

1 **The effects of artificial rearing and fostering on the growth, carcass and meat quality of**  
2 **lambs**

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14

15 **Abstract**

16 Lamb rearing is a key point to ensure good quality at the end of the production cycle. Fostering and  
17 artificial rearing are techniques commonly used when natural rearing is compromised. However,  
18 there is a lack of research investigating their impact on the product's quality, especially when  
19 lambs are slaughtered late, around 6 months of age. The current study investigated the effects of  
20 artificially reared and fostered lambs on growth, carcass and meat quality. The three foster  
21 methods under study were birth fluids, cervical stimulation combined with birth fluids and restraint.  
22 Animals were weaned at 3 months of age, and processed at 6 months of age. Artificially reared  
23 lambs presented lower weight gains than ewe reared ones at young ages. They also presented  
24 worse conformation scores at the processing plant. No differences could be found for growth rates,  
25 carcass or meat quality among the foster methods tested.

26

27 **Keywords**

28 Lamb; Fostering; Artificial rearing; Carcass quality; Meat quality.

29

30 **1. Introduction**

31 In 2013, the world's production of sheep meat surpassed 8.589 million tonnes, with Europe  
32 producing around 1.130 million tonnes (FAOSTATS, 2016). In the specific case of the English lamb  
33 industry, it has been estimated that only 54% of lambs reach acceptable market requirements  
34 (EBLEX 2007). Subsequently, if the UK produces around 289,000 tonnes of sheep meat per year  
35 (FAOSTATS, 2016) this could theoretically indicate that a large amount of meat could be  
36 potentially wasted because of lambs not reaching acceptable market requirements. An important  
37 aspect to ensure that lambs reach an acceptable market standard is the proper care from birth and  
38 appropriate use of husbandry techniques (Diaz et al., 2002; Chestnutt, 1994). A key step during  
39 lamb rearing is weaning, and its effects (early vs. late) on carcass and meat quality have been  
40 widely studied (Cañeque et al., 2000; Napolitano et al., 2002; Norouzi and Valizadeh, 2011; Ekiz  
41 et al., 2012). In general, late weaning is associated with better growth rates and conformation  
42 scores but regarding meat quality no significant effects have been usually reported. These effects  
43 on growth and carcass quality are traditionally linked to the physiological changes needed to switch  
44 from a liquid to a solid food source and its repercussions in overall intake (Cañeque et al., 2000).  
45 There is also extensive literature on the effects that artificial vs. maternal rearing has on lambs at  
46 weaning (Napolitano et al., 2006; Norouzi and Valizadeh, 2011). Most studies conclude  
47 suggesting that initial weight differences at weaning can be found, but with no lasting effects on  
48 carcass characteristics at time of slaughter. Some other studies though (Lanza et al., 2006; Vicenti  
49 et al., 2004) have reported significant differences on carcass weight, meat colour and fat contents  
50 with lambs fed on ewe milk being heavier, with lighter meat colour and lower fat content.  
51 Conversely, Napolitano et al., (2002) reported that the artificially-reared lambs produced better  
52 quality meat than lambs receiving ewe milk (significantly higher carcass yield percentage, second  
53 grade cut percentage and significantly less leg fat percentage). Fostering is a rearing technique

54 commonly used within the lamb industry worldwide. However, there is a lack of research  
55 investigating its impact on the quality of the resulting products, especially in production systems  
56 where lambs are slaughtered late, around 140-180 days old, such as the UK industry.

57 The current study investigated the differences between artificially reared (AR) and fostered lambs  
58 on growth and live morphometric indices, carcass quality and meat quality. The three foster  
59 methods under study were birth fluids (BF), cervical stimulation combined with birth fluids (CSBF)  
60 and restraint (R). The present paper was part of a larger study investigating the effects of different  
61 foster methods on the welfare of ewes, where R ewes presented higher cortisol levels and lowered  
62 maternal behaviours representing compromised welfare (Ward et al. in preparation). These rearing  
63 treatments were compared to control ewes raising their own twins in a commercial setting where  
64 lambs were weaned at 3 months but kept grazing until slaughter at 6 months of age. If differences  
65 were still present among treatments at the time of slaughter this could mean long-term implications  
66 of distress early in life, implications that could not be resolved by a long compensatory post-  
67 weaning period. If foster methods such as R, detrimental to ewe welfare as mentioned above, were  
68 to affect lamb performance as well, they should be considered not suitable and their use  
69 discouraged.

## 70 **2. Materials and Methods**

### 71 2.1. Animals

72 Moulton College Sheep Farm (Northampton, UK) is home to approximately 1000 North Country  
73 mule ewes. 84 ewes in total were monitored during two lambing seasons (spring 2009 and 2010)  
74 for the current experiment. Experimental ewes were multiparous ( $n = 48$ ) or primiparous ( $n = 36$ ). A  
75 total of 180 North Country mule lambs, of both genders (97 females and 83 males), classified as  
76 natal (raised by their own mother), alien (fostered) or AR (bottle fed) were included in the current  
77 experiment.

### 78 2.2. Housing and husbandry

79 Ewes were naturally mated and grazed outdoors until approximately four weeks prior to lambing.  
80 They were then housed together in large covered sheds according to their pregnancy scan results,  
81 creating three groups: singles, twins or triplets. At lambing, ewes were left on their own unless

82 difficulties arose, in which case an experienced shepherd aided delivery. Each ewe and its lamb/s  
83 were relocated to an individual pen (1.52m x 1.14m) within four hours from delivery time, where  
84 interference from other ewes was avoided and maternal bonds could be better established. After  
85 four hours in the individual pen, the lambs were routinely checked and treated (ear tagging and  
86 treatment of the navels and watery mouth). The fostered and AR lambs were selected from ewes  
87 giving birth to triplets. A triplet was allocated a foster dam from the group giving birth to single  
88 lambs and housed in an individual pen; the fostering method was then applied choosing among the  
89 three treatments to be tested (see Table 1). For the R treatment, special restraint pens measuring  
90 1.20mx1.10m were used.

### 91 2.3. Treatments

92 Foster was performed immediately after the single-bearing ewe delivered her lamb, if any recent  
93 triplets were available. Weights at birth and lamb gender were allocated to try and create the most  
94 homogeneous treatment groups possible, but as the work was carried out in commercial facilities  
95 these confounding effects could not be completely balanced. The treatment groups were classified  
96 as birth fluids foster (BF, N=48 lambs); cervical stimulation combined with birth fluids foster (CSBF,  
97 N=24 lambs), restrained foster (R, N=48 lambs), AR lambs (N=12 lambs) and the control group  
98 (N=48 lambs). Only successful fosters were included in the study, as the purpose was to  
99 investigate the long term implications of different fostering techniques. BF treatment (from 12  
100 primiparous and 12 multiparous ewes, 48 lambs in total) consisted in coating the alien lamb with  
101 the birth fluids from the single lamb-bearing fostering ewe. CSBF treatment (from 12 multiparous  
102 ewes only, 24 lambs in total) involved the shepherd gently pushing his hand into the cervix of the  
103 single-lamb bearing fostering ewe and simulating contractions by opening and closing the hand at  
104 ten seconds intervals. Then the shepherd coated the alien lamb using the foster ewe' birth fluids.  
105 Due to the fragile nature of primiparous ewes CSBF was not performed on them. R treatment (from  
106 12 primiparous and 12 multiparous ewes, 48 lambs in total), was conducted in specific pens where  
107 the ewes heads were locked outside by the neck between vertical bars. The lambs were then  
108 placed inside the pen, behind the ewe's head. The restraint pens enable the ewes to lie down,  
109 stand and have access to food and water. However they inhibit its ability to look and sniff at the  
110 lambs. The ewes were left in the restraint pens for a maximum of 5 days, depending on their level  
111 of acceptance of the lamb and the lambs' ability to successfully feed. These three fostering

112 methods were selected for the experiment because it was previously found that they were the most  
113 commonly used by UK farmers (Ward et al., 2011). A random sample of 24 ewes (12 primiparous  
114 and 12 multiparous, 48 lambs in total) were selected from the group of ewes scanned as twins and  
115 used as controls. AR lambs ( $n=12$ ) were placed in a lambing pen provided with a heat lamp and  
116 were initially force fed natural cow colostrum sourced from the Moulton College dairy unit using a  
117 stomach tube. Subsequent feedings took place every three hours with warm artificial milk powder  
118 (*Lamb Force ewe milk replacer*, Downland®; Carlisle, UK) mixed at 20g of milk powder for 250ml  
119 of warm water. Each lamb was fed from individual bottles at a rate of 50ml per kg of body weight.  
120 This milk powder contained 23% oils, 23% protein and 8% ash, and it was enriched with vitamins  
121 A, D<sub>3</sub>, E and Selenium. Bottle feeding occurred individually, with three persons (two stockpersons  
122 and one researcher) taking turns to bottle feed the 12 AR lambs every three hours for their first 2  
123 weeks of life (during the lambing season). The authors acknowledge that this technique is  
124 potentially less adequate to feed AR lambs than *ad libitum* feeding through automatic equipment,  
125 but it is still a common occurrence in small to medium UK farms and thus valid to be studied.  
126 These lambs were weaned (all milk supplements removed) at 3 months of age as the other  
127 experimental lambs.

128 After three days, experimental ewes and lambs were identified with spray markers and relocated  
129 into group mothering pens of approximately 400m<sup>2</sup>. These pens were also covered areas within  
130 the lambing sheds which housed up to 10 ewes and their lambs. When lambs were at least one  
131 week old, ewes and lambs were taken to the surrounding fields remaining in outdoor grass  
132 pastures with supplementary feeding of lamb creep pellets. At around three months of age, all  
133 experimental lambs were weaned, and kept grazing in the same fields without their dams until  
134 approximately six months of age when they were sent to slaughter. The trial was approved by the  
135 ethical committee at Moulton College and the University of Northampton and followed the ARRIVE  
136 guidelines where necessary. As the animals were not subjected to stressful manipulations other  
137 than those included in routine farm rearing, no other licenses or permits were needed for the study.

138 2.4. Data collection

139 *Pre-Slaughter data*

140 All lambs were weighed and measured on their date of birth (day 0) and then on days 7, 30, 90 and  
141 180. These days were chosen as coincident with relevant husbandry procedures. Day 7 referred to  
142 the weight/measures before the lambs were put out to pasture. Day 30 coincided with the routine  
143 medication for the lambs (fly-strike and prophylactic endoparasitic treatment). Day 90 represented  
144 weight/measures at weaning. Finally, day 180 corresponded to weight/measures of the finished  
145 lambs, on the day prior to slaughter. Weights were taken using a digital spring balance (Portable  
146 Electronic Scale, OCS-1, London, UK) with the lambs placed in a bucket until they reached 20kg  
147 (30 days of age). Salter Brecknell® LS300 (Brecknell®, West Midlands, UK) weighting scales were  
148 used for 90 and 180 day weights. Daily weight gain was calculated for the first week of life (period  
149 1), between day 8 and 30 (period 2), between day 31 and 90 (period 3) and from day 91 to 180  
150 days, when lambs were slaughtered (period 4). Average daily gain for the whole experiment was  
151 also calculated. Additional morphometric measurements were taken including external body length  
152 (BL; base of neck to beginning of tail), torso length (TL; shoulder to ischium), height at shoulder  
153 (HS; floor to shoulder), rump length (RL; ilium to ischium), rump width (RW; left ilium to right ilium),  
154 chest depth (CD; largest depth of ribs at shoulder) and chest circumference (C). BL, TL, HS, RL  
155 and C were taken using a measuring tape and a calliper was used for RW and CD. Several indices  
156 were calculated from the measures taken: relative torso depth ( $RTD = (CD/HS) \times 100$ ), pelvic index  
157 ( $PEI = (RW/RL) \times 100$ ), transversal pelvic index ( $TPI = (RW/HS) \times 100$ ), longitudinal pelvic index  
158 ( $LPI = (RL/HS) \times 100$ ), body index ( $BI = (TL/C) \times 100$ ), relative shortness index ( $RSI = (TL/HS) \times$   
159  $100$ ), compactness index ( $CI = (weight/BL) \times 100$ ), relative weight index ( $RWI = (weight/HS) \times 100$ )  
160 and proportionality index ( $PRI = (TL/HS) \times 100$ ). All indices were calculated for each  
161 weighing/measuring day (day 0, 7, 30, 90 and 180).

162 *Post-Slaughter data*

163 Joseph Morris abattoir and butchery (EU approved; South Kilworth, Leicestershire, UK) was  
164 selected to minimise travelling distance. The average journey length was 35 minutes for all  
165 experimental lambs. On the day of slaughter, animals were loaded at 05.00 am into an Ifor  
166 Williams® DP120 (model: 10'x6' H/R) livestock trailer. On arrival to the abattoir, the animals were

167 unloaded into the lairage area which consisted of concrete flooring with solid metal separation  
168 gates between pens of approximately 8.6 m<sup>2</sup>. Animals were housed in their travelling groups and  
169 remained in this area for 30 minutes. The lambs were slaughtered using electrical stunning then  
170 bled out immediately. Carcasses were kept in the abattoir's cold storage room at 4°C for 24h after  
171 processing.

172 On the day of slaughter, conformation and fatness scores were recorded using the EUROP system  
173 on the experimental carcasses at the end of the processing line. Conformation was graded as E,  
174 U, R, O or P, where E was classified as excellent and P classified as poor. Fatness was graded as  
175 1, 2, 3, 4 or 5 where a grade 1 was very lean and grade 5 was very fat. An additional set of carcass  
176 measurements were taken to assess carcass quality, including chest width (Wr; widest carcass  
177 measurement at the ribs), chest depth (Th; maximum distance between the sternum and back of  
178 the carcass at the sixth thoracic vertebra), buttock length (G; widest buttock measurement in a  
179 horizontal plane), leg length (F; length from perineum to distal edge of the tarsus) and internal  
180 carcass length (L; length from cranial edge of the pelvic symphysis to the cranial edge of the first  
181 rib). Th, Wr and G were measured using a calliper and a measuring tape was used for L and F.  
182 Two carcass conformation indices were also calculated: chest roundness index ( $Wr/Th \times 100$ ) and  
183 buttock/leg index ( $G/F$ ). Ultimate pH was assessed 24h *post-mortem* at the *Longissimus dorsi*  
184 *lumborum* level using a 507 spear tip electrode with portable pH meter (Crison®, Barcelona,  
185 Spain). Cold carcass weights (CCW) were also recorded at this point and carcass compactness  
186 ( $CCW/L \times 100$ ) and commercial dressing indices ( $CCW/\text{slaughter weight} \times 100$ ) were calculated.

187 The lambs were then butchered and the left loin (*Longissimus dorsi thoracis et lumborum*) was  
188 removed and taken to the laboratory at Moulton College without breaking the cold chain (by placing  
189 samples inside Styrofoam boxes and covering them with ice packs). Once at the laboratory, a slice  
190 of the loin, approximately 3cm wide, was separated for the colour measures while a second piece,  
191 of a minimum of 30g, was also separated for the water holding capacity (WHC) assessment. Both  
192 pieces were placed into polystyrene boxes, covered with O<sub>2</sub> permeable film and stored in the fridge  
193 at 4°C for a further 24 hours. Colour readings were measured at 36 hours *post-mortem* (including  
194 24h of blooming) with a MINOLTA® colorimeter (model: CR-200b) to measure lightness (L\*),  
195 redness (a\*) and yellowness (b\*) of the meat samples in the CIEL\*a\*b\* space, with an Illuminant

196 D65 and a 10° observer. Each sample was measured three times and an average score was  
197 calculated for each parameter. WHC was also measured 36 hours *post-mortem* and was  
198 expressed as the percentage (%) of expelled juice after compression, using the Grau and Hamm  
199 Method as outlined by Beriain et al., (2000).

## 200 2.5. Statistical analysis

201 SPSS® version 17 was used for the statistical analysis of all data, which proved to be normally  
202 distributed. Mean daily weight gains for the ewe-reared lambs were analysed using general linear  
203 models with lamb origin (natal/alien), foster method (BF or R) and ewe experience (primiparous or  
204 multiparous) as independent variables. Rearing type (ewe-reared, fostered or artificially-reared,  
205 compared to controls) was analysed using Kruskal Wallis tests due to the unequal group sizes  
206 between the AR, controls and pooled ewe-reared data (for the three foster treatments).  
207 Investigations were performed separately for each time period. Conformation and fatness scores  
208 were converted into numerical data for statistical analysis (assigning numbers from 1, for P-, up to  
209 15, for E+, regarding conformation scores, and again numbers from 1, for 1-, up to 15, for 5+,  
210 regarding fatness scores). Carcass and meat quality parameters including CCW, conformation,  
211 fatness, commercial dressing, chest roundness index, buttock/leg index, carcass compactness  
212 index, ultimate pH, WHC and colour (L\*, a\*, b\*), were also analysed using a general linear model  
213 with the foster method, ewes' experience and lamb origin as independent variables. Rearing type  
214 was again analysed using a Kruskal Wallis test with the inclusion of data for artificially reared  
215 lambs, fostered lambs and controls.

216

## 217 **3. Results**

### 218 3.1. Pre-Slaughter data

219 Given the lack of statistically relevant differences among foster methods for any of the variables  
220 analyzed, results are presented grouped as one general foster treatment. There was a significant  
221 rearing effect on daily weight gain on period 1, period 2 and period 3 with lambs reared by ewes  
222 gaining significantly more weight than AR lambs (P<0.001 for periods 1 and 2, and P<0.05 for  
223 period 3). However, period 4 did not show any significant differences between ewe and AR lambs



224 (Figure 1). Figure 2 shows the results for the live morphometric measurements and indices when  
225 comparing ewe-reared (foster and control) vs. AR lambs. No significant differences were found in  
226 any of the indices at 180 days as expected, most likely due to the compensatory growth occurring  
227 after weaning within the commercial long-rearing system. However, significant differences were  
228 found in all indices at some stage within the rearing period with ewe-reared lambs showing  
229 significantly better indices. When considering the effect of fostering, there were no differences in  
230 daily weight gain or live morphometric measurements among the different foster methods. Weights  
231 at day 0 and day 7 showed that natal lambs were significantly heavier than alien lambs ( $P<0.05$ ) as  
232 expected, however at days 30, 90 and 180 the differences had disappeared. There were no  
233 significant differences found between the average daily weight gain of the natal compared to the  
234 alien lambs for any of the time periods analysed. Results suggest that ewe experience affected  
235 weight gain, with lambs reared by multiparous ewes, gaining significantly more weight during  
236 periods 1, 3 and 4 ( $P<0.001$  in all cases, see Table 2).

### 237 3.2. Post-slaughter data

238 When comparing the carcass quality of lambs subjected to different rearing conditions, results  
239 suggest that ewe-reared lambs had significantly better conformation scores and chest roundness  
240 indices than AR lambs ( $P<0.01$  and  $P<0.05$  respectively; Table 3). Other parameters were not  
241 found to be affected by rearing condition including slaughter weight. There were no significant  
242 differences for any of the carcass or meat quality parameters among foster methods. This was also  
243 the case for the comparison between alien and natal lambs. The ewes' experience had a  
244 significant impact on the live slaughter weight and cold carcass weight ( $P<0.05$  in both cases, see  
245 Table 2) with the multiparous ewes rearing significantly heavier lambs compared to the primiparous  
246 ewes. The ultimate pH was also significantly affected by the ewes' experience with the multiparous  
247 ewe lambs showing significantly lower pH values ( $P<0.05$ , see Table 2). The remaining carcass  
248 and meat quality parameters showed no significant differences between multiparous and  
249 primiparous ewes.

**251 4. Discussion**

252 Results showed that for at least the initial three months of life, before weaning, the artificial rearing  
253 of lambs under the conditions of the current study significantly reduced the lambs' daily weight  
254 gain. The use of any fostering method was beneficial when compared to AR, and fostered animals  
255 followed a similar growth rate to the control lambs. These results coincide with work by Oztabak  
256 and Ozpinar (2006) and Napolitano et al., (2006) that showed that average daily weight gain for  
257 ewe-reared lambs was significantly higher than for AR lambs, from birth up until 21 days. However,  
258 Napolitano et al., (2002) and Sevi et al., (2003) found no differences between the AR and ewe-  
259 reared lambs average growth rates. The contradictory results are most likely due to the *ad libitum*  
260 basis feeding of the previous studies, therefore having access to milk at all times. Due to the  
261 setting of the current study, this feeding apparatus was not available and the AR lambs had  
262 feeding sessions every three hours which was similar to the setup from Oztabak and Ozpinar  
263 (2006). In general, morphometric indices were found to evolve normally with age. Those indices  
264 directly linking height/length measures with weight (compactness and relative weight index)  
265 showed a steady increase up until weaning and a drop afterwards, as it was expected according to  
266 age variations on bone growth rate and muscle and body fat deposition (Riva et al. 2004).  
267 Morphometric indices at varying points between 0 and 90 days of age were found to be  
268 significantly better for the ewe-reared lambs compared to the AR lambs, which suggests that AR  
269 lambs were not growing at the same rate as ewe-reared lambs, up until weaning. Previous studies  
270 have found that there are strong correlations between body weight and live morphometric  
271 measurements (Alderson, 1999; Arthur and Ahunu, 1989; Ribeiro et al., 2004) with different body  
272 features being more prominent at different ages in growing lambs, and results from the current  
273 study agree. The daily weight gain and the morphometric indices showed no differences between  
274 the rearing treatments between 91 and 180 days (period 4). This period of time corresponded to  
275 the after-weaning rearing and all animals were fed on grass with access to the same pastures; it  
276 seems that, as expected, AR lambs were able to compensate their weight gain during this period of  
277 equal resource availability. Norouzian and Valizadeh (2011) also found that after weaning the  
278 growth rates were not affected by the rearing treatment. Additionally to the results from the current

279 experiment, artificial rearing has been associated with a reduction in animal welfare probably due  
280 to the impact of the physiological and psychological stressors caused by the early separation of the  
281 lamb and ewe (Cockram et al., 1993; Napolitano et al., 1995; Napolitano et al., 2002)

282 Regarding the potential separate effects of each fostering technique, neither the average daily gain  
283 nor the morphometric indices varied among the three foster methods studied, for any of the time  
284 periods analysed. These daily gains and indices did not differ from those of control twins either.  
285 This was due to the fact that experimental lambs came from successful fosters only. However,  
286 alien lambs were significantly lighter than the natal lambs at 0 and 7 days of age, which is due to  
287 the fact that alien lambs were born as triplets and natal lambs as singletons. These weight  
288 differences have been already observed in previous studies (Hernandez et al., 2009, Snowden and  
289 Knight, 1995). Although the lamb weights were different for the initial week of life, there were no  
290 significant differences in the daily weight gain between alien and natal lambs, which suggest that  
291 both were able to feed as needed. Weights and average daily gain for the alien and natal lambs at  
292 30, 90 and 180 days of age did not show significant differences between them. This seems to  
293 indicate that successful fosters, even if including a lighter and potentially weaker lamb, can  
294 produce similar results to lambs being reared by their own dam. It was found that multiparous ewes  
295 raised heavier lambs, with significantly higher weight gains, than primiparous ewes during periods  
296 1, 3 and 4. No previous research has compared the rearing ability of North Country mules with  
297 respect to growth rates. However, these results could be linked to the better ability of multiparous  
298 ewes to stimulate the lambs to suckle and encourage them to feed (Dwyer and Lawrence, 2000)  
299 and also due to the fact that primiparous ewes generally produce lighter offspring, which has been  
300 linked to their lower bodyweight and age at lambing (Dwyer, 2003). These results suggest that  
301 when selecting ewes for fostering, an experienced ewe would be more beneficial to ensure a high  
302 daily weight gain for each lamb compared to a primiparous ewe. Behavioural and cortisol results  
303 from these same experimental ewes (presented and discussed in Ward *et al.* in preparation)  
304 showed that primiparous ewes spent less time tending to their lambs and had significantly higher  
305 cortisol levels compared to multiparous ewes. This suggests that, not only do primiparous ewes  
306 produce lighter offspring, but also perform different behaviours than experienced dams and are  
307 more influenced at the physiological level by parturition and fostering.

308 Rearing was found to have a significant effect on conformation scores and chest roundness index  
309 with ewe-reared lambs achieving higher scores than AR lambs. Further research in this area would  
310 be advantageous to investigate effects of rearing on carcass quality, as some farmers are paid  
311 according to carcass conformation in addition to weight. Although carcass conformation is a  
312 common quality parameter used at the abattoir level, it is a subjective measure and caution is  
313 needed if using it alone. The majority of carcass quality parameters assessed on the current study  
314 were not found to be different between the rearing treatments due to the late slaughter age (6  
315 months of age) and the long post-weaning period (90 days) spent grazing under similar conditions,  
316 which provided enough time for any potential differences from the nursing period to even out.  
317 These results were also expected, but it is difficult to draw comparisons from them to the available  
318 bibliography because most literature has been conducted with lambs slaughtered at an earlier age.  
319 Regarding the potential separate effects of each fostering technique, carcass and meat quality  
320 parameters did not differ among foster methods. No differences were either found for the  
321 comparison between lambs' origin (alien vs. natal). It has been suggested that fostering and AR  
322 cause ewe-lamb bonds to be broken which can be distressing, and that distress during the initial  
323 stages of life could have detrimental effects on the lambs' behaviour, immune and endocrine status  
324 (Napolitano, 2003). Early life distress and its consequences could also ultimately influence carcass  
325 quality (Gregory, 1998). However, the current results imply that any potential distress caused by  
326 fostering or AR did not have long-term implications on the carcass or instrumental meat quality at a  
327 slaughter age of 180 days.

328 Multiparous ewes were able to rear lambs with significantly higher live slaughter weight and cold  
329 carcass weights than primiparous ewes. This could be linked again to the increased experience of  
330 multiparous ewes and their ability to produce more milk and to better attend lambs. The ultimate  
331 pH was also significantly lower in lambs reared by multiparous compared to primiparous ewes. The  
332 pH of the lambs reared by primiparous ewes fell slightly out of the normal range for this type of  
333 meat (5.4 - 5.8). A high ultimate pH can cause undesirable odours and flavours, affect palatability  
334 and reduce storage time compared to meat with a lower pH (Pethick and Jacob, 2000). High pH  
335 levels have been linked to many forms of acute distress including heat, transportation, dehydration,  
336 hunger, injury and fear (Ferguson and Warner, 2008). But it is difficult to find an explanation to this  
337 result because only data indicative of distress in the current study was taken at time of birth

338 (behaviour, cortisol and heart rate frequencies, Ward et al. in preparation). Early life distress could  
339 be having an effect on the lambs' temperament, and it has been shown that nervous temperament  
340 associates with stronger fear reactions (Bickell et al., 2011) which could have had an effect under  
341 slaughter conditions on meat quality indicators. However, more research is needed in this area to  
342 clarify these results and hypotheses.

343 The current study investigated growth rates, carcass and meat quality parameters for lambs within  
344 a commercial farming system using a 6 months slaughter age. Differences were noted between AR  
345 and ewe-reared lambs' average daily gain at young ages, as seen in previous studies. However,  
346 due to the extended post-weaning period where all lambs were grazing together, any differences  
347 were compensated and AR lambs produced similar meat quality results as ewe-reared lambs. AR  
348 lambs however did show significantly lower conformation scores and chest roundness indices,  
349 suggesting that ewe-rearing, and therefore fostering, could offer some advantages even when  
350 working at late slaughter ages. A lack of differences between growth rates, carcass and meat  
351 quality characteristics among the different foster methods, and also between alien and natal lambs,  
352 showed that once a foster of any type was successfully established, the alien lamb was enabled to  
353 feed similarly to the natal lamb and gain weight at the same rate as the natal lamb. Multiparous  
354 ewes were capable of rearing heavier lambs with higher average daily gains than primiparous  
355 ewes therefore suggesting that they would be better suited for fostering. Choosing foster methods  
356 should then be based on success rates and implications for the ewes' welfare (Ward et al. in  
357 preparation), as implications for the lambs' performance seem to be negligible. In conclusion, ewe-  
358 rearing and successful fostering seem to offer some proven advantages over AR under the  
359 conditions of the current study, even at late slaughter ages, and multiparous ewes seem to be  
360 better candidates as fosterers than primiparous ewes.

361

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366

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503 **Table 1:** Summary of experimental treatments and animals involved, expressed as: number of  
504 lambs (number of ewes). BF = birth fluids, CSBF = cervical stimulation and birth fluids, R =  
505 restraint.

	<b>CONTROL, <i>ewe reared</i></b>	<b>FOSTERED, <i>ewe reared</i></b>			<b>ARTIFICIALLY REARED</b>
		<b>BF</b>	<b>CSBF</b>	<b>R</b>	
<b>Primiparous</b>	24 (12)	24 (12)	-	24 (12)	-
<b>Multiparous</b>	24 (12)	24 (12)	24 (12)	24 (12)	-
<b>TOTAL</b>	48 (24)	48 (24)	24 (12)	48 (24)	12

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507

508 **Table 2:** Mean ( $\pm$  SE) for the different growth rates and carcass quality parameters for lambs  
 509 slaughtered at 180 days according to ewe's experience. Different superscripts in the same row  
 510 indicate significant differences at  $p < 0.05$ , a-b and  $p < 0.001$ , c-d.

		<b>Ewe experience</b>	
		<b>Primiparous</b>	<b>Multiparous</b>
<b>Average Weight</b>	Period 1	0.23 $\pm$ 0.06 <sup>a</sup>	0.27 $\pm$ 0.11 <sup>b</sup>
<b>Daily Gain</b>	Period 2	0.30 $\pm$ 0.08 <sup>a</sup>	0.31 $\pm$ 0.08 <sup>b</sup>
	Period 3	0.27 $\pm$ 0.04	0.31 $\pm$ 0.08
	Period 4	0.22 $\pm$ 0.03 <sup>a</sup>	0.27 $\pm$ 0.06 <sup>b</sup>
<b>Carcass Quality</b>	Live Slaughter Weight	44.79 $\pm$ 2.06 <sup>c</sup>	50.19 $\pm$ 1.92 <sup>d</sup>
	Cold Carcass Weight	23.89 $\pm$ 1.47 <sup>c</sup>	25.77 $\pm$ 1.42 <sup>d</sup>
	Ultimate pH	5.78 $\pm$ 0.02 <sup>c</sup>	5.82 $\pm$ 0.02 <sup>d</sup>

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512

513 **Table 3:** Mean ( $\pm$  SE) for the different carcass and meat quality parameters for lambs slaughtered  
 514 at 180 days according to their rearing methods. Different superscripts in the same row indicate  
 515 significant differences at  $p < 0.05$ . Chest Roundness Index = (chest width/chest depth) x 100;  
 516 Buttock/Leg Index = buttock length/leg length; Carcass Compactness = (cold carcass  
 517 weight/internal carcass length) x 100; Chest Depth Index = (cold carcass weight/slaughter weight)  
 518 x 100.

Parameters	Ewe Reared		
	Control	Fostered	Artificially Reared
Live Slaughter Weight	46.66 $\pm$ 2.10	48.45 $\pm$ 1.97	43.46 $\pm$ 1.20
Cold Carcass Weight	23.04 $\pm$ 1.39	23.65 $\pm$ 1.37	20.51 $\pm$ 0.85
Conformation score	10.05 $\pm$ 0.39 <sup>a</sup>	10.66 $\pm$ 0.45 <sup>a</sup>	8.90 $\pm$ 0.56 <sup>b</sup>
Fatness score	7.68 $\pm$ 0.19	8.22 $\pm$ 0.28	8.00 $\pm$ 0.30
Ultimate pH	5.80 $\pm$ 0.02	5.80 $\pm$ 0.02	5.81 $\pm$ 0.02
Water Holding Capacity	19.36 $\pm$ 0.47	19.35 $\pm$ 0.32	19.37 $\pm$ 0.31
L* (Lightness)	35.52 $\pm$ 0.79	34.50 $\pm$ 0.86	35.67 $\pm$ 0.32
a* (Redness)	7.04 $\pm$ 0.04	7.01 $\pm$ 0.93	6.99 $\pm$ 0.08
b* (Yellowness)	3.31 $\pm$ 0.05	3.32 $\pm$ 0.08	3.25 $\pm$ 0.13
Chest Depth Index	48.97 $\pm$ 5.20	47.27 $\pm$ 4.37	47.38 $\pm$ 2.19
Chest Roundness Index	91.55 $\pm$ 2.56 <sup>a</sup>	89.72 $\pm$ 2.57 <sup>a</sup>	81.85 $\pm$ 3.44 <sup>b</sup>
Buttock/Leg Index	69.54 $\pm$ 2.01	73.04 $\pm$ 2.46	76.01 $\pm$ 1.06
Carcass Compactness	35.12 $\pm$ 3.08	35.76 $\pm$ 2.99	35.29 $\pm$ 1.25

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526 Figure captions

527

528 **Figure 1.** Daily weight gains across the different foster method treatments and artificially reared  
529 lambs. Different letters indicate significant differences (a-b,  $p < 0.05$ ; c-d,  $p < 0.005$ ). Period 1 =  
530 average daily gain from day 0 - 7, Period 2 = average daily gain from 8 - 30, Period 3 = average  
531 daily gain from 31 – 90, Period 4 = average daily gain from 91 – 180 and TOTAL = average daily  
532 gain from day 0 to 180 for all treatments. Data markers represent means  $\pm$  SE.

533

534 **Figure 2:** Indices calculated from live morphometric measurements (means  $\pm$  SE) assessed at 0,  
535 7, 30, 90 and 180 days of age. Different letters indicate significant differences (a-b,  $p < 0.05$ ; c-d,  $p$   
536  $< 0.005$ ). **2a.** Pelvic Index = (rump width/rump length) x 100; Transversal Pelvic Index = (rump  
537 width / height at shoulder) x 100; Longitudinal Pelvic Index = (rump length/height at shoulder) x  
538 100 **2b.** Relative Torso Depth = (chest depth/height at shoulder) x 100; Compactness Index =  
539 (weight/ body length) x 100; Relative Weight Index = (weight/ height at shoulder) x 100 **2c.** Body  
540 Index = (torso length/chest circumference) x 100; Proportionality Index =(torso length/ height at  
541 shoulder) x 100; Relative Shortness Index = (torso length/ height at shoulder) x 100.

542