
171 i in the herd j , X_{ij} is a matrix containing all adjustment variables previously cited, β is the vector
172 of coefficients associated with these variables, u_{ij} is the random nested effect for a cow i in a
173 herd j and α_j is a herd random effect for the herd j . The random effect u_{ij} and α_j were assumed
174 to be normally distributed with a mean of 0 and a variance of σ_u^2 and σ_α^2 respectively.

175

176 The quality of the models was estimated using the Akaike Information Criterion (AIC).
177 The model containing the most variables with the lowest AIC was retained. Sixteen Cox
178 proportional hazard models were constructed: for each reproductive performance: one for the
179 overall welfare category, four for each welfare principle scores and 11 for each criteria score.
180 Each welfare score was taken into account alone, and its introduction in the multivariate models
181 aimed to evaluate its effect corrected for the other variation factors susceptible to influence
182 reproductive performance.

183

184 All statistical analyses were performed by using R software². Cox models were
185 performed using the survival package³ (Therneau and Grambsch, 2000) and mixed logistic
186 regression using the lme4 package (Bates et al., 2015). The effect of each welfare score in the
187 different models was evaluated using drop 1 function of stat package and ANOVA function of
188 car package.

189

190 **Results**

191 *Characteristics of the sample studied*

192 The final data set included 3951 AIs (2172 AI1, 1182 AI2 and 597 AI3) from 2755 cows
193 in 124 herds. The mean number of lactating cows per herd was 51 ± 17 (mean \pm SD). A majority
194 of the herds (52.4%) were located in lowlands vs. 47.6% in highlands, 42.0% used straw
195 bedding vs. 58.0% cubicles. Milking was performed in a parlor for 83.1% of the herds and with
196 an automatic system for 16.9%. Cows had access to pasture during the grazing season in 79%
197 of the herds.

198

199 The overall welfare category was enhanced in 38.7% ($n=48/124$) of the herds,
200 acceptable in 57.3% ($n=71/124$) and poor welfare in 4.0% ($5/124$) of them. None of the herds
201 were classed as excellent. The overall welfare category, four principle and 11 criterion-scores
202 recorded in the 124 herds are presented in Table 2. They were described by de Boyer des Roches
203 et al. (2014).

204

205 Briefly, the main welfare problems highlighted by the median of criterion welfare scores
206 were Absence of pain induced by management procedures and Absence of disease. In the first

² See: The R Project for Statistical Computing <https://www.r-project.org> (Accessed 19 March 2019)

³ See : Therneau T., 2015. A package for survival analysis in R. version 2.38 <https://CRAN.R-project.org/package=survival>. (Accessed 21 March 2019)

207 quartile, the Good feeding score was low mainly due to a low Absence of prolonged thirst score
208 which was attributed when there were too few drinkers (>15 cows by drinking point). The
209 absence of prolonged hunger score was also low in the first quartile, which was related to >23%
210 of cows being very thin (<2.5). The good housing score was low when comfort around resting
211 was not adequate. This was related to a long time taken to lie down and to a high percentage of
212 cows which had dirty lower legs. Ease of movement score was high in all the farms because all
213 the cows were loose-housed. The good health score was low in the first quartile mostly related
214 to dehorning practices (disbudding without anesthetic or analgesic), to disease, essentially due
215 to a high percentage of cows with somatic cell counts > 400 000 cells/mL and finally to small
216 integument alterations and lameness. The low appropriate behavior score in the first quartile
217 was related to a high number of head butts or other aggressive events per cow per hour (low
218 score for expression of social behaviors), to the low percentage of cows which could be touched
219 or approached within less than 50 cm (low score for good human-animal relationship) and
220 finally, to negative terms attributed to describe cow behavior (low score for positive emotional
221 state).

222

223 The number of cows per herd inseminated during the observation period ranged from
224 one (in one herd) to 56 (in one herd). Most of the cows were bred in the herds classified as
225 enhanced ($n=1145/2755$; 41.6%) and acceptable ($n=1526/2755$; 55.4%) welfare. Only 3.0%
226 ($n=84/2755$) were bred in the poor welfare herds. The welfare scores observed for the 2755
227 cows are described in Supplementary material S1. The sample was comprised of mainly
228 Montbéliarde (50.9%) and Prim'Holstein (45.7%) cows. Reproductive performance was for the
229 Prim'Holstein, Montbéliarde and other breeds respectively 83, 72, 73 days for the CFSI median
230 and 27.1, 40.9 and 43.2% for the CR. The result from the 95 cows (3.4%) classed as other
231 breeds were grouped with the Montbéliarde cows since their reproductive performance was

232 similar. Parity ranged from 1 to 13. Maximum and mean daily milk production during the first
233 3 months of lactation were respectively 32.8 ± 7.8 and 30.1 ± 7.3 kg/d. The main cow
234 characteristics recorded for the cows are presented in Table 3. Crossbreeding was used for
235 16.4% of the AIs ($n=649/3951$) and sex-sorted semen was used for only 75 AI of the 3951
236 performed.

237

238 The median of CFSI was 76 days (mean 81.5 ± 27.7 days; $n=2172$) and CR was 34.5%
239 for the whole sample.

240

241 *Relationship between animal welfare and CFSI*

242 When introduced in the multivariate model the overall welfare category was
243 significantly related to CFSI ($P=0.02$). CFSI tended to be associated with the criterion C6
244 (absence of injuries, $P=0.06$) and C9 (expression of social behavior, $P=0.07$; Table 4). For the
245 overall welfare category and C6 (absence of injuries), the higher the welfare category/score the
246 shorter was the CFSI (-11 to -7 days). The relationship was the opposite for C9. CFSI was
247 shorter in the herds where high levels of agonistic interactions were observed between cows (-
248 2 days).

249

250 Among the covariates, only breed, season of calving and season of AI were significantly
251 related to CFSI. Median CFSI was shorter in Montbéliarde and other breeds compared to
252 Prim'Holstein cows (72.0 vs. 83.0 days; $P < 0.001$), when calving occurred in autumn compared
253 to spring/summer (72.0 vs. 98.0 days; $P < 0.0001$) and when insemination occurred in autumn
254 compared to winter/spring (73.0 vs. 77.0 days; $P < 0.0001$).

255

256 *Relationship between animal welfare and CR*

257 The variables crossbreeding and type of semen were not retained in the multivariate
258 model because their contribution to model quality was not significant.

259

260 The overall welfare category was not related to CR ($P=0.54$). CR was significantly
261 related with the P2 criteria (good housing, $P=0.05$; Table 5) and this effect was explained by
262 the relationship between CR and C3 (comfort around resting; $P=0.05$). Two trends were
263 observed: CR tended to be related to C1 (absence of prolonged hunger; $P=0.07$) and C6
264 (absence of injuries; $P=0.09$). For all these associations the higher the score, the higher was the
265 CR (odds ratio 1.21 to 1.24).

266

267 Among the covariates taken into account in the models, breed and milk yield were
268 significantly associated with CR. CR was lower in Prim'Holstein cows than in Montbéliardes
269 and other breeds (OR=0.40; $P<0.0001$) and was reduced in lower producing (≤ 26.3 kg/d) vs
270 higher producing cows (>32.8 kg/d; OR=0.66; $P=0.002$).

271

272 **Discussion**

273 This study aimed to assess the relationship between welfare measured at the herd level
274 and reproductive performance in a population selected to reflect the diversity of French dairy
275 farms. We considered potential confounding factors of our two indicators of reproductive
276 performance: calving to first service interval (CFSI) and calving rate (CR). In most of our herds,
277 cows go to pasture for the grazing period. This is likely to affect their welfare: access to food
278 and water, comfort around resting, cleanliness, integument alterations, lameness, diseases,
279 somatic cell count, expression of social behavior might be modified when grazing. We therefore
280 limited our observations to the indoor period. This reduced the size of our dataset. However,

281 the number of inseminations selected was high enough to investigate relationships between
282 welfare and reproduction performance considering known confounding factors.

283

284 The herds included in our sample were slightly larger in size than the average French
285 herd (51 vs. 41 dairy cows, (Agreste, 2016)). We included mainly Prim'Holstein and
286 Montbéliarde cows in our study which are the main two French dairy breeds (66 and 17% of
287 the French population, (France Génétique Elevage, 2016).

288

289 The reproductive performance of the cows enrolled in this study were close to that
290 observed for the French cow population (Le Mezec, 2017). Mean CFSI was slightly shorter
291 than that observed in the French cow population (98 days for Prim'Holstein and 80 for
292 Montbéliarde cows, (Le Mezec, 2017)). The high proportion of Montbéliarde cows in our
293 sample reduced the mean CFSI observed. Moreover, we excluded CFSIs over to 200 days from
294 our analysis. CR was slightly lower than that observed in the French population (37.1% in
295 Prim'Holstein cows and 49.2% in Montbéliarde ones, (Le Mezec, 2017)). However, Le Mezec
296 calculated the calving rate without taking into account culled cows. Moreover, they included
297 only parity from 1 to 3. In our analysis, all the culled cows were considered to be not pregnant
298 and we included all ranks of lactation (range from 1 to 13). This might have reduced our
299 estimation of CR (Walsh et al., 2011).

300

301 In our study, none of the herds were classified as excellent after welfare was evaluated
302 and only five herds were not classified (poor welfare, considered to be unacceptable). The
303 absence of excellent herds has already been observed by de Vries et al. (2013) in a sample of
304 196 herds in The Netherlands even though they were selected to have a wide range of levels of
305 animal welfare. This could mean that the level of dairy herd welfare is low in Europe or that

306 the system of evaluation is not adapted to current dairy cow rearing practices. The low number
307 of poor welfare farms might be explained by the fact that herd recruitment was voluntary in our
308 study. Consequently, the relatively low variability in the welfare score in our sample might
309 have reduced the statistical power of our investigation.

310

311 The calving to first service interval was related to the overall welfare category calculated
312 with the Welfare Quality Protocol: the median CFSI was reduced by 11 days in the herds with
313 the best score (enhanced and acceptable in our study) compared to the worst (poor welfare).
314 This is in favor of a positive relationship between welfare and productivity.

315

316 However, CFSI was not significantly associated with the principle or criterion scores
317 were significantly associated to CFSI. Two welfare criteria tended to be associated with CFSI:
318 Absence of injuries and expression of social behavior. The higher the score for Absence of
319 injuries, the shorter was the median CFSI. Lameness is taken into account in this criterion and
320 a negative relationship with CFSI has already been observed by Fourichon et al. (2000) in their
321 meta-analysis and by Hernandez et al. (2001) in 837 Holstein cows. For Hernandez et al. (2005),
322 calving to conception interval was increased in lame cows which may be related to an effect on
323 CFSI but also on conception rate. Moreover, Sandgren et al. (2009), explored the potential of
324 using information recorded in the national database for use as indicators of animal welfare and
325 they identified a relationship between calving interval with a score for injuries and
326 inflammation and animal cleanliness (the better the score the shorter was the calving interval).
327 This is in agreement with our observation.

328

329 Herds with a high frequency of agonistic interactions (taken into account in C9,
330 expression of social behavior) tended to have a shorter CFSI. We can hypothesise that, the

331 shorter the CFSI, the higher was the probability to observe cows in heat in the herd. Indeed,
332 agonistic interactions between cows are observed when they are in oestrus (Orihuela, 2000;
333 Kerbrat and Disenhaus, 2004; Roelofs et al., 2010).

334

335 Surprisingly, the criterion absence of prolonged hunger estimated by the proportion of
336 very thin cows, was not related to CFSI even though low body condition score at calving and
337 high BCS loss after calving are known to increase the length of postpartum anoestrus in dairy
338 cows (Chagas et al., 2007; Crowe et al., 2014; Bedere et al., 2018). This might be related to the
339 methodology used to estimate this criterion in the Welfare Quality protocol. BCS was evaluated
340 on a sample of lactating and dry cows and pregnant heifers. A very lean cow corresponding to
341 a BCS < 2. The criterion was noted at a herd level and the score is lower than 20 (as in our first
342 quartile) if between 20% to 100% of cows are very lean. In high producing dairy herds, a
343 physiological loss of BCS is observed after calving. A proportion of 20% of thin cows is
344 perhaps not detrimental enough to affect CFSI if only observed in early lactating cows. It might
345 be of interest to differentiate between two criteria in the Welfare Quality Protocol: very low
346 BCS observed in dry cows, pregnant heifers, late lactating vs. early lactating cows. Therefore,
347 it seems that an improvement in animal welfare is likely to reduce the interval between calving
348 and insemination even though no specific aspect of animal welfare seems to have a prominent
349 effect.

350

351 In our study, CR rate was not related to the overall welfare category. However, a
352 significant relationship was observed between the principle good housing, the criterion comfort
353 around resting and CR. In our study, this was not related to the type of housing (cubicles vs.
354 straw bedding, data not shown). To our knowledge, the link between cow comfort and CR has
355 not been previously documented. The score for comfort around resting was the main factor

356 which influence the good housing score in our study. The other parameter taken into account
357 to calculate the P2 principle (good housing) is ease of movement which was high in all our
358 herds because all the cows were reared in loose housing systems. CR also tended to be
359 associated with absence of prolonged hunger and absence of injuries which is in agreement with
360 previous observations: low body condition score, lameness and claw disorders have been shown
361 to be related to low conception rate (Fourichon et al., 2000; Hernandez et al., 2001; Lopez-
362 Gatus et al., 2003; Hernandez et al., 2005; Bedere et al., 2018). All the association or trends
363 observed were positive: CR was higher when welfare scores were high. However, CR seemed
364 only to be related to certain specific aspect of welfare aspect (comfort around resting) and this
365 needs further investigations to be understand.

366

367 Finally, CFSI was more closely related to animal welfare measured at herd level than
368 CR. Therefore, the CFSI seems therefore to be more relevant when selecting herds before
369 conducting visits for on farm welfare assessment.

370

371 The other risk factors for poor reproductive performance identified in this work have
372 often been observed in other studies. CFSI was related to cow breed, season of calving and
373 season of AI as observed for French cattle in general (Le Mezec, 2017). CR was related to cow
374 breed and milk yield. The breed effect observed in this study has already been described in the
375 French and in the European cattle populations (European Food Safety Authority, 2009; Le
376 Mezec, 2017). The positive association between milk yield and CR (increase of CR with the
377 increase in milk yield) is not consistent with the generally accepted idea that there is a negative
378 relationship between milk yield and reproductive performance. However, some authors have
379 highlighted potential bias in this association (LeBlanc, 2010). In our study, the lower category
380 of milk production during the three first months of lactation was very low (≤ 26.3 kg/d). Animals

381 which produce less than this might have an alteration in health or a nutritional deficiency if the
382 diet is insufficient/unbalanced.

383

384 **Conclusions**

385 We identified positive associations between good welfare and reproductive
386 performance. CFSI was shorter for the cows bred in herds with enhanced and acceptable overall
387 welfare category and a trend was observed for the association with absence of injuries. CR was
388 not related to overall welfare category but was significantly higher in the farms with a high
389 comfort around resting score. Our study suggests that CFSI might be reduced by better animal
390 welfare. This result is likely to encourage dairy producers to improve welfare on their farms.
391 Moreover, a long CFSI which is routinely recorded, could be used as a criterion to help in the
392 identification of herds where it would be appropriate look more closely at animal welfare.

393

394 **Conflict of interest statement**

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396 financial or personal relationships that could inappropriately influence or bias the content of the
397 paper.

398

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409

410 **Appendix: Supplementary material**

411 Supplementary data associated with this article can be found in the online version at
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500 **Tables**

501 **Table 1**

502 The Welfare Quality protocol in dairy cattle: observations used to estimate the four principles
 503 (P) and the 12 criteria (C) welfare scores.

504

Principle and Criteria	Measure
P1: Good Feeding	
C1: Absence of prolonged hunger	Body condition score
C2: Absence of prolonged thirst	Provision of water
P2: Good Housing	
C3: Comfort around resting	Behavior at lying Cleanliness of cows
C4: Thermal comfort	No measure available
C5: Ease of movement	Possibility for cows to walk
P3: Good Health	
C6: Absence of injuries	Clinical observations: Lameness Clinical observation: Integument alterations
C7: Absence of disease	Clinical observations (coughing, nasal discharge, dyspnoea, vulval discharge...) Farm records: Milk somatic cell count over the 3 last months; dystocia; downer cow; mortality over the last 12 months
C8: Absence of pain induced by management procedures	Dehorning practices
P4: Appropriate behavior	

C9: Expression of social behaviors	Interaction between cows (aggressive events per cow per h)
C10: Expression of other behaviors	Access to pasture
C11: Good Human-Animal relationship	Avoidance distance of cow when approached at the feeding rack
C12: Positive emotional state	Qualitative behavior assessment

505

506

507 **Table 2**508 Welfare scores ^a recorded in 124 herds according to the Welfare Quality protocol assessment

509

Variable	Minimum	First quartile	Median	Third quartile	Maximum
Good feeding (P1)	3.5	14.6	43.5	64.8	100.0
Absence of prolonged hunger (C1)	2.5	27.9	49.3	100.0	100.0
Absence of prolonged thirst (C2)	3.0	3.0	60.0	100.0	100.0
Good housing (P2)	35.2	51.6	59.4	66.2	79.8
Comfort around resting (C3)	0.0	26.1	38.6	49.2	70.9
Ease of movement (C5)	95.0	95.0	95.0	95.0	95.0
Good health (P3)	13.4	25.5	29.5	35.8	52.4
Absence of injuries (C6)	8.7	39.1	55.7	69.2	100.0
Absence of disease (C7)	11.9	26.6	33.4	44.9	86.1
Absence of pain induced by management procedures (C8)	2.0	20.0	20.0	28.0	100.0
Appropriate behavior (P4)	6.5	26.6	37.4	44.7	69.0
Expression of social behaviors (C9)	0.0	20.5	41.3	61.7	95.8
Expression of other behaviors (C10)	0.0	77.2	82.3	86.5	100.0
Good human-animal relationship (C11)	13.7	33.5	41.6	51.0	69.6
Positive emotional state (C12)	1.3	34.9	49.0	66.5	93.3

510 ^a Scores were estimated on a scale of 0 (poor score) to 100 (best score)

511

512 **Table 3**

513 Characteristics of the 2,755 dairy cows included in the study.

514

Variable	<i>n</i>	Percentage
Overall welfare category of the herd		
Enhanced	1145	41.6
Acceptable	1526	55.4
Poor welfare	84	3.0
Cow breed		
Prim'Holstein	1258	45.7
Montbeliarde and others ^a	1497	54.3
Parity		
Primiparous	974	35.4
Multiparous	1781	64.6
Month of calving		
Spring and Summer (April to September)	995	36.1
Autumn (October to December)	1579	57.3
Winter (January to March)	181	6.6
Highest daily milk production during the first 3 months (kg/d)		
≤28.6	910	33.0
(28.6 ; 35.6)	927	33.6
>35.6	918	33.3
Mean daily milk production during the first 3 months (kg/d)		
≤26.3	908	33.0
(26.3 ; 32.8)	927	33.6
>32.8	920	33.4

515 ^a 95 cows of other breeds

516

517 **Table 4**

518 Associations between overall welfare category, principles and criteria scores (measured at herd
 519 level) and calving to first service interval (CFSI) in 124 French dairy herds ($n= 2172$ AI1). The
 520 scores were introduced one by one in a multivariate model taking into account breed, parity,
 521 season of calving, season of AI, milk production and interactions between milk
 522 production*breed and milk production*parity.

	Score	<i>n</i>	CFSI median	HR	95% CI	<i>P</i>
Overall welfare category	Acceptable	1202	76	Ref	-	
	Enhanced	907	75	0.93	0.78 - 1.12	0.02
	Poor welfare	63	86	0.68	0.86 - 1.06	
Good feeding (P1)	≤14.6	573	75	Ref.	-	0.65
	>14.6	1599	76	1.05	0.86 - 1.28	
Good housing (P2)	≤52.0	601	79	Ref.	-	0.26
	>52.0	1571	74	1.12	0.92 - 1.35	
Good Health (P3)	≤25.5	561	80	Ref.	-	0.14
	>25.5	1611	75	1.16	0.95 - 1.41	
Appropriate behavior (P4)	≤26.7	576	77	Ref.	-	0.67
	>26.7	1596	76	0.96	0.79 - 1.17	
Absence of prolonged hunger (C1)	≤28.9	552	82	Ref.	-	0.19
	>28.9	1620	74	1.15	0.94 - 1.40	
Absence of prolonged thirst (C2)	≤3.0	573	75	Ref.	-	0.65
	>3.0	1599	76	1.05	0.86 - 1.28	
Comfort around resting (C3)	≤26.8	601	79	Ref.	-	0.26
	>26.8	1571	74	1.12	0.92 - 1.35	

Absence of injuries	≤ 40.6	559	81	Ref.	-	0.06
(C6)	> 40.6	1613	74	1.20	0.99 - 1.45	
Absence of disease (C7)	≤ 24.6	541	78	Ref.	-	0.37
	> 24.6	1631	75	1.10	0.90 - 1.34	
Absence of pain induced	≤ 20.0	1362	76	Ref.	-	0.54
by management	> 20.0	810	76	0.95	0.79 - 1.13	
procedures (C8)						
Expression of social	≤ 23.9	580	74	Ref.	-	0.07
behaviors (C9)	> 23.9	1592	76	0.84	0.69 - 1.01	
Expression of other	≤ 77.2	593	76	Ref.	-	0.99
behaviors (C10)	> 77.2	1579	76	1.00	0.82 - 1.22	
Good human-animal	≤ 34.1	549	77	Ref.	-	0.63
relationship (C11)	> 34.1	1623	76	0.95	0.79 - 1.16	
Positive emotional state	≤ 34.1	557	75	Ref.	-	0.53
(C12)	> 34.1	1615	76	1.07	0.87 - 1.30	

523 HR, Hazard ratio; CI, Confidence Interval; Ref., Reference category

524

525 **Table 5**

526 Associations between overall welfare category, principles and criteria scores (measured at herd
 527 level) and calving rate (CR) in 124 French dairy herds ($n=3,951$; rank 1 - 3 artificial
 528 insemination [AI] in 2,755 dairy cows). The scores were introduced one by one in a multivariate
 529 model taking into account breed, parity, season of calving, season of AI, rank of AI, milk
 530 production and interactions between milk production*breed and milk production*parity.

		<i>n</i>	OR	95% CI	<i>P</i>
Overall welfare category	Acceptable	2182	Ref.	-	
	Enhanced	1647	1.12	[0.91 ; 1.37)	0.54
	Poor welfare	122	1.12	[0.66 ; 1.91)	
Good feeding (P1)	≤ 14.6	1031	Ref.	-	0.62
	> 14.6	2920	1.06	[0.85 ; 1.32)	
Good housing (P2)	≤ 52.0	1084	Ref.	-	0.05
	> 52.0	2867	1.24	[1.00 ; 1.55)	
Good Health (P3)	≤ 25.5	1010	Ref.	-	0.46
	> 25.5	2941	1.09	[0.87 ; 1.38)	
Appropriate behavior (P4)	≤ 26.7	1047	Ref.	-	0.43
	> 26.7	2904	1.09	[0.88 ; 1.37)	
Absence of prolonged hunger (C1)	≤ 28.9	1061	Ref.	-	0.07
	> 28.9	2890	1.24	[0.98 ; 1.57)	
Absence of prolonged thirst (C2)	≤ 3.0	1031	Ref.	-	0.62
	> 3.0	2920	1.06	[0.85 ; 1.32)	
Comfort around resting (C3)	≤ 26.8	1084	Ref.	-	0.05
	> 26.8	2867	1.24	[1.00 ; 1.55)	
Absence of injuries (C6)	≤ 40.6	1017	Ref.	-	0.09

	>40.6	2934	1.21	[0.97 ; 1.52)	
Absence of disease (C7)	≤24.6	996	Ref.	-	0.46
	>24.6	2955	1.09	[0.86 ; 1.38)	
Absence of pain induced by	≤20.0	2516	Ref.	-	0.38
management procedures (C8)	>20.0	1435	1.09	[0.89 ; 1.34)	
Expression of social behaviors	≤23.9	995	Ref.	-	0.98
(C9)	>23.9	2956	1.00	[0.80 ; 1.25)	
Expression of other behaviors	≤77.2	1102	Ref.	-	0.83
(C10)	>77.2	2849	0.98	[0.78 ; 1.22)	
Good human-animal	≤34.1	1006	Ref.	-	0.53
relationship (C11)	>34.1	2945	0.93	[0.75 ; 1.16)	
Positive emotional state (C12)	≤34.1	976	Ref.	-	0.99
	>34.1	2975	1.00	[0.80 ; 1.25)	

531 OR, Odds Ratio; CI, Confidence Interval; Ref., Reference category

532