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Growth parameters, behavior, and meat and ham quality of heavy pigs subjected to photoperiods of different duration

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3 **Growth parameters, behaviour, meat and ham quality of heavy pigs subjected to photoperiods**
4 **of different duration.**

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6 **Running title: Photoperiod in heavy pigs**

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ABSTRACT

15
16 In order to attain a good level of animal welfare pigs require a sufficient environmental illumination.
17 Therefore minimum levels for light duration and light intensity have been set up by the European
18 legislation (Directive 2008/120). An experimental trial was designed to determine whether an
19 increased duration of the photophase (up to 16 hours of light per day) could modify the behaviour,
20 productive parameters, meat and ham quality of Italian heavy pigs. Forty crossbred (Large White ×
21 Landrace) castrated males pigs (initial average BW: 26 kg) intended for PDO (Protected Designation
22 Origin, according to EU Regulation 1151/2012) dry-cured ham production were raised according to
23 Parma Ham production rules up to the weight of 160kg. Pigs were homogeneously allotted to two
24 experimental groups, each comprising 20 pigs. The Short Photoperiod group (SP) received the
25 minimum mandatory number of hours of light per day (corresponding to 8 hours/day), whereas the
26 Long Photoperiod group (LP) was subjected 16 hours of light per day during the whole production
27 cycle. Light intensity was maintained at 40 lux (*i.e.*, the minimum mandatory level) for both the
28 experimental groups. Growth and slaughtering parameters, carcass traits, fatty acid composition, meat
29 and dry-cured ham quality and animal behaviour were assessed. Pigs in the LP group showed a greater
30 live weight and carcass weight compared to the SP group ($P = 0.005$ and 0.007 , respectively).
31 Similarly, hams obtained from the LP group were significantly heavier and their weight losses during
32 the dry-curing period was reduced ($P < 0.01$) when compared to the SP group. No significant
33 differences were detected between the experimental groups as concerns meat and ham quality or fatty
34 acid composition of the subcutaneous fat. Pigs in the LP group spent more time resting and less time
35 pseudo-rooting ($P < 0.01$). Our results indicate that, given an appropriate dark period for animal rest,
36 an increased duration of the photoperiod, even at the lower mandatory light intensity level, can
37 favourably affect growth parameters of heavy pigs without any negative effect on animal behaviour,
38 carcass traits, meat or long-cured ham quality. Therefore rearing pigs in semi-darkness should be
39 considered as a baseless practice, contrary to animal welfare.

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41 **Key words:** animal welfare, ham quality, heavy pig, light duration, meat quality

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INTRODUCTION

44

45 In order to guarantee a satisfactory level of animal welfare and to avoid the practice of rearing pigs
46 in semi-darkness, mandatory levels of environmental illumination for pigs are set by the European
47 legislation (EC, 2008) to a minimum of 40 lux for at least 8 hours per day. This provision reflects the
48 existence of a need of pigs in terms of light intensity and duration, which must be fulfilled in order to
49 allow their explorative and social activities and thus ensure the attainment of a sufficient level of
50 animal welfare (EFSA, 2007). If the behavioural and welfare aspects linked to different illumination
51 regimes have already been investigated (Van Putten and Elshof, 1984; Baldwin and Start, 1985;
52 Taylor et al., 2006), their effects on swine growth parameters and on the quality of the derived
53 products have been poorly explored so far. To our knowledge, the only studies on the effects of
54 photoperiod on meat quality were conducted by Virgili & Schivazappa (2002) and Virgili et al. (2002),
55 who found a circannual rhythm for cathepsin B activity in hams, which had been in turn related to
56 the development of excessive softness and other sensorial defects in the hams during the dry-curing
57 period (Parolari et al., 1994; Virgili et al., 1998).

58 Previous studies from our research group indicated that a longer photophase (14 vs. 8 hours of light
59 over the 24 hours) may have some positive effects on growth parameters and behavioural traits
60 (Martelli et al., 2005), and that a higher light intensity (80 vs. 40 lux) reduces aggressive behaviours
61 of heavy pigs (Martelli et al., 2010). Besides, neither the increase in light intensity (80 vs. 40 lux) nor
62 in the duration of the photophase (14 vs. 8 hours of light) impaired growth parameters, meat or dry-
63 cured ham quality (Sardi et al., 2012). The aim of the present trial was to investigate the effects of a
64 further increase in the duration of the photophase (16 vs. 8 hours of light over the 24 hours) at the
65 minimum mandatory level of light intensity (*i.e.*, 40 lux), on swine behaviour, growth parameters,
66 carcass traits, meat and long-cured hams quality.

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MATERIAL AND METHODS

The trial was carried out in the facilities of the Department of Veterinary Medical Sciences of the University of Bologna, Italy, in observance of current Italian legislation implementing European Council Directive 2008/120 on swine protection. The institutional Ethic Committee of the University of Bologna approved the experimental protocol.

Animals, Housing and Feeding

Forty crossbred (Large White × Landrace) castrated males pigs were used in this trial. The average Body Weight (BW) at the beginning of the trial was (26 ± 2.65) kg . Animals were raised until reaching approximately 160 kg BW and a minimum age of 9 months, according to the rules established for Parma Ham production (Consortium for Parma Ham, 1992).

Pigs were kept in collective pens (5 animals per pen) on a totally slatted floor, with a floor space of 1.20 m² per pig. Each pen was equipped with a bite drinker and a collective stainless steel feeder (0.3 m wide x 3.5 m long). Environment was enriched by providing steel hanging chains. Pens were located in temperature- and humidity-controlled rooms (RH 65% and T° 22°C) equipped with a forced-air ventilation system. Water was available *ad libitum* through nipple drinkers. In order to meet the pigs' requirements, three commercial diet formulations were used (first phase from 26 to 75 kg BW: 3620 kcal DE/kg DM, CP 17.9% DM; second phase from 75 to 100 kg BW: 3630 kcal DE/kg DM, CP 16.7% DM; third phase from 100 kg BW to slaughtering: 3580 kcal DE/kg DM, CP 15.4% DM). Feed was offered twice a day (at 8:30 and 14:30) as wet (meal to water ratio = 1:3) and, according to traditional practices for Italian heavy pig production, rationed at 9% of the metabolic BW ($BW^{0.75}$), up to a maximum of 2.8 kg dry matter per pig, per day. Pigs were weighed every 7 weeks to adjust the daily rations. Lighting was entirely artificial and was supplied by neon tubes

93 (OSRAM LUMILUX, cool white, luminous flux 3350 lm, light colour 840, rated colour temperature
94 4000 K) placed at 280 cm above the floor. Luminous intensity was measured at pig-eye level using a
95 luxmeter device (model HD 8366, Delta Ohm, Italy) and was kept at 40 lux for both groups,
96 corresponding to the minimum mandatory level for light intensity according to EU legislation
97 (European Council Directive 2008/120). During the period of darkness, light intensity was 1.5 lux.
98 Animals were allotted to two experimental groups, each comprising 4 pens of 5 pigs, which were
99 subjected to the following light regimens

- 100 - Short Photoperiod (**SP**): pigs received 8 hours of light per day, from 08:00 to 16:00, followed
101 by a 16-hour scotophase (dark period) (**8L:16D**);
- 102 - Long Photoperiod (**LP**): pigs received 16 hours of light per day, from 06:00 to 22:00, followed
103 by a 8-hour dark period (**16L:8D**).

104

105 ***Growth Parameters***

106

107 Pigs were individually weighed at the beginning of the trial, after 155 days and at the end of the trial
108 period to calculate average daily gain (ADG). Feed intake of every replication was recorded daily to
109 calculate the gain-to-feed ratio (G:F). The collection of growing parameters stopped on the 251st day
110 of the trial, when half of the pigs attained the required slaughter BW of 160 kg and were slaughtered.
111 The remaining pigs were kept under the experimental conditions up to the day in which these pigs in
112 turn attained the final body weight of about 160 kg and were transported to the slaughter plant.

113

114 ***Behavioural Traits***

115

116 Between day 155 and day 251 of the trial (corresponding to the phase between 100 and 160 kg live
117 weight), the behaviour of all pigs was videotaped during the light period (corresponding to 8h in the
118 SP group, 16 hours in the LP group) by means of a digital closed circuit system (Mesa, Arezzo, Italy).

119 The cameras were mounted on a rail attached to the wall in front of each pen up to 3m above the
120 ground. Pigs were videotaped once every month, corresponding to 4 videotaping sessions for each
121 replication. Videos were examined by a single trained operator and the behavioural pattern was
122 assessed by scan sampling technique at 10 min intervals according to predetermined ethogram for
123 heavy pigs (Martelli et al., 2014) reporting the following behaviours: standing inactive, sitting
124 inactive (dog-sitting), sternal recumbency, lateral recumbency, walking, eating, drinking, chain/bar
125 biting, exploring the floor, social interactions. The choice of videotaping pigs only during the second
126 phase was based on the assumption that behavioural alterations are more likely to occur during this
127 period, when less space per animal is available and feed restriction becomes more severe (Scipioni et
128 al., 2009).

129

130 ***Carcass Traits, Meat and Fat Quality***

131

132 At the average BW of 160 kg, pigs were transported to a commercial slaughterhouse (the journey
133 lasted about 1 hour). Slaughtering took place after a 15-hour fast and was preceded by electrical
134 stunning. Thereafter, the dressing out percentage was calculated (based on the hot carcass weight)
135 and the lean meat yield of carcasses was assessed by Fat-o-Meater (FOM-SFK, Copenhagen, DK).
136 At 45' post mortem, the pH value of the *Semimembranosus* muscle was measured by means of a
137 portable pH meter (model 250A, Orion Research, Boston, MA). Thereafter, each carcass was
138 dissected into the main commercial cuts, whose weights were recorded. At 24 hours post mortem, a
139 second measurement of the pH value was taken from the *Semimembranosus* muscle. The colour of
140 the lean portion of the thighs (*Biceps femoris* muscle) was assessed, at 24 hours post mortem,
141 according to the CIELAB System (CIE, 1976), using a Minolta Chromameter CR-200 (Minolta
142 Camera Co., Ltd., Osaka, Japan) equipped with a D65 illuminant. Subcutaneous fat thickness was
143 measured on the outer portion of trimmed fresh legs, vertically at the head of the femur (Consortium
144 for Parma Ham, 1992).

145 Drip loss and cooking loss were evaluated in samples taken from the *Longissimus dorsi* muscle
146 according to the method described by Honikel (1998).
147 Samples of subcutaneous fat (outer and inner layers) were taken in the overhanging area of the *Biceps*
148 *femoris* muscle in order to determine the fatty acid composition by gas chromatograph (HRGC8560
149 Series Mega 2 gas chromatograph; Fisions Instruments, Milan, Italy). Samples were collected from
150 14 randomly-selected thighs per each experimental group. Total lipids were extracted from each
151 sample of subcutaneous fat by means of the chloroform/methanol (2:1, vol/vol) method described by
152 Folch et al. (1957), and measured gravimetrically. Fatty acids were esterified using 5% methanolic
153 hydrogen chloride. The fatty acid methyl esters were separated by gas chromatography using a
154 Supelco SP- 2330 capillary column (30m × 0.25mm, 0.20 µm; Supelco, Bellefonte, PA, USA).
155 Injector and detector temperatures were kept at 220°C and 280°C, respectively. The column was
156 programmed as follows: 140°C for 1 min; the temperature was then raised to 220°C (3°C/min) and
157 held constant for 15 min. Fatty acids were identified by comparing the retention times of the peaks
158 with those of known standards. Results are expressed as percentages of total fatty acids.
159 The Iodine number was assessed according to the AOAC method (AOAC, 2000).

160

161 ***Ham Yield and Quality***

162

163 Hams were cured according to Parma Ham production rules (Consortium for Parma Ham, 1992).
164 Thighs were studied over a 18-month curing period. They were weighted before and after trimming,
165 after salting (25-30 days from slaughtering) and at the end of the curing period, in order to calculate
166 the weight losses after the different phases of the curing process. Twenty-eight samples of *Biceps*
167 *femoris* muscle were taken from seasoned hams (fourteen for each group) and analysed for moisture,
168 crude protein, sodium chloride content (AOAC 1995, 2000) and proteolysis index (Careri et al.,
169 1993). Colour was assessed in cured hams both in samples of the *Semimembranosus* muscle and in
170 samples of subcutaneous fat according to the CIELAB System (CIE, 1976), using a Minolta

171 Chromameter CR-200 (Minolta Camera Co., Ltd., Osaka, Japan). Subcutaneous fat samples (outer
172 and inner layers) were taken from the skin-covered fat in the overhanging area of the *Biceps femoris*
173 muscle and analysed by gas chromatography as described above (HRGC8560 Series Mega 2 gas
174 chromatograph; Fisions Instruments, Milan, Italy) for fat from the raw thighs. Subcutaneous fat was
175 analysed for Peroxide Value (AOAC, 2000) and Tiobarbituric Acid Reactive Substances (TBARS)
176 according to the method proposed by Wang et al. (2002).

177 Cured hams were visually evaluated by a panel of five trained experts, who subjectively rated hams
178 based on a predetermined checklist containing the main sensory characteristics of the lean and of the
179 fat portions (Mordenti et al., 2012). The characteristics assessed were lean part firmness, lean colour
180 homogeneity, lean colour bitonality, marbling, ham fatness and fat firmness. Sensory evaluation was
181 expressed on a 10-point scale where 1 was attributed to the absence of the trait and 10 to its maximum
182 presence. An overall evaluation was also given as the total impression the panelist got evaluating a
183 ham, where 10 was attributed to hams with optimal characteristics, whereas 1 was attributed to poor
184 quality hams (Consortium for Parma Ham, Personal Communication).

185

186 *Statistical Analysis*

187

188 Data were analysed using the STATISTICA 10 package (StatSoft Inc., 2011). Normality of data was
189 assessed by the Kolmogorov–Smirnov test and the data obtained were submitted to analysis of
190 variance using duration of photoperiod as the main effect. The pen (5 pigs) was taken as the
191 experimental unit for G:F and behavioural observations; individual data were taken to be the
192 experimental unit for ADG, slaughtering parameters, meat, and ham qualitative traits. For
193 nonparametric data (behavioural traits and sensory evaluation of hams), the Mann-Whitney test was
194 used. The significance level for all statistical tests was set at $P < 0.05$.

195

196

RESULTS

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198 No occurrence of disease was recorded during the trial.

199 Growing parameters are shown in table 1. Pigs which were subjected to a longer photoperiod showed
200 an increased body weight after 155 days of trial ($P = 0.007$). Such a difference is maintained until the
201 end of the trial ($P = 0.044$ after 251 days). ADG is also higher in the LP than in the SP group during
202 the first phase of the trial ($P = 0.010$) and the overall ADG is higher in the LP than in the SP group (P
203 $= 0.048$). Overall G:F results higher in LP group, and the difference is significant ($P = 0.044$) during
204 in the first period of the trial (up to 155d).

205 Slaughtering parameters and carcass traits are shown in Table 2. Pigs belonging to the LP group,
206 showed increased live weight at slaughter, and therefore carcass weights ($P = 0.005$ and 0.007 ,
207 respectively) compared to their counterparts in SP group. No significant differences were observed
208 between the experimental groups with respect to lean meat percentage calculated by F-o-M or lean
209 and fatty cuts yield.

210 Similarly, our results did not reveal any significant difference among the groups with respect to the
211 qualitative traits of meat (colour, post-mortem glycolysis, water holding capacity; see Table 3).

212 Table 4 shows the characteristics of subcutaneous fat of uncured (raw) thighs. Fat thickness was
213 significantly higher in LP than in SP group ($P = 0.038$). No significant differences were observed
214 between the two groups concerning the single fatty acid content although the LP group showed a
215 tendentially higher content in oleic acid and a tendentially lower content in linoleic acid compared to
216 the SP group ($P = 0.10$ and $P = 0.066$, respectively). Consequently, the content of polyunsaturated fatty
217 acid (PUFA) was significantly lower, and the MUFA/PUFA ratio was tendentially higher ($P = 0.047$
218 and 0.064 , respectively) in the LP than in the SP group. Although the difference between the
219 experimental groups was not significant, also the iodine number appears to be the lower in the LP
220 group.

221 Ham weights and ham weight losses are shown in Table 5. The weight of the thighs before trimming
222 was significantly higher in LP than in SP group ($P = 0.001$). These differences remained significant

223 during the following phases of the curing process (trimmed weight, weight after salting and final
224 weight, $P=0.001$). Overall weight loss during the dry curing process was lower in hams deriving from
225 pigs belonging to LP compared to SP group ($P=0.01$).

226 As concerns dry-cured hams, no significant differences were observed with respect to moisture, crude
227 protein, proteolysis index, fat and meat colour or fatty acid composition (see Table 6). The only
228 significant difference was related to sodium chloride content, which was lower in LP than in SP group
229 ($P=0.033$). Although not significant, dry-cured fat belonging to the LP group showed a positive trend
230 as concerns oxidative stability, in particular as concerns peroxide value, which was lower in the LP
231 than in the SP group. This finding is in agreement with the observation that the loss of PUFAs during
232 dry curing was less extensive in the LP than in the SP group (from 15.19 to 11.71% vs. from 13.61 to
233 12.26%, respectively).

234 Sensory analysis of cured hams (data not shown) didn't reveal any significant difference between the
235 experimental groups, although hams from pigs belonging to the LP group scored a higher overall
236 evaluation (7.25 vs. 6.63 points).

237 Behavioural observations (Table 7) indicate that during the prolonged photophase to which LP pigs
238 were subjected, animals spent more time in lateral recumbency than SP pigs ($P < 0.01$), increased the
239 total recumbency time (sternal and lateral recumbencies, $P < 0.001$) and showed a reduction in the
240 percentage of time spent exploring the pen floor, i.e., pseudo-rooting ($P < 0.001$).

241

242

DISCUSSION

243

244 It is worth noting that since pigs seem to dislike excessively high light intensities and prefer darkness
245 for sleep (Baldwin & Start, 1985; Taylor et al., 2006), in the present trial light intensity was kept at a
246 moderate range (40 lux, i.e. the minimum mandatory level), and the artificial photoperiod always
247 allowed for an 8-h period of darkness for sleep.

248 The LP group showed better growth parameters (final weight and overall ADG) than the SP group.
249 This difference is mostly due to the first phase of the trial, as confirmed by ADG and G:F, which are
250 significantly different between groups during this period. Overall ADG fell within the limits
251 recommended for the Italian heavy pig production (i.e, below 600g/die on the whole production cycle,
252 since animals must be at least 9 months old at slaughter and the average body weight of each batch
253 must not exceed 160 ± 10 kg, according to the rules established by the Consortium for Parma Ham,
254 1992).

255 Despite their higher slaughtering weight when compared to pigs receiving the minimum mandatory
256 light duration (SP), LP pigs did not show any negative impact on lean cuts yield as was demonstrated
257 by similar F-o-M values and single cut percentages on the whole carcass. This outcome, which agrees
258 with our previous findings obtained on pigs receiving a moderate increase of the light period (Martelli
259 et al., 2005, Sardi et al., 2012) is indicative of an overall higher body development of LP animals,
260 regardless of carcass composition. Taking into account the fact that pigs were fed-restricted, thus the
261 limited differences in feed intake cannot explain a 13% difference for ADG in the first period, other
262 anabolic pathways may be advocated. In this framework an increase of Growth Hormone (GH) cannot
263 be ruled out, even though we did not carry out any specific analyses. Claus and Weiler (1994)
264 hypothesized that the increased daylength during summer may stimulate GH in pigs, and such an
265 effect has been observed in goats (Jin et al., 2012). It has also been demonstrated that darkness
266 produces a decrease in the baseline GH level in pigs of both sexes (Dubreuil et al., 1988) and that GH
267 secretion is increased during resting in lambs (Laurentie et al., 1989). The joint effects of a shorter
268 dark period and a longer time spent resting during light hours may have improved GH secretion and
269 hence overall body development, which would explain the higher body weights at slaughter given an
270 identical carcass composition (similar lean-to-fat ratio). The increased body development, in fact, can
271 be deduced from the fact that LP pigs had higher F and SR values, as recorded by the Fat-o-Meater,
272 therefore the increased carcass weight of LP pigs was due to an increased thickness both of the
273 subcutaneous fat and of the loin, i.e. by the fact that animals were larger, but not fatter.

274 Besides, the high level of calmness (LP pigs devoted part of their longer light period in resting
275 regardless of the shortening of the scotophase) observed between 100 and 160 kg BW may have
276 reduced the amount of energy consumed (and wasted) through the expression of other behaviours,
277 such as pseudo-rooting and pen exploration, which are typically observable under stressful and/or
278 frustrating conditions. Nevertheless it should be stressed that, facing to overall better growth
279 parameters of LP pigs, differences in ADG and G:F were significant only during the first phase of the
280 trial when no video-recordings were taken.

281 As concerns animal behaviour, our observations also showed that the prolongation of the photophase
282 determined a redistribution of pigs' activities during the light period. As mentioned, pigs in the LP
283 group spent an increased portion of the photophase in lateral recumbency, indicating that the
284 prolongation of the photophase did not impair the pigs' possibility to rest. Besides, the reduced
285 percentage of time LP pigs spent exploring the pen structures during the photophase is indicative of
286 how their exploratory behaviour has been, in fact, redistributed along the light hours.

287 In our previous researches, an increase in light duration from 8 to 14 hours at 70 lux resulted in a
288 significant improvement of ADG and in a tendential increase of slaughtering BW (Martelli et al.,
289 2005; Sardi et al., 2012), whereas a different light intensity did not affect pig's production traits
290 (Martelli et al., 2010). It may therefore be concluded that the further increase in light duration applied
291 in this study (8 vs. 16 hours), although at the minimum recommended light intensity, has an even
292 more evident effect on body growth, with light duration showing a greater impact than light intensity.
293 It is however worth highlighting that this positive effect did not result in an impairment of meat or fat
294 quality. The increased duration of the photoperiod, in fact, determined an increase in subcutaneous
295 fat thickness in the LP group (most likely linked to the higher body development, as explained above),
296 which is in turn associated with an increased MUFA and a reduced PUFA content and with a
297 subsequent increase in the MUFA/PUFA ratio. These results can be interpreted as a consequence of
298 the different slaughter weights between the experimental groups: an increased slaughter weight is in
299 fact associated with a lower degree of lipid unsaturation. The increase in backfat thickness has been

300 associated with a higher level of saturated and monounsaturated fatty acids and a notable reduction
301 in polyunsaturated fatty acids content (Virgili et al., 2003; Lo Fiego et al., 2005), with subsequent
302 reduction in PUFA to SFA ratio (Raj et al., 2010). This variation in acidic composition can be
303 positively considered, as it makes possible to obtain fat whose characteristics are more suitable for
304 the dry-curing process, being less subjected to lipid oxidation. In this trial, although the difference
305 between the experimental groups was not significant, lower peroxide and TBARS values were
306 observed in the subcutaneous fat of dry-cured hams belonging to the LP group, which could suggest
307 an increased oxidative stability.

308 Overall, the results from the present experiment fall within the ranges reported by other Italian authors
309 with respect to fatty acids profile of raw thighs (Scipioni and Martelli, 2001; Virgili et al., 2003; Lo
310 Fiego et al., 2005; Pugliese et al., 2006; Mordenti et al., 2012; Nannoni et al. 2013a and 2013b). The
311 iodine number was below 70 for all thighs, according to the limit set by Parma Ham production rules
312 (Consortium for Parma Ham, 1992). Ham yields and their weight losses during the curing process
313 reflect the different initial weights of the raw thighs and overall weight losses were more favourable
314 in the LP group.

315 With respect to the quality of the cured hams, the only significant difference found in this trial was a
316 lower sodium chloride content in LP hams. This difference might once again be due to the higher
317 weight of the LP thighs, which is likely to have slowed down salt penetration. However, sodium
318 chloride content fell within the limits for Parma Ham production (4.5-6.7%; Consortium for Parma
319 Ham, 1992). This difference could be regarded favourably from a human nutrition standpoint
320 (Ruusunen and Puolanne, 2005). Lastly, the sensory analysis of cured hams did not reveal any
321 significant differences among groups in terms of colour and consistency of the lean and the fat
322 components, although hams belonging to the LP group showed slightly higher overall scores,
323 probably due to the better colour homogeneity of their lean fraction and to their slightly increased
324 fatness.

325

CONCLUSIONS

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327

328 The specific illumination requirements of pigs are linked to their need to receive an appropriate
329 sensory input and to express their behavioural repertoire. Our previous investigations demonstrated
330 that a moderate increase in light intensity and/or light duration can positively affect heavy pig welfare
331 and/or growth parameters (Martelli et al., 2005, 2010) without affecting dry-cured ham quality (Sardi
332 et al., 2012). The results of the present trial demonstrate that a further increase in the duration of the
333 photoperiod (up to 16 hours of light per day) can, even at the minimum recommended light intensity
334 (40 lux) and given an adequate dark period for rest, improve on one hand pigs growth parameters,
335 and on the other hand ham nutritional and technological quality, without negatively affecting animal
336 behaviour.

337 Rearing pigs in a semi-darkness environment in order to avoid competitions between the animals is
338 once more confirmed to be a baseless practice; on the contrary, increasing the hours of light does not
339 impair animal ability to rest and calmness level and improves growth parameters.

340 Once again we wish to stress that behavioural problems, such as aggressions, arising from poor
341 rearing conditions should be solved by addressing the root causes (lack of space, feed inadequacy,
342 barren environment) rather than reducing environmental lighting as it is still inappropriately done by
343 some farmers.

344

LITERATURE CITED

345

346

347 AOAC. 1995 Official Methods of Analysis. 15th ed. Assoc. Off. Anal. Chem., Arlington, VA.

348 AOAC. 2000. Official Methods of Analysis 17th ed. Assoc. Off. Anal. Chem., Gaithersburg, MD.

349 Baldwin, B. A., and I. B. Start. 1985. Illumination preferences of pigs. *App. Anim. Behav. Sci.*
350 14:233–243.

351 Claus, R. and U. Weiler. 1994. Endocrine regulation of growth and metabolism in the pig: a review.

352 Livest. Prod. Sci. 37:245-260.

353 Careri, M., A. Mangia, G. Barbieri, L. Bolzoni, R. Virgili, and G. Parolari. 1993. Sensory Property
354 Relationships to Chemical Data of Italian type Dry-cured Ham. *J. Food Sci.* 58:968–972.

355 Consortium for Parma Ham. 1992. Prosciutto di Parma (Parma Ham), Protected Designation of
356 Origin. Specifications and Dossier.
357 http://www.prosciuttodiparma.com/pdf/en_UK/Specifications.pdf (Accessed April 2014).

358 Dubreuil, P., H. Lapierre, G. Pelletier, D. Petitclerc, Y. Couture, P. Gaudreau, J. Morisset, and P.
359 Brazeau. 1988. Serum growth hormone release during a 60-hour period in growing pigs. *Dom.*
360 *Anim. End.* 5:157–164.

361 EFSA (European Food Safety Authority). 2007. Scientific Opinion of the Panel on Animal Health
362 and Welfare on a request from the Commission on Animal health and welfare in fattening pigs
363 in relation to housing and husbandry. *EFSA Journal* 564:1–14.

364 European Council. 2008. Council Directive 2008/120/EC of 18 December 2008 laying down
365 minimum standards for the protection of pigs (codified version). *OJEU L* 47:5–13.

366 EU, 2012. Regulation (EU) No 1151/2012 of the European Parliament and of the Council of 21
367 November 2012 on quality schemes for agricultural products and foodstuff. *OJEU L* 343:1-
368 29.

369 Folch, J., M. Lees, and G. H. Sloane Stanley. 1957. A simple method for the isolation and purification
370 of total lipids from animal tissues. *J. Biol. Chem.* 226:497–509.

371 Honikel, K. O. 1998. Reference methods for the assessment of physical characteristics of meat. *Meat*
372 *Sci.* 49:447–457.

373 Jin, J., T. Yaegashi, K. Sawai, K. and T. Hashizume. 2012. Effects of photoperiod on the secretion of
374 growth hormone in female goats. *Anim. Sci. J.* 83:610-616.

375 Laurentie, M. P., B. Barenton, J. Charrier, R. Garcia-Villar, P. G. Marnet, M. Blanchard, and P. L.
376 Toutain. 1989. Instantaneous secretion rate of growth hormone in lambs: relationships with
377 sleep, food intake and posture. *Endocrinology* 125:642–651.

- 378 Lo Fiego, D. P., P. Santoro, P. Macchioni, and E. De Leonibus. 2005. Influence of genetic type, live
379 weight at slaughter and carcass fatness on fatty acid composition of subcutaneous adipose
380 tissue of raw ham in the heavy pig. *Meat Sci.* 69:107–114.
- 381 Martelli, G., R. Boccuzzi, M. Grandi, G. Mazzone, G. Zaghini, and L. Sardi. 2010. The effects of two
382 different light intensities on the production and behavioural traits of Italian Heavy pigs. *Berl.*
383 *Munch. Tierarztl.* 123:10–15.
- 384 Martelli, G., L. Sardi, L. Stancampiano, N. Govoni, A. Zannoni, E. Nannoni, M. Forni and M.L.
385 Bacci. 2014. A study on some welfare-related parameters of hDAF transgenic pigs when
386 compared to their conventional close relatives. *Animal*, in press.
- 387 Martelli, G., M. Scalabrin, R. Scipioni, and L. Sardi. 2005. The effects of the duration of the artificial
388 photoperiod on the growth parameters and behaviour of heavy pigs. *Vet. Res. Comm.*
389 29(Suppl. 2):367–369.
- 390 Mordenti, A. L., G. Martelli, N. Brogna, E. Nannoni, G. Vignola, G. Zaghini, and L. Sardi. 2012.
391 Effects of a soybean-free diet supplied to Italian heavy pigs on fattening performance, and
392 meat and dry-cured ham quality. *It. J. Anim. Sci.* 11:459–465.
- 393 Nannoni, E., G. Martelli, M. Cecchini, G. Vignola, M. Giammarco, G. Zaghini and L. Sardi. 2013a
394 Water requirements of liquid-fed heavy pigs: Effect of water restriction on growth traits,
395 animal welfare and meat and ham quality. *Livest. Sci.* 151:21-28.
- 396 Nannoni, E., G. Martelli, P. Parazza, G. Zaghini and L. Sardi. 2013b. The effects of soybean press
397 cake on productive traits and meat quality of Italian heavy pigs intended for Parma ham
398 production. *Acta Agriculturae Slovenica Suppl.*4:81-84.
- 399 Parolari, G., R. Virgili, and C. Schivazappa. 1994. Relationship between cathepsin B activity and
400 compositional parameters in dry-cured hams of normal and defective texture. *Meat Sci.*
401 38:117–122.
- 402 Pugliese, C., O. Franci, A. Acciaioli, R. Bozzi, G. Campodoni, F. Sirtori, and G. Gandini. 2006.
403 Physical, chemical and technological traits of dry cured ham of Cinta Senese pigs reared

404 outdoors and indoors. *It. J. Anim. Sci.* 5:265–276.

405 Raj, St., G. Skiba, D. Weremko, H. Fandrejewski, W. Migdal, F. Borowiec, and E. Polawska. 2010.
406 The relationship between the chemical composition of the carcass and the fatty acid
407 composition of intramuscular fat and backfat of several pig breeds slaughtered at different
408 weights. *Meat Sci.* 86:324–330.

409 Ruusunen, M., and E. Puolanne. 2005. Reducing sodium intake from meat products. *Meat Sci.*
410 70:531-541.

411 Sardi L., E. Nannoni, M. Grandi, G. Vignola, G. Zaghini, and G. Martelli. 2012. Meat and ham quality
412 of Italian heavy pigs subjected to different illumination regimes. *Berl. Munch. Tierarztl.*
413 125.11/12:463–468.

414 Scipioni, R., and G. Martelli. 2001. Consequences of the use of ensiled sugar beet-pulp in the diet of
415 heavy pigs on performances, carcass characteristics and nitrogen balance: a review. *Anim.*
416 *Feed Sci. Technol.* 90:81–91.

417 Scipioni, R., G. Martelli, and, L. A. Volpelli, 2009. Assessment of welfare in pigs. *Ital. J. Anim. Sci*
418 8(Suppl. 1): 117-137.

419 StatSoft, Inc. 2011. *Electronic Statistics Textbook*. StatSoft, Tulsa, Oklahoma.

420 Taylor, N., N. Prescott, G. Perry, M. Potter, C. Le Sueur, and C. Wathes. 2006. Preference of growing
421 pigs for illuminance. *Appl. Anim. Behav. Sci.* 96:19–31.

422 Van Putten, G., and W. J. Elshof. 1984. The influence of three light levels on the behaviour of fattening
423 pigs. *KTBL Schrift.* 199:197–216.

424 Virgili, R., M. Degni, C. Schivazappa, V. Faeti, E. Poletti, G. Marchetto, M. T. Pacchioli, and A.
425 Mordenti. 2003. Effect of age at slaughter on carcass traits and meat quality of Italian heavy
426 pigs. *J. Anim. Sci.* 81:2448–2456.

- 427 Virgili, R., G. Parolari, C. Schivazappa, C. Soresi Boldrini, and R. Volta. 1998. Proteases in fresh
428 pork muscle and their influence on bitter taste formation in dry-cured ham. *J. Food Biochem.*
429 22:53–63.
- 430 Virgili, R., and C. Schivazappa. 2002. Muscle traits for long matured dried meats. *Meat Sci.* 62:331–
431 343.
- 432 Virgili, R., T. Toscani, C. Schivazappa, L. Mazzotta, R. Manfredini, and F. Portaluppi. 2002. Effect
433 of seasonal changes on muscle cathepsin B activity and pH 24h of Italian heavy pig. In: *Proc.*
434 *48th Int. Congr. Meat Sci. Technol., Rome, Italy.* 202. p. 600–601.
- 435 Wang, B., R. D. Pace, A. P. Dessai, A. Bovell-Benjamin, and B. Phillips 2002. Modified extraction
436 method for determining 2-Thiobarbituric acid values in meat with increased specificity and
437 simplicity. *J. Food Sci.* 67, 2833–2836.
- 438

439 Table 1. Productive parameters of heavy pigs subjected to different photoperiods (SP=Short
 440 Photoperiod; LP=Long Photoperiod)

	Photoperiod		SEM ¹
	8L:16D (SP)	16L:8D (LP)	
Pigs, n.	20	20	-
Body weight, kg			
Initial live weight	26.1	26.3	0.45
Intermediate weight (155d)	96.3 ^B	106.4 ^A	8.22
Final weight (251d)	155.4 ^b	166.8 ^a	15.77
Average daily weight gain (ADG), g/d			
ADG 1-155d	452 ^B	518 ^A	13.3
ADG 156-251d	616	630	14.9
ADG 1-251d	515 ^b	561 ^a	11.8
Gain:Feed (G:F) [as-fed basis]			
Replications	4	4	-
G:F 1-155d	0.27 ^b	0.30 ^a	0.01
G:F 156-251d	0.24	0.25	0.01
G:F 1-251d	0.25	0.28	0.01

441 ^{A,B} Means within a row with different superscripts differ (P < 0.01)

442 ^{a,b} Means within a row with different superscripts differ (P < 0.05)

443 ¹ SEM = Standard Error of the Mean

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447 Table 2: Slaughtering parameters and carcass quality of heavy pigs subjected to different photoperiods
 448 (SP=Short Photoperiod; LP=Long Photoperiod)

	Photoperiod		SEM ¹
	8L:16D (SP)	16L:8D (LP)	
Pigs, n.	20	20	-
Live weight, kg	162.8 ^B	175.0 ^A	2.27
Cold Carcass weight (CW), kg	132.1 ^B	142.5 ^A	2.00
Dressing out ² , %	81.4	81.1	0.28
F-o-M F, mm	59.8	63.7	
F-o-M SR, mm	22.7	27.0	
Lean Meat (F-o-M), %	50.15	50.16	0.55
Loin ³ , %CW	23.53	23.24	0.17
Tight, %CW	23.82	24.05	0.17
Lean Cuts, %CW	60.8	60.7	0.32
Fat Cuts, %CW	31.7	31.7	0.33
Lean/Fat cuts	1.92	1.91	0.04

449 ^{A,B}, Means within a row with different superscripts differ (P < 0.01)

450 ¹ SEM = Standard Error of the Mean

451 ² Dressing Out % was calculated as Hot Carcass Weight / Live Weight

452 ³Rachis with ribs

453 Table. 3: Meat quality of heavy pigs subjected to different photoperiods (SP=Short Photoperiod;
 454 LP=Long Photoperiod)

	Photoperiod		SEM ¹
	8L:16D (SP)	16L:8D (LP)	
Pigs, n.	20	20	-
pH (<i>Semimembranosus</i> muscle)			
pH 45 min	6.16	6.20	0.04
pH 24 h	5.62	5.60	0.01
Colour (<i>Biceps femoris</i> muscle)			
L	50.72	50.54	0.40
Hue	0.78	0.77	0.02
Chroma	9.19	8.99	0.25
Water Holding Capacity (<i>Longissimus dorsi</i> muscle)			
Drip Loss, %	3.34	3.39	0.13
Cooking Loss, %	20.22	20.50	0.54

455 ¹ SEM = Standard Error of the Mean
 456 No significant difference was detected at the statistical analysis.
 457

458 Table 4: Fatty acid composition of subcutaneous fat from raw thighs of heavy pigs subjected to
 459 different photoperiods (SP=Short Photoperiod; LP=Long Photoperiod)

	Photoperiod		SEM ¹
	8L:16D (SP)	16L:8D (LP)	
Samples, n.	14	14	-
Fat thickness, cm	2.47 ^b	2.89 ^a	0.42
C 14:0, %	1.79	1.63	0.05
C 16:0, %	23.34	23.23	0.24
C 16:1, %	2.13	2.11	0.08
C 18:0, %	12.23	12.42	0.26
C 18:1, %	42.65	44.04	0.58
C 18:2, %	13.86	12.42	0.52
C 18:3, %	0.67	0.57	0.03
C 20:1, %	0.92	0.98	0.02
C 20:4, %	0.67	0.61	0.03
Saturated (SFA), %	37.52	37.45	0.25
Monounsaturated (MUFA), %	45.46	47.13	0.62
Polyunsaturated (PUFA), %	15.19 ^b	13.61 ^a	0.57
UFA/SFA	1.62	1.63	0.03
MUFA/PUFA	3.04 ^b	3.49 ^a	0.13
Iodine number	67.70	65.74	0.71

460 ^{a,b} Means within a row with different superscripts differ (P < 0.05)

461 ¹ SEM = standard error of the mean

462 Table 5: Ham weights and weight losses of heavy pigs subjected to different photoperiods (SP=Short
 463 Photoperiod; LP=Long Photoperiod)

	Photoperiod		SEM ¹
	8L:16D (SP)	16L:8D (LP)	
Hams, n.	20	20	-
Pre-trimming weight, kg	16.26 ^B	17.95 ^A	0.28
Trimmed weight (TW), kg	13.33 ^B	14.51 ^A	0.18
Weight after salting, kg	13.01 ^B	14.19 ^A	0.18
Final weight (after 18 months), kg	9.16 ^B	10.39 ^A	0.18
Weight loss after trimming, %	17.85	19.09	0.46
Weight loss after salting, %TW	2.35	2.24	0.18
Weight loss of cured hams, %TW	30.57 ^A	28.43 ^B	0.47

464 ^{A,B}, Means within a row with different superscripts differ (P < 0.01)

465 ¹ SEM = Standard Error of the Mean

466

467 Table 6: Chemical composition, oxidation state and colour of cured hams from heavy pigs subjected
 468 to different photoperiods (SP=Short Photoperiod; LP=Long Photoperiod)

	Photoperiod		SEM ¹
	8L:16D (SP)	16L:8D (LP)	
Samples, n.	14	14	-
<i>Meat characteristics</i>			
Moisture, %	60.64	61.01	0.41
Crude protein, % (wet basis)	27.36	27.61	0.18
Sodium chloride, % (wet basis)	6.89 ^a	6.32 ^b	0.24
Proteolysis index	25.06	26.56	0.47
<i>Subcutaneous fat oxidation</i>			
Peroxide value	10.0	8.48	0.82
TBARS, MDA mg/kg ²	1.39	1.32	0.13
<i>Fatty acid composition of subcutaneous fat from cured hams</i>			
Saturated (SFA), %	34.03	34.20	0.21
Monounsaturated (MUFA), %	52.56	52.60	0.51
Polyunsaturated (PUFA), %	11.71	12.26	0.49
<i>Subcutaneous fat colour</i>			
L	70.32	71.35	0.27
Hue	-1.38	-1.32	0.03
Chroma	6.99	6.62	0.13
<i>Meat colour (Semimembranosus muscle)</i>			
L	34.58	35.08	0.67
Hue	0.36	0.31	0.02
Chroma	8.37	8.80	0.47

469 ¹ SEM = Standard Error of the Mean

470 ² Tiobarbituric Acid Reactive Substances, expressed as mg malonaldehyde/kg

471

472

473 Table 7 – Behavioural patterns of heavy pigs subjected to different photoperiod (SP=Short
 474 Photoperiod; LP=Long Photoperiod). Data are expressed as percentage of total observed
 475 behaviours.

	Photoperiod		476
	8L:16D (SP)	16L:8D (LP)	477 SEM ¹ 479
Replications, n.	4	4	480
Standing inactive	0.06	0.13	481 0.04
Sitting inactive	1.41	1.59	0.19
Lateral recumbency	41.40 ^B	52.78 ^A	2.27
Sternal recumbency	34.87	31.91	1.60
Total recumbency	76.26 ^B	84.68 ^A	1.35
Eating	9.13	6.62	0.75
Drinking	0.04	0.12	0.04
Walking	0.02	0.02	0.01
Bar biting	0.08	0.15	0.07
Exploring the floor	12.20 ^A	6.17 ^B	0.87
Others	0.88	0.67	0.23

483 ¹ SEM = Standard Error of the Mean

484 ^{A,B}, Means within a row with different superscripts differ (P < 0.01)

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