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1 **Evaluation of reference lactation length in Chios dairy sheep**

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14

15 **Abstract**

16 Definition and establishment of a fixed reference lactation length could
17 provide useful tools for on-farm comparison of ewes and flock management
18 as well as genetic evaluations for the breeding programme. The objectives of
19 this study were to (i) evaluate different reference lactation lengths for the
20 Chios dairy sheep and (ii) define the most suitable reference length for the
21 breed. A total of 260,042 test-day milk records from 24,474 ewes in 130 flocks
22 collected between 2003 and 2014 were used. Fifteen (15) different lactation
23 lengths were evaluated ranging from 120 to 260 days, defined at 10-day
24 intervals as reference for the Chios sheep. The evaluation criteria included: **a)**
25 heritability and repeatability of milk yield in each reference lactation, **b)**

26 genetic correlation of reference lactation milk yield with actual lactation milk
27 yield and yield at first test-day record and **c)** correlated response in reference
28 lactation milk yield from selection based on first test-day milk yield. The latter
29 emulates genetic gains achieved for milk yield based on early lactation
30 selection. Heritability and repeatability estimates of reference lactation milk
31 yield and genetic correlation with actual lactation yield favoured long
32 reference lactations (180-230 days). On the contrary, correlation with first test-
33 day record milk yield was higher for short lactations (120-170 days).
34 Moreover, selection on first test-day record milk yield would lead to a
35 correlated response in reference yield in 220 days equal to 90% of the highest
36 estimate achieved in the maximum reference length of 260 days (190 days
37 when only considering first lactation milk yield). Based on the results of the
38 present study, an overall reference lactation length for the Chios breed of 220
39 days post-lambing and a first lactation reference length of 190 days post-
40 lambing are recommended.

41

42 **Keywords:** Standard lactation length, milk, Chios breed, Sheep management,
43 Genetic improvement

44

45

46 **Implications**

47 Lactation lengths differ amongst individual dairy ewes raised in the
48 same flock. Lactations following spring lambings tend to be shorter than those
49 starting in the autumn, especially in the semi-extensive production systems in
50 the Mediterranean countries. In the present study, standardised reference
51 lactation lengths are derived and evaluated for the Chios sheep in Greece.
52 Results can provide useful tools for on-farm management and genetic
53 improvement programmes.

54

55 **Introduction**

56 Lactation length is one of the main factors affecting milk yield in dairy
57 sheep. Total lactation milk yield has been traditionally used for on-farm
58 management, on-farm selection of ewes, and genetic evaluation and selection
59 of breeding animals at population level (Moioli and Pilla, 1994; Barillet, 1997).
60 Although test-day genetic evaluation models are now used frequently in
61 animal breeding instead of lactation models (Schaeffer *et al.*, 2000; Silvestre
62 *et al.*, 2005; Lidauer *et al.*, 2003; Komprej *et al.*, 2013), lactation milk yield
63 continues to provide useful information for management and comparison
64 purposes.

65 Lactation length may be influenced by several factors, amongst which
66 season of lambing seems to be the most important. When seasonal lambing
67 is practiced, as is the case in most Mediterranean sheep production systems,
68 the lactation length of ewes lambing in spring tends to be shorter compared to
69 ewes lambing in the autumn and winter. The effect of season of lambing on
70 lactation length has already been reported in many dairy sheep breeds such

71 as Chios (Mavrogenis and Papachristoforou, 1990), Sarda (Carta *et al.*, 1998)
72 and Barbaresca Siciliana (Portolano *et al.*, 2001).

73 Varying lactation lengths pose a problem when farmers wish to make
74 management decisions regarding management of their stock. Definition of a
75 fixed reference lactation length (also known as standard length) in dairy sheep
76 could provide useful tools for on-farm comparison of animals and overall flock
77 management as well as genetic evaluations in the breeding programme
78 (Basdagianni *et al.*, 2004).

79 A reference lactation length of 305 days has been well established and
80 accepted worldwide for dairy cattle. However, reference lactation length in
81 dairy sheep varies according to breed and production system. In literature
82 there are many studies that have aimed to define the best reference length
83 definition for genetic evaluation purposes. Most studies focused on the
84 projection and extension of part lactation (Gabina *et al.*, 1993; De La Fuente
85 *et al.*, 1995; Carta *et al.*, 1998; Rosati and Fioretti, 2001; Portolano *et al.*,
86 2001; Ugarte *et al.*, 2002; Berger and Thomas, 2004; Cappelletti *et al.*, 2006;
87 Oravcova *et al.*, 2006; Jonas *et al.*, 2011). Very few studies (El-Saied *et al.*,
88 1998a; El-Saied *et al.*, 1998b; Gutierrez *et al.*, 2007) have used specific
89 criteria to evaluate the length of a reference lactation. The reference lactation
90 length must have certain properties that make it useful and reliable in practical
91 applications, such as being representative of the actual lactation and having a
92 high correlation with milk yield in early lactation (Basdagianni *et al.*, 2004).

93 The objectives of the present study were to (i) evaluate different
94 reference lactation lengths for the Chios dairy sheep and (ii) define the most

95 suitable reference length for the breed. Chios is the highest milk producing
96 sheep in Greece and one of the most productive dairy breeds worldwide.

97

98 **Materials and methods**

99 *Data*

100 Test-day records and pedigree information were obtained from the
101 database of the Chios Sheep Breeders' Cooperative "Macedonia", which
102 implements the genetic improvement programme for the breed in Northern
103 Greece since 1997. Lambing is seasonal and occurs either in autumn/winter
104 or in spring. After a suckling period of approximately 6 weeks, ewes are
105 milked mostly twice daily. Milk recording is performed monthly by trained field
106 officers. The first milk record is collected between 42 to 94 days after lambing
107 and milk yield is measured using the A4 method.

108 Lactations with at least two monthly test-day records that took place
109 between 2003 and 2014 were considered for the present study, following the
110 guidelines of the International Committee for Animal Recording (ICAR, 2016).
111 After these edits the number of remaining test-day milk yield records was
112 260,042. These were produced from 24,474 ewes during 46,505 lactations in
113 130 flocks. Ewes were daughters of 2,060 sires and 22,482 dams. These data
114 were linked to a breed pedigree file including 87,261 animals spanning 10
115 generations. Two seasons of lambing (September to February and March to
116 August; Figure 1) and four lactation classes (1st, 2nd, 3rd, 4th or higher
117 lactation) were defined.

118 Actual lactation milk yield was calculated for each animal and lactation using
119 the Fleischmann method (Barillet, 1985). Additionally, reference lactation milk

120 yield was calculated for each animal for fifteen (15) different reference lengths
121 ranging from 120 to 260 days post-lambing, defined in 10-day interval (i.e.
122 120, 130,.....,250, 260). In each case, the last monthly test-day record of the
123 ewe had to be no more than 14 days prior to the corresponding reference
124 length end-date, as required by the Fleischmann method (Barillet, 1985).
125 Lactations longer than 260 days were not considered in the study due to the
126 limited number of data.

127 In order to evaluate the reference lactation lengths, the following
128 criteria were considered: **a)** heritability and repeatability of reference lactation
129 milk yield, **b)** genetic correlation of reference lactation milk yield with actual
130 lactation milk yield and yield at first test-day record and **c)** correlated response
131 in reference lactation milk yield from selection based on the first test-day milk
132 yield.

133

134 *Data analysis*

135 Each trait (actual lactation milk yield, lactation yield in 15 reference
136 lengths and first test-day record milk yield) was first analysed separately using
137 the following mixed model:

$$138 Y_{ikjo} = \mu + HYS_i + b \cdot \text{age} + PF_k + L_j + X_o + P_o + e_{ikjo} \quad [1]$$

139 where: Y_{ikjo} is the trait value for animal o ; μ is the overall population mean;
140 HYS_i is the fixed effect of herd-year-season of lambing i ($i=1-3120$); b is the
141 linear regression coefficient on age at lambing (age); PF_k is the fixed effect of
142 prolificacy class (number of lambs born alive) k ($k=1-3+$); L_j is the fixed effect
143 of lactation number j ($j=1-4+$); X_o is the random additive genetic effect of ewe

144 o including all available pedigree; P_o the random permanent environment of
145 ewe o: e is the random residual.

146 In the analysis of actual lactation milk yield, duration of lactation i.e.,
147 actual lactation length was added as a covariate in model [1]. When the first
148 test-day record milk yield was analysed, days in milk was also included as a
149 covariate in model [1].

150 In separate analyses, the ewe effect in Model (1) was replaced by the
151 sire of the ewe random effect, essentially rendering this a sire model.

152 In all analyses, variance components for each trait were estimated and
153 used to derive heritability and repeatability estimates.

154 Bivariate analyses based on Model [1] were subsequently used to
155 estimate the genetic correlations between traits.

156 In further separate analyses, only first lactation milk yield records were
157 considered; in this case, the fixed lactation and the random permanent
158 environment effects were removed from mode [1].

159 All the above analyses were performed with the ASReml 4.1 (Gilmour
160 *et al.*, 2014).

161 Finally, the correlated response in each reference lactation milk yield
162 from selection based on the first test-day milk yield record was estimated
163 using the following formula (Van Vleck, 1981):

$$164 CR_y = i_x a_x r_{xy} s_{d_y} \quad [2]$$

165 where: CR_y is the correlated response in response variable y (reference
166 lactation milk yield); i_x is the selection intensity on variable x (first test-day
167 record milk yield); a_x is the accuracy of selection on variable x ; r_{xy} is the

168 correlation between variables y and x ; sd_y is the genetic standard deviation of
169 variable y .

170 Since selection intensity and accuracy of selection in equation [2]
171 pertained to the same variable (first test-day record milk yield), evaluation of
172 different reference lactations with this criterion was performed for constant
173 intensity and accuracy of selection; thus the evaluation was practically based
174 on the correlation between first test-day record milk yield and reference
175 lactation yield, and the genetic standard deviation of reference lactation yield.

176

177 **Results**

178 Table 1 summarises the descriptive statistics of all studied traits.

179 The sire model i.e., when sire was included as a random effect in
180 model [1], yielded the lowest residual variance estimates and, therefore, was
181 deemed to have the best fit. Hereafter, results shown pertain to the sire model
182 but it should be noted that animal model (ewe as random effect in model [1])
183 results were very similar.

184 Heritability estimates of milk yield in each reference lactation ranged
185 from 0.12 to 0.30 (standard errors 0.02-0.12) (Figure 2). Heritability estimates
186 increased with longer reference lactation, with highest values pertaining to
187 reference length of 200-230 days. When the analysis concerned only first
188 lactation records the heritability estimates of reference lactation milk yield
189 were between 0.08 and 0.37 (Figure 2). In comparison, heritability of actual
190 lactation milk yield and first test-day milk yield were 0.15 ± 0.02 and 0.10 ± 0.02 ,
191 respectively (0.09 ± 0.03 and 0.11 ± 0.03 for first lactation yield).

192 Repeatability estimates of milk yield in each reference lactation ranged
193 from 0.29 to 0.48, and increased with increasing reference length (Figure 3).

194 Repeatability estimates of actual lactation milk yield and first test-day record
195 milk yield were 0.33 ± 0.01 and 0.21 ± 0.01 , respectively.

196 Genetic correlation estimates between milk yield in different reference
197 lactation lengths and actual lactation yield are shown in Figure 4. Reference
198 lactations lengths between 180 and 220 days had the highest genetic
199 correlation values (0.98-0.99) and are considered to be the most
200 representative of actual lactation yield in this regard. When considering only
201 first lactation records genetic correlations were also high, with the highest
202 values at reference lactation length of 160 to 180 days.

203 Genetic correlations between reference lactation milk yield and first
204 test-day record milk yield are shown in Figure 5. The estimates of the genetic
205 correlation were particularly high (≥ 0.95) for the short lactation periods (120-
206 170 days), with a decreasing trend for reference lactations lengths above 180
207 days. The trend was the same in the analysis of first lactation records only.

208 Correlated responses in milk yield achieved in different reference
209 lactation lengths from selection on first test-day record milk yield were
210 increased with increasing reference length and expressed in percentage
211 relatively to the highest reference length of 260 days for all lactation and 230
212 days for first lactation record analysis (Figure 6). Correlated response (genetic
213 progress) for the shorter reference lactations (120-200 days) were 49 - 76% of
214 that achieved in maximum length, while for longer reference lactation this
215 percentage was over 85%. When only first lactation records were considered,

216 reference lactations of 120 -190 days showed genetic progress 44 - 68% of
217 that at maximum length.

218

219 **Discussion**

220 Our goal was to evaluate candidate reference lactation lengths and
221 define a reference lactation length suitable for Chios dairy sheep. Expressing
222 total dairy production at a reference lactation length would facilitate the
223 objective comparison between animals and related on-farm decisions.

224 The reference lactation length had to be representative of the actual
225 lactation length and corresponding milk yield should have a high correlation
226 with the milk yield of the first test-day record and that of the actual lactation.

227 Heritability estimates for actual lactation milk yield (0.15 ± 0.02) in the
228 present study was lower than those obtained by Mavrogenis and
229 Papachristoforou (1990) and Ligda *et al.* (2000) in the same breed (0.23-0.33)
230 for animals raised in experimental flocks. However, ours is the first heritability
231 estimate of Chios sheep at population level. Data analysis from experimental
232 flocks often yield higher heritability estimates because of better defined and
233 controlled management conditions. Moreover, low heritability in our study
234 might be also due to relatively low levels of genetic connectedness between
235 flocks as a result of predominantly natural mating with own rams in the Chios
236 ewes; this might also result in lower accuracy of heritability estimates. In other
237 Greek dairy sheep breeds, Kominakis *et al.* (1998) reported estimated
238 heritabilities for lactation milk yield across various models ranging between
239 0.18 and 0.30 for Boutsiko and Nikolaou *et al.* (2004) between 0.16 and 0.20
240 for Lesbos. In Spanish dairy sheep breeds Carriedo *et al.* (1995) estimated

241 heritability of total milk yield in Churra between 0.15 and 0.29. In the improved
242 Awassi and East Friesian breeds, reported heritabilities were 0.10 and 0.15,
243 respectively (Pollott and Gootwine, 2001; Hamann *et al.*, 2004). In the Italian
244 sheep breeds Comisana, Sarda and Leccese, heritabilities of milk yield were
245 0.25-0.28 (Selvaggi *et al.*, 2017).

246 Heritability estimate for first test-day record milk yield in the present
247 study was 0.10 ± 0.02 and was similar to those reported by Oravcova (2014)
248 for the Tsigai breed. Heritability is generally lower at the early stages of
249 lactation as a consequence of higher residual variance as reported in several
250 sheep (Kominakis *et al.*, 2001; Komprej *et al.* 2013) and cattle studies
251 (Rekaya *et al.*, 1999; Silvestre *et al.* 2005).

252 Heritability estimates of milk yield in different reference lactation
253 lengths in the present study were higher (0.19 - 0.30) for longer lactations of
254 200-230 days. Legarra and Ugarte, (2001) reported heritability 0.20 for the
255 Latxa breed and Serrano *et al.* (2003), 0.18 in Manchega ewes for milk yield
256 in reference lactation length of 120 days. Gutierrez *et al.* (2007) reported
257 heritabilities between 0.13 and 0.18 for 180-day reference milk yield. High
258 heritability facilitates the accurate genetic evaluation and the selection; from
259 this standpoint, our study suggests that longer reference lactations are
260 preferable.

261 Repeatability estimates for different reference lactation milk yields ranged
262 from 0.29 to 0.48 in the present study. El-Saied *et al.* (1998b) reported
263 repeatability 0.38 in 120 day standardised milk yield. In the present study, the
264 repeatability estimates were higher (>0.40) in longer reference lactations

265 (200-260 days), which render the latter more suitable for on-farm selection of
266 ewes and flock management.

267 Estimates of genetic correlation between reference lactation milk yield
268 and actual lactation yield were high and ranged from 0.98 to 0.99, for
269 reference lactation length of 180-230 days. These estimates are higher than
270 those reported of Mavrogenis and Papachristoforou (1990) in Chios sheep in
271 Cyprus, for reference length of 60 and 90 days (0.91 and 0.92 respectively).
272 In Churra breed, El-Saied *et al.* (1998b) found genetic correlation between
273 actual lactation milk yield and 120-day standardised lactation milk yield 0.99,
274 and Portolano *et al.* (2001) reported similar genetic correlations between total
275 milk yield and milk yield at standard lactation length of 180 and 200 days
276 (0.94 and 0.97) in Valle del Belice dairy sheep. Similar high estimates of
277 genetic correlation (0.99) were also reported in the Spanish Assaf breed by
278 Gutierrez *et al.* (2007) considering reference yield at 180 days. Reference
279 lactations lengths with higher genetic correlation are more representative of
280 the actual lactation, which is a desirable characteristic in the choice of the
281 former. Based on this criterion, reference length of 180-230 days in the
282 present study would be desirable for the Chios sheep. By the same token,
283 reference lactation length of 160 to 190 days would be preferable for first
284 lactation milk yield (Figure 4). This discrepancy between all and first lactation
285 may be due to the fact that yearling have not had the opportunity to express
286 their full genetic capacity as actual lactations were shorter due to most of
287 them lambing in spring.

288 Genetic correlations between reference lactation milk yield and first
289 test-day record milk yield favoured short reference lactation lengths in the

290 present study (0.98 for 120 days versus 0.88 for 260 days), with higher values
291 (>0.95) at reference lactations 120-170 days. These estimates were similar to
292 those reported by Banos *et al.* (2005) for the same breed and suggest that
293 more accurate predictions of the lactation milk yield from the first test-day
294 record can be achieved for shorter reference length (120-170 days). However,
295 even for the longer lactations lengths (180-260 days), the genetic correlation
296 is considerably high (0.88-0.94), meaning that milk yield at first test-day
297 record can be useful in predicting the total reference lactation milk yield of the
298 ewes in nearly all cases.

299 Of the above criteria used to evaluate the reference lactation length in
300 the Chios sheep, genetic parameters (heritability, repeatability) of reference
301 lactation milk yield and genetic correlation with actual lactation yield would
302 favour long reference lactations (180-230 days), whereas genetic correlation
303 with first test-day record milk yield would advocate for short reference
304 lactations (120-170 days). In order to combine the above criteria, correlated
305 responses in reference lactation milk yield to selection based on the first test-
306 day record milk yield were estimated. Selection based on early lactation yield
307 (first test-day record the present study) can facilitate early decisions and
308 enhance the efficiency of on-farm management (e.g. setting up mating
309 strategies). According to our results, correlated response would favour milk
310 yield in the maximum reference lactation length considered in the present
311 study (260 and 230 days for all and first lactation, respectively). This is
312 primarily due to higher genetic variance estimates associated with longer
313 lactation milk yield. However, such long lactations are not representative of
314 the actual length (Table 1) and may not be practical for farm management.

315 Furthermore, prolonged lactations of low milk production would not be
316 beneficial to the overall profitability of the farm (Gutierrez *et al.*, 2007).

317 Combining all evaluation criteria, it is suggested that a reference
318 lactation length 220 days post-lambing would be most useful for the
319 management of the Chios breed stock. This length is close to the average
320 actual lactation length of the breed (208 days; Table 1); therefore, it can be
321 considered representative for the Chios sheep. Furthermore, milk yield in 220
322 days had one of the highest heritability estimates and the highest genetic
323 correlation with actual lactation yield amongst all reference lactation yields. In
324 addition, milk yield in 220 days had a reasonable genetic correlation with first
325 test-day record milk yield which amounted to 92% of the most highly
326 correlated reference yield (in 120 days). Finally, selection on first test-day
327 record milk yield would lead to correlated response in reference yield in 220
328 days equal to 90% of the highest estimate achieved in the maximum (albeit
329 unrealistic) reference length of 260 days.

330 Following the same reasoning, a reference length of 190 days would
331 be the most suitable for first lactation ewes. These animals may require a
332 separate reference length because they tend to have shorter lactations due to
333 predominantly spring lambings.

334

335 **Conclusions**

336 Reference lactation length of 220 days post-lambing is recommended
337 for the Chios sheep breed as it gives on balance the best results regarding
338 genetic parameter estimates, genetic correlation with actual lactation and first
339 test-day record milk yield, and correlated response to selection for increased

340 first test-date yield. By the same token, a first lactation reference length of 190
341 days is recommended. Future research should assess the validity of the
342 recommended reference length for other dairy sheep breeds.

343

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346 Cooperative "Macedonia".

347

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465

466 **Table 1** *Descriptive statistics for milk yield traits in the Chios sheep breed.*

Trait	Records	Mean	SD	CV%
Actual lactation milk yield (kg)	46,505	324	134.3	41
Lactation length (days)	46,505	208	48.2	23
First test-day record milk yield (g)	46,505	1,910	821.3	43
Yield in reference length 120 days (kg)	43,169	221	83.9	38
Yield in reference length 130 days (kg)	41,873	237	88.1	37
Yield in reference length 140 days (kg)	39,905	253	92.1	36
Yield in reference length 150 days (kg)	37,527	268	96.1	36
Yield in reference length 160 days (kg)	34,750	284	99.7	35
Yield in reference length 170 days (kg)	31,980	299	103.2	34
Yield in reference length 180 days (kg)	28,938	316	106.4	34
Yield in reference length 190 days (kg)	25,539	333	109.6	33
Yield in reference length 200 days (kg)	22,340	349	113.3	32
Yield in reference length 210 days (kg)	18,995	363	116.7	32
Yield in reference length 220 days (kg)	15,433	377	118.5	31
Yield in reference length 230 days (kg)	12,239	391	120.9	31
Yield in reference length 240 days (kg)	9,160	407	120.7	30
Yield in reference length 250 days (kg)	6,629	421	122.4	29
Yield in reference length 260 days (kg)	4,116	433	124.4	29

467

468

469 **Figure 1** Distribution of lambings in the Chios sheep breed.

470

471 **Figure 2** Heritability estimates of milk yield in different reference lactation
472 lengths; standard errors range from 0.02 to 0.12 for all lactations (all lac) and
473 from 0.03 to 0.18 for first lactation (1st lac).

474

475 **Figure 3** Repeatability estimates of milk yield in different reference lactation
476 lengths; standard errors range from 0.01 to 0.03.

477

478 **Figure 4** Genetic correlation estimates between milk yield in different
479 reference lactation lengths and actual lactation yield; standard errors were
480 lower than 0.02 in all cases.

481

482 **Figure 5** Genetic correlation estimates between milk yield in different
483 reference lactation lengths and first test-day record milk yield; standard errors
484 ranged from 0.01 to 0.10 for all lactations (all lac) and from 0.00 to 0.03 for
485 first lactation (1st lac).

486

487 **Figure 6** Correlated response in reference lactation milk yield to selection
488 based on the first test-day record milk yield, expressed as a percentage
489 relatively to response in highest reference length of 260 days (230 days for 1st
490 lactation records).

491