Original Research Article

# Body weight and range usage affect net energy utilisation in commercial free-range laying hens when evaluated in net energy chambers

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A B S T R A C T

Within a given free-range flock, some hens prefer to spend the majority of their time in the shed (stayers), while others frequently access the range (rangers). Laying performance has been associated not only with the development of these sub-populations but also with different body weights (BW). The purpose of this study was to determine if range usage, BW or a combination of both is associated with energy metabolism and as such contribute to improved hen performance. Forty-eight Lohmann Brown hens at 74 wk of age were selected from a commercial free-range farm based on their BW and range usage over a 56-week period. Using a $2 \times 2$ factorial arrangement, hens were either classified as heavy (mean $\pm$ SEM; 2.01 $\pm$ 0.02 kg, $n = 24$) or light (1.68 $\pm$ 0.01 kg, $n = 24$), and also classified as rangers (accessed the range for 84.1% of available days, 242 $\pm$ 3.75 d; $n = 24$) or stayers (accessed the range for 7.17% of available days; 23.4 $\pm$ 6.08 d, $n = 24$). Stayers had significantly higher metabolizable energy (ME) intake per metabolic BW per d (0.852 vs. 0.798 MJ/kg BW$^{0.75}$ per d; $P = 0.025$), higher heat production (0.637 vs. 0.607 MJ/kg BW$^{0.75}$ per d; $P = 0.005$), higher heat increment (0.267 vs. 0.237 MJ/kg BW$^{0.75}$ per d; $P = 0.005$) and retained more nitrogen (1.59 vs. 1.46 g/hen per d; $P = 0.023$) compared to the rangers. Light hens had significantly higher metabolic energy intake per metabolic BW (0.854 vs. 0.796 MJ/kg BW$^{0.75}$ per d; $P = 0.018$), net energy (NE) intake (0.595 vs. 0.551 MJ/kg BW$^{0.75}$ per d; $P = 0.032$), and retained energy (0.225 vs. 0.181 MJ/kg BW$^{0.75}$ per d; $P = 0.032$), as well as lower heat production (0.936 vs. 1.003 MJ/hen per d; $P = 0.002$) compared to heavier hens. An interaction was observed across levels of analysis i.e. between light stayers and light rangers. The light rangers had significantly higher NE intake compared to the light stayers (9.77 vs. 9.27 MJ/kg BW$^{0.75}$ per d; $P = 0.024$). In conclusion, light hens were more energy efficient compared to heavy hens. Moreover, light rangers had a more efficient feed utilisation compared to the light stayers.

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## 1. Introduction

Cage-free husbandry systems such as barn or free-range facilities allow hens to exhibit a variety of behaviors including running, flying, dust and solar bathing, beak cleaning, preening, and stretching (Miao et al., 2005). This freedom of movement and locomotion can affect metabolic energy needs (Armstrong and Cermak, 1989). In free-range systems, the metabolic need of individual hens may vary even further due to the exposure of some hens to adverse weather conditions on the range (e.g. temperatures and humidity above or below the thermoneutral zone)

(Olson et al., 1972; Peguri and Coon, 1993; Yahav et al., 1996). In addition, free-range hens may have an opportunity to forage and ingest a variety of pastures, shrubs, insects and other materials present in the extended environment which can interfere with the digestion of their formulated diet (Glatz and Ru, 2001, 2002; Svihus, 2012). Within a given free-range flock, some hens prefer to spend most of their time in the shed (stayers), while others frequently access the range (rangers) (Gebhardt-Heinrich et al., 2014). The development of these sub-populations has been associated with different hen performance. For example, hens that range frequently come significantly earlier into lay (Sibanda and Ruhnke, 2018). Singh et al. (2016) and Iqbal et al. (2017) showed that hens with access to pasture are frequently heavier compared to stayers or hens without pasture access, indicating that the range or pasture access per se may contribute to a better nutrient utilisation. This is most likely due to the additional intake of the structural fibre component present in pasture as fibre in the diets have shown to have beneficial effects on the digestive organ development, starch digestibility and consequently feed efficiency (Hetland and Svihus, 2001; Amerah et al., 2009). To date it remains unclear to what degree body (and organ) weight as such, or/and the range access contributes to energy requirements and if there is a need to manage this for improved egg production. It has previously been observed that hens housed in loose husbandry systems have higher feed conversion ratios (FCR) than caged hens, and also that lighter hens are more feed efficient than heavy ones (Tiller, 2001; Akter et al., 2019). While the higher activity level of non-caged hens is considered responsible for the higher maintenance energy of free-range and barn housed hens, lighter hens seem to utilise their nutrients for egg production rather than body fat content (Tiller, 2001; Akter et al., 2019). The evaluation of the efficiency of energy utilisation in laying hens provides a comprehensive method of optimizing production (Reid et al., 1978; de Almeida Brainer et al., 2012). The net energy (NE) is the metabolizable energy (ME) of the feed corrected for the energy losses in the heat increment due to digestion and cellular processes and is directly available for maintenance, growth and production. Therefore, NE is a more accurate reflection of the energy requirement (Pirgozliev and Rose, 1999). While body weight (BW) and range usage vary widely in free-range housing conditions, the aim of this study was to determine the impact of BW and range usage on NE utilisation of commercial free-range laying hens.

## 2. Materials and methods

### 2.1. Experimental animals

This research was approved by the Animal Ethics Committee (AEC17-120), University of New England, NSW, Australia. Forty-eight Lohmann Brown hens at 74 wk of age were selected from a commercial free-range farm based on their BW as well as their range usage recorded over a 56-week period. Prior selection, the experimental animals were housed amongst a 40,000-hen flock and traced for range usage using a custom-made RFID system (Science and Engineering workshop at the University of New England, Armidale, NSW, Australia) as previously described by Sibanda et al. (2019). At time of depopulation, the 48 hens subject to this research were selected by screening for hens that spent more than 75% or less than 10% of their available days on the range and met also the selection criteria of presenting a BW either above 1.90 kg or below 1.70 kg. Cut off points for range access and BW

**Table 1**
Composition and calculated nutrient content of the diet fed to the experimental hens (as fed, %).

| Item | Content |
| --- | --- |
| Ingredients | |
| Sorghum | 45.8402 |
| Soybean meal | 14.2115 |
| Wheat | 10.0 |
| Barley | 9.00 |
| Meat meal | 7.50 |
| Lime grit | 7.4276 |
| Canola meal | 2.00 |
| Vegetable oil | 1.00 |
| Opticell | 0.8333 |
| Single-cell protein | 0.6667 |
| Blood meal | 0.50 |
| Methionine hydroxide-liquid | 0.2616 |
| Layer premix[1] | 0.20 |
| Salt | 0.1333 |
| Sodium bicarbonate | 0.10 |
| Lysine-HCl | 0.09 |
| Choline Cl liquid | 0.0667 |
| Synthetic emulsifier[2] | 0.04 |
| Egg yolk pigments[3] | 0.06 |
| *L*-threonine | 0.0359 |
| Liquid xylanase | 0.0333 |
| Nutrient content of the diet | |
| ME, kcal/kg | 2,728.9 |
| ME including enzyme activity, kcal/kg | 2,775 |
| Crude protein | 18.9 |
| Lysine | 0.92 |
| Methionine | 0.49 |
| Methionine + Cysteine | 0.79 |
| Threonine | 0.69 |
| Isoleucine | 0.7 |
| Leucine | 1.58 |
| Tryptophan | 0.21 |
| Arginine | 1.11 |
| Histidine | 0.45 |
| Valine | 0.88 |
| T. Dig. Lysine | 0.83 |
| T. Dig. Methionine | 0.45 |
| T. Dig. Methionine + Cysteine | 0.70 |
| T. Dig. Threonine | 0.60 |
| T. Dig. Isoleucine | 0.64 |
| T. Dig. Leucine | 1.40 |
| T. Dig. Tryptophan | 0.18 |
| T. Dig. Arginine | 1.00 |
| T. Dig. Valine | 0.79 |
| Crude fat | 4.10 |
| Linoleic acid | 1.21 |
| Crude fibre | 3.41 |
| Starch | 38.5 |
| Total xanthophyll | 0.001 |
| Red xanthophyll | 0.001 |
| Phytate phosphate | 0.23 |
| Ash | 12.4 |
| Calcium | 3.90 |
| Av. phosphate | 0.63 |
| Total phosphate | 0.76 |
| Sodium | 0.21 |
| Chloride | 0.21 |
| Potassium | 0.65 |
| Vitamin and mineral premix[1] | 0.2 |

T. Dig. = total digestible; Av. = available.

[1] Layer premix, vitamin and mineral premix per tonne diet: vitamin A, 8 MIU; vitamin E, 30 g; thiamin $B_1$, 2 g; niacin (vitamin $B_3$), 30 g; pantothenic acid (vitamin $B_5$), 6.44 g; folate (vitamin $B_9$), 1.5 g; biotin (vitamin H), 300 mg; pyridoxine (vitamin $B_6$), 4.5 g; vitamin $B_{12}$, 30 mg; vitamin D, 3 MIU; vitamin K, 3.5 g; copper, 3.74 g; zinc, 30 g; selenium, 0.2 g; manganese, 30 g; chromium, 0.15 g; iron, 11.25 g. MIU = million international units.

[2] Synthetic emulsifier: each 1 kg contains 100% Glycerol polyethyleneglycol ricinoleate (Bredol, Akzo, Nobel, Sweden).

[3] Egg yolk pigments: xanthophylls and canthaxanthin provided by Jabiru yellow and Jabiru Red L (Jabiru, Bowral, NSW, Australia).

**Table 2**
Energy utilisation of commercial free-range laying hens.

| Main effect RU | BW | GE intake, MJ | ME (DM feed basis), MJ/kg | $ME_i$, kg/$BW^{0.75}$ | RE, kg/$BW^{0.75}$ | NE (DM basis), MJ/kg | HP/hen per d, MJ/kg | HP/hen per d, MJ/kg $BW^{0.75}$ | HI, MJ/kg $BW^{0.75}$ | $NE_i$, MJ/kg $BW^{0.75}$ | NE/ME | RN/hen per d, g | RN, % | Total egg number/3 hens per 3 d | LR, % | Total egg mass/hen per d, g |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rangers | | 15.07 | 13.67 | 0.7975[a] | 0.1904 | 9.59 | 0.965 | 0.607[b] | 0.237[a] | 0.5604 | 0.70 | 1.46[a] | 45.6 | 8.210 | 91.30 | 60.80 |
| Stayers | | 15.44 | 13.69 | 0.8517[b] | 0.2150 | 9.41 | 0.9738 | 0.637[a] | 0.267[b] | 0.5850 | 0.71 | 1.59[b] | 48.4 | 7.790 | 86.70 | 63.20 |
| | Light | 15.09 | 13.67 | 0.8537[b] | 0.2245[b] | 9.52 | 0.935[a] | 0.629 | 0.259 | 0.5945[b] | 0.69 | 1.54 | 48.2 | 8.460 | 94.00 | 63.19 |
| | Heavy | 15.41 | 13.69 | 0.7955[a] | 0.1809[a] | 9.48 | 1.003[b] | 0.615 | 0.245 | 0.5509[a] | 0.69 | 1.49 | 45.7 | 7.540 | 84.00 | 60.81 |
| Two-way interaction (RU × BW) | | | | | | | | | | | | | | | | |
| Rangers | Light | 14.64 | 13.80[b] | 0.8243 | 0.2143 | 9.77[b] | 0.9193 | 0.610 | 0.2400 | 0.5843 | 0.70 | 1.49 | 47.9 | 8.670 | 96.30 | 61.34 |
| Rangers | Heavy | 15.50 | 13.54[ab] | 0.7708 | 0.1665 | 9.42[ab] | 1.0113 | 0.6045 | 0.2345 | 0.5365 | 0.69 | 1.42 | 43.2 | 7.750 | 86.30 | 60.27 |
| Stayers | Light | 15.55 | 13.54[a] | 0.8830 | 0.1953 | 9.27[a] | 0.9515 | 0.6483 | 0.2783 | 0.6048 | 0.69 | 1.61 | 48.5 | 8.250 | 91.80 | 60.29 |
| Stayers | Heavy | 15.32 | 13.85[ab] | 0.8203 | 0.2348 | 9.55[ab] | 0.9940 | 0.6247 | 0.2547 | 0.5653 | 0.70 | 1.57 | 48.2 | 7.330 | 81.70 | 66.12 |
| P-values | | | | | | | | | | | | | | | | |
| RU | | 0.477 | 0.850 | 0.025 | 0.192 | 0.190 | 0.652 | 0.005 | 0.005 | 0.192 | 0.318 | 0.023 | 0.076 | 0.373 | 0.373 | 0.988 |
| BW | | 0.539 | 0.834 | 0.018 | 0.032 | 0.795 | 0.002 | 0.107 | 0.107 | 0.032 | 0.130 | 0.302 | 0.101 | 0.067 | 0.067 | 0.304 |
| RU × BW | | 0.298 | 0.044 | 0.830 | 0.816 | 0.040 | 0.155 | 0.296 | 0.296 | 0.816 | 0.470 | 0.750 | 0.145 | 1.000 | 1.000 | 0.981 |

RU = range usage; BW = body weight; GE = gross energy; ME = metabolizable energy; $ME_i$ = metabolizable energy intake; RE = retained energy; NE = net energy; HP = heat production; HI = heat increment; $NE_i$ = net energy intake; RN = retained nitrogen; LR = laying rate.
Means were obtained from 4 replicate cages of 3 birds each.
[a, b] Within a column, means with no common superscript are significantly different at $P < 0.05$.

were determined based on the 90th percentile results obtained from the selection cohort. The 48 hens were either classified as heavy (mean ± SEM; 2.01 ± 0.02 kg, $n = 24$) or light (1.68 ± 0.01 kg, $n = 24$), and also classified as rangers (accessed the range for 84.1% of available days, 242 ± 3.75 d; $n = 24$) or stayers (accessed the range for 7.17% of available days; 23.4 ± 6.08 d, $n = 24$).

### 2.2. NE measurements

On the day of hen selection, hens were transported to the experimental facilities at the University of New England and placed in calorimetry chambers for 10 d with ad libitum feed and water allowing for acclimatisation to the new, climate-controlled environment. The diet offered was identical with the one fed on the commercial farm prior to hen relocation (Table 1). Hens were assigned to 1 of the 4 treatment groups according to a 2 × 2 factorial arrangement with range use (stayers or rangers) and BW (heavy or light) as 2 factors resulting in the following: 12 hens classified as Rangers Heavy (RH), 12 hens classified as Rangers Light (RL), 12 hens classified as Stayers Heavy (SH), and 12 hens classified as Stayers Light (SL). Three hens of the same category were placed together in one closed-circuit calorimetry chamber (Barzegar et al., 2019). The cage was considered to be a replicate and 4 replicates per treatment were applied.

After the 10-d acclimatization period, hens were maintained an additional 4 d in the closed-circuit calorimetry chamber with air pumps running. After this period, the closed-circuit calorimetry chambers were sealed airtight with a lid over a trough filled with water and their feed intake, excreta output, egg production, oxygen intake and carbon dioxide output were measured in 24 h intervals for the duration of 3 d following an established protocol (Swick et al., 2013; Wu et al., 2019; Barzegar et al., 2019). All parameters involving energy balance, nitrogen retention (RN) and egg number were calculated as previously described (Barzegar et al., 2019).

### 2.3. pH and organ weight

Immediately before and after completion of the NE chamber measurement, all the hens were individually weighted before being placed in the energy chamber and at the completion of the NE chamber measurement. Hens were humanely sacrificed, and gross necropsy performed at the end of the experiment. The pH of the individual gastrointestinal segments from crop to cecum were measured directly by inserting the spear tip probe of a pH meter (Ecoscan, Eutech instruments, Singapore) into the digesta. The empty organ weights of crop, gizzard, pancreas and liver (after visceral fat was removed) were obtained using a commercial scale (Shinko Denshi, RoHS Compliant, Japan) and were expressed as the percentages relative to the BW of the hens. The values were calculated using the following equation:

$$\text{Relative organ weight} = (\text{Organ weight}/\text{BW}) \times 100\%$$

### 2.4. Statistical analysis

Statistical analysis was performed using SPSS statistics v.24 (IBM Corp., Armonk, NY, USA). Two-way factorial ANOVA was conducted to compare the main effects of range usage and BW and their interactions. Further analysis of interaction was followed using One-way ANOVA within and between the levels of the analysis. The graphs were created using JMP Statistics software

(v14 IBM SAS Institute Inc., Cary, NC). The level of significance was set at $P < 0.05$.

## 3. Results

### 3.1. Energy and nitrogen balance

The stayers had significantly higher ME intake ($P = 0.025$), higher heat production ($P = 0.005$), and higher heat increment per metabolic BW ($P = 0.005$) compared to the rangers (Table 2). Similarly, stayers retained a greater fraction of nitrogen intake ($P = 0.023$) compared to the rangers. The light hens had significantly higher metabolic energy intake ($P = 0.018$), NE intake ($P = 0.032$), and retained energy per metabolic BW ($P = 0.032$) whereas lower heat production ($P = 0.002$) compared to the heavy hens as shown in Table 2. An interaction was observed between BW and range where rangers had significantly higher NE intake compared to the stayers only in light birds ($P = 0.024$; Table 3) but not in heavy birds.

### 3.2. Organ size or weight, and pH

The total gizzard, liver and pancreas weight were found to be different in heavy and light hens where heavy hens had significantly smaller relative gizzard (1.40% vs. 1.53%; $P = 0.008$), liver (2.08% vs. 2.3%; $P = 0.022$) and pancreas (0.17% vs. 0.19%; $P = 0.008$) weight compared to the light hens (Figs. 1 and 2). Organ weight was

**Table 3**
One-way ANOVA analysis of 4 different sub groups[1] obtained from a commercial free-range farm kept in net energy chambers (DM basis, MJ/kg).

| Item | | ME | NE |
|---|---|---|---|
| Treatment groups[1] | RL | 13.80 | 9.77 |
| | RH | 13.54 | 9.42 |
| | SL | 13.54 | 9.27 |
| | SH | 13.85 | 9.55 |
| P-values | RH × RL | 0.172 | 0.094 |
| | RH × SH | 0.109 | 0.519 |
| | RH × SL | 0.988 | 0.404 |
| | RL × SL | 0.168 | 0.024 |
| | SH × SL | 0.106 | 0.171 |

ME = metabolizable energy; NE = net energy; DM = dry matter; RL = Rangers Light; RH = Rangers Heavy; SL = Stayers Light; SH = Stayers Heavy.
[1] RL, hens with light BW which frequently access the range; RL, hens with heavy BW which frequently access the range; SL, hens with light BW which prefer to spend the majority of their time in the shed; SH, hens with heavy BW which prefer to spend the majority of their time in the shed, within a given free-range flock.

found to be significantly different based on BW but not on range usage. The pH of the organs did not differ significantly ($P > 0.05$) among the 4 treatment groups (Fig. 3).

## 4. Discussion

The current study demonstrates that the NE utilisation differs between heavy and light stayers and rangers when being confined in the closed-circuit NE chamber. This clearly indicates that the capacity to use energy differs among the investigated flock subpopulations.

The ME and NE intakes expressed in metabolic BW (kg BW$^{0.75}$) were significantly higher in light hens compared to heavy hens. On contrary, heavy hens had significantly higher heat production compared to light hens (Table 2) which indicates that the more ME might have been used for heat production rather than maintenance of egg production in heavy hens. This is in line with the research performed by Akter et al. (2019) investigating Isa Brown caged hens, where light hens were significantly more feed efficient than heavy hens. Moreover, Parkinson et al. (2015) found lighter hens to exhibit superior laying persistency compared to heavier hens. However, it was observed that the relative weight of the organs associated with metabolism such as liver, pancreas, and gizzard were significantly higher in the light hens subject to this study. The visceral organs mass can have a high energy expenditure rate and as such increase the total energy requirement (Ferrell and Koong, 1986; Jorgensen et al., 1996). However, this was not observed in the hens subject to our research where lighter individuals were more efficient despite the higher relatively organ weights. Carre et al. (2008) reported that inefficient hens were heavier and had greater fat deposition compared to lean highly efficient hens. This has also been observed in the light caged hens (which were also the most feed efficient hens) of Akter et al. (2019), who had significantly less intraabdominal fat compared to their heavy counterparts. The higher relative gizzard weight observed in this research was suspected to lead to greater nutrient availability in the small intestine and therefore greater feed efficiency (Akter et al., 2019). This might indicate that the light hens are more energy efficient compared to the heavy hens and therefore, there is a need to determine the energy requirements and the lower BW threshold limit for feed formulation and better energy efficiency. In order to distinguish more precisely between energy deposited in organ development, egg production or fat storage, the intraabdominal fat
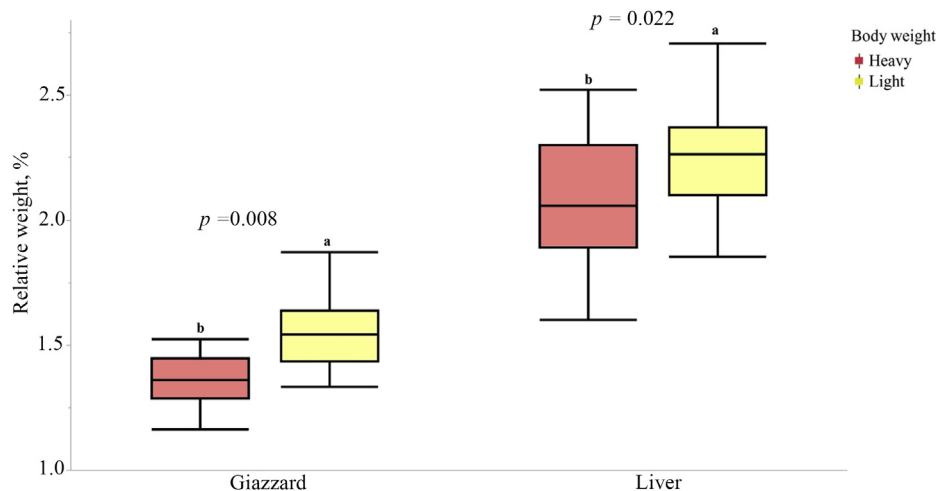


**Fig. 1.** Relative gizzard and pancreas weight of the heavy and light hens from a commercial free-range farm kept in net energy chambers. [a, b] Means with different superscripts indicate difference ($P < 0.05$).
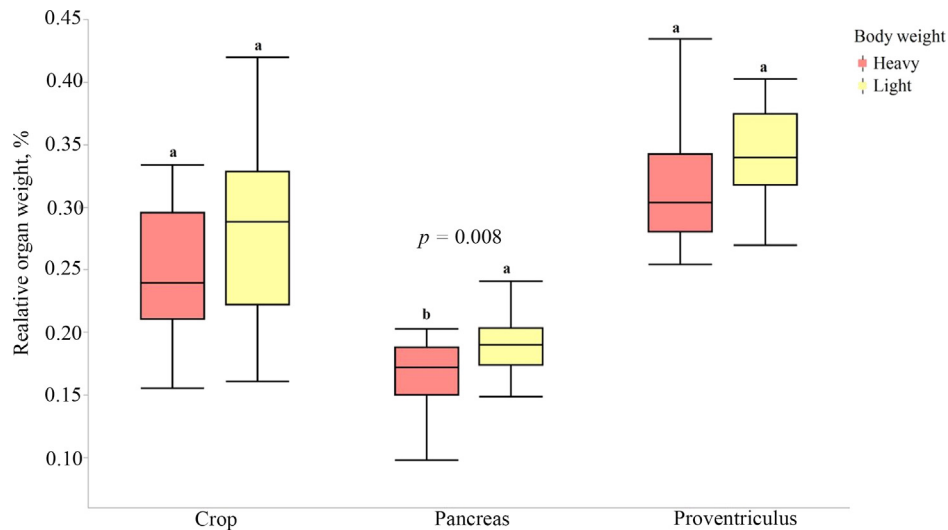
**Fig. 2.** Relative crop, pancreas and proventriculus weight of the heavy and light hens from a commercial free-range farm kept in net energy chambers. [a, b] Means with different superscripts indicate difference ($P < 0.05$).
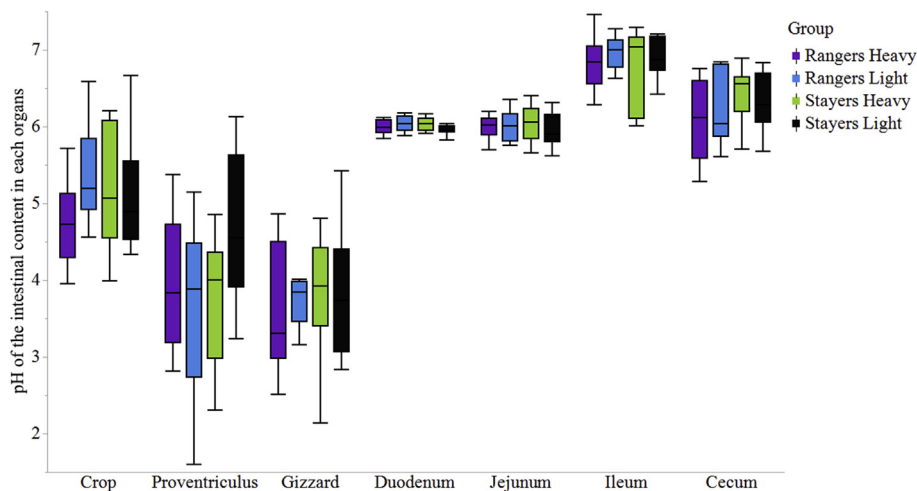


**Fig. 3.** pH of the intestinal content in each organ of the stayers- and rangers-groups from a commercial free-range farm kept in net energy chambers. RL = Rangers Light; RH = Rangers Heavy; SL = Stayers Light; SH = Stayers Heavy. RL, hens with light BW which frequently access the range; RL, hens with heavy BW which frequently access the range; SL, hens with light BW which prefer to spend the majority of their time in the shed; SH, hens with heavy BW which prefer to spend the majority of their time in the shed, within a given free-range flock.

pad and the carcass composition should be measured in all future NE studies.

The stayers had a significantly higher ME intake per metabolic BW compared to the rangers when being confined in the NE chambers. While this may lead to the conclusion that the increased ME intake in stayers might be related to their higher requirement for maintenance, it may also be possible that the ME was used for heat production, indicated by the higher heat increment and heat production (Table 2). Care must be taken to consider that the confined situation in the NE chambers provides a different environment than the free range shed and the energy expenditure that we observed in the experimental conditions may be significantly different when the hens were located in the field. Interestingly, light rangers had significantly higher ME and NE intake which showed that they were able to metabolize their energy more efficiently, indicating their ability to better derive energy per unit of feed than the light stayers. Moreover, the ME for the stayers might have been lost as heat for maintenance. Kolakshyapati et al. (2019a,

2019b) has shown that the stayers are more fearful compared to the rangers. Moreover, there was an increase in corticosterone level in the stayers compared to rangers (Kolakshyapati et al., 2019a, 2019b). Any form of stress in birds such as poor weather, predation, social stress etc. can result in increased levels of corticosterone that modifies body metabolism (Wingfield and Kitaysky, 2002; Downing and Bryden, 2008). This might have been the case in the field situation, resulting in the development of different coping styles (Campbell et al., 2016), allowing stayers and rangers to respond differently to the transport and NE chamber confinement. Therefore, it might be possible that the stayers are more stressed than rangers which might impact their energy metabolism.

In a study by Singh et al. (2016), ranging hens at 63 wk of age showed increased gizzard and intestinal weight which might contribute to better nutrient utilisation. On contrary, there was no difference in the organ weight between rangers and stayers in hens subject to the present research. Range use provides opportunities for hens to explore and ingest a variety of materials such as forage,

insects and others (Glatz and Ru, 2001, 2002; Svihus, 2012) that might alter the microbial composition of these hens. The different microbial population in the gastrointestinal tract plays an important role in the energy efficiency and is different in high and low performing birds (Stanley et al., 2012). Therefore, it will be interesting to investigate the microbial composition and their metabolites in rangers and stayers.

## 5. Conclusion

In conclusion, the light rangers were significantly more efficient in feed utilisation compared to light stayers and the energy from feed was more available for production. This information is important for poultry nutritionists, formulating diets of various nutrient composition. If feed formulation is based on NE requirements, the percentage of a flock that utilises the range as well as the expected BW should be taken into account. Further research is required to determine a minimum BW threshold on NE metabolism of the modern laying hen. Alternative methodology to measure energy utilisation by free range birds without confining them to chambers would be beneficial in future research studies to allow more precise data collection when investigating rage use.

## Conflict of interest

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the content of this paper.

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