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ORIGINAL PAPER

# Assessment of metabolizable energy requirements for broilers in both conventional indoor and free-range rearing systems

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**ABSTRACT.** The current study aimed to determine the metabolizable energy (ME) requirements of broiler chickens reared under free-range conditions and compared their energy use and performance with birds raised in a conventional indoor system. Ninety-six Cobb-500 male broilers were assigned to indoor or free-range treatments from 14 to 42 days of age. Growth performance, behaviour, and energy partitioning were assessed. A digestibility trial and comparative slaughter method were used to determine ME intake (MEI), energy retention, and heat production (HP). No significant differences were observed in body weight (BW) gain, feed intake, or feed conversion ratio between both systems. Free-range broilers displayed significantly higher foraging and locomotion, and reduced feeding and resting behaviours, reflecting their increased physical activity. Consequently, they retained less energy (mainly in the form of body fat) and had higher HP than indoor birds. The additional ME required for outdoor activity in the free-range group was estimated at 40.50 kcal/kg $BW^{0.75}$/day, representing approximately 8% of total MEI. Free-range broilers maintained productive performance despite higher energy demand and expressed more natural behaviours. These results indicate that dietary energy supply in free-range systems may require adjustment to improve feeding strategies in order to balance economic efficiency and animal welfare.

## Introduction

It is well-established that feed accounts for over 70% of total poultry production costs, with energy sources representing the most significant portion of the diet (40–60%). Therefore, reducing energy-related expenses while maintaining performance can improve the profitability of broiler production (Lopez and Leeson, 2008; Abouelezz et al., 2019). Dietary energy is a key component of poultry feed as it directly regulates voluntary feed intake and consequently influences the utilisation efficiency of all other nutrients (Ahiwe et al., 2018).

The energy content of feed in commercial nutrition and research is typically expressed as metabolizable energy (ME) or net energy (NE). ME provides a reliable estimation of available energy in poultry feed with adequate accuracy and low variation (Lopez and Leeson, 2008). ME intake is mainly divided into energy retained (ER) in body tissues (as protein and/or fat) and heat production (HP), which can be further subdivided into the thermic effect of

feeding, fasting heat production, and heat generated from physical activity (Noblet et al., 2003; Lopez and Leeson, 2008).

Defining the energy requirement of genetically improved broiler breeds is crucial to fully realize their genetic potential. Underestimating ME can impair growth performance and energy utilisation, while overestimating ME leads may exacerbate problems associated with fast-growing broilers such as leg disorders, metabolic failure, fatty liver, ascites, sudden death syndrome, and increased mortality rate during the finishing phase (Abouelezz et al., 2019).

Recently, demand has increased chickens raised in free-range systems, valued for their meat quality and adherence to organic production standards (Lusk, 2018). Unlike the well-established data on ME requirements for broilers in intensive production systems, scientific information concerning broilers raised in free-range systems is relatively scarce (Brainer et al., 2016). Importantly, there is a clear lack of information regarding the energy expenditure associated with the physical activity of free-range broilers. Existing energy requirement models for conventional broilers are not directly applicable to free-range systems, as outdoor access significantly increases energy expenditure due to increased physical activity (Brainer et al., 2016).

Considering the higher energy expenditure associated with outdoor physical activity in free-range broilers compared to the indoor-reared birds, this study aimed to assess their ME requirements. The objective was to provide evidence-based guidance for dietary adjustments to maintain optimal growth and performance under such alternative systems. Additionally, the study compared behavioural patterns, growth performance, and energy utilisation efficiency between conventional and free-range systems.

# Material and methods

### Ethical statement

Birds were maintained according to the guidelines of the Bioethical Committee at the Campus of Biological and Agricultural Sciences in FMVZ, UADY on Animal Care (Approval Code: CB-CCBA-PD-2022-001).

### Study location

The study was conducted at the Faculty of Veterinary Medicine and Animal Science (FMVZ), University of Yucatan (UADY), Merida, Yucatan, Mexico during the winter season (December to February). The climate was sub-humid, with an average annual rainfall (highly variable) of

approximately 960 mm and 6–7 months of dry period. The average daily winter temperature was 23 °C (max. 32 °C, min. 15 °C) and the natural photoperiod was 11–13 h (CONAGUA, 2020).

### Birds, treatments, and management

A total of 96 Cobb-500 male broiler chicks (14 days of age; mean initial body weight 485.55 ± 24.48 g) were randomly assigned to two experimental treatments, each with eight replicates of six birds. The treatments were: a conventional indoor housing (control) and a free-range group (with outdoor access). Birds were reared in a semi-closed facility with galvanised wire mesh sides for natural ventilation. All birds were allocated to 1 of 8 floor pens (1 × 1 m) per treatment; in addition, broilers in the free-range treatment had voluntary access to outdoor range without grass or herbs but with small shrubs (1.5 × 6 m per replicate) for 10 h a day. The temperature difference between systems during the free-range period was approximately 1 ± 0.3 °C (Sánchez-Casanova et al., 2019). A lighting program was applied that complied with recognised broiler welfare standards.

The experimental diet was formulated to meet strain-specific nutrient requirements (Table 1). Broilers had *ad libitum* access to feed and water

**Table 1.** Composition and chemical analyses of the experimental diet, %

| Ingredients | Composition, % |
|---|---|
| Yellow corn | 64.70 |
| Soybean meal, 46% CP | 30.02 |
| Soybean oil | 2.40 |
| Dicalcium phosphate | 0.86 |
| Calcium carbonate | 1.50 |
| Sodium chloride | 0.28 |
| Anti-coccidial compound | 0.05 |
| Mycotoxin adsorbent | 0.10 |
| Antioxidant | 0.01 |
| Pre-mixture of vitamins[1] | 0.03 |
| Pre-mixture of minerals[2] | 0.05 |
| Total | 100 |
| Chemical analysis, % on DM basis | |
| CP* | 18.03 |
| ME*, kcal/kg | 3050 |
| crude fibre* | 2.03 |
| calcium** | 0.83 |
| available phosphorus** | 0.35 |
| lysine** | 0.90 |
| methionine** | 0.35 |
| methionine + cystine** | 0.79 |

CP – crude protein, DM – dry matter, ME – metabolizable energy; [1] contained per kg of diet: IU: vit. A 8000, vit. D 2500, vit. E 8; mg: vit. K 2, vit. B12 0.002, riboflavin 5.5, pantothenic acid 13, niacin 36, choline 500, folic acid 0.5, thiamine 1, pyridoxine 2.2, biotin 0.05; [2] contained per kg of diet: mg: manganese 65, iodine 1, iron 55, copper 6, zinc 55, selenium 0.3; * analysed, ** calculated

throughout the 4-week experimental period. Birds were weighed individually every week; feed intake (FI), body weight gain (BWG), and feed conversion ratio (FCR) were also determined every week.

A 4-day digestibility trial was conducted to determine the ME (apparent gross energy digestibility) of the experimental diet using titanium dioxide (TiO$_2$) as an indigestible marker, according to the procedure of Ravindran et al. (1999). Ten broilers were randomly selected from each treatment group and euthanised by electrical stunning to ileal digesta collection. The collected digesta samples were immediately freeze-dried and ground to pass through a 0.5 mm sieve. Gross energy (GE) of the samples was determined using a Parr adiabatic bomb calorimeter (Model 1261; Parr Instrument Company, Moline, IL, USA).

## Behavioural observations

Six mutually exclusive behaviours were assessed: feeding, drinking, foraging, locomotion (walking/running), resting, and dust bathing, using a structured ethogram (Fanatico et al., 2016; Sánchez-Casanova et al., 2022). A trained observer conducted scan sampling at 10-min intervals during three daily periods (09:00–10:00, 12:00–13:00, and 15:00–16:00) on a fixed day in weeks 4 and 6 of the rearing period. Behaviours were recorded individually and expressed as percentages of total observed activity. These data were then pooled to obtain average behavioural profiles for comparative analysis.

## Determination of ME requirements

The ME requirement was estimated using the comparative slaughter method. A control group of 10 chicks with a similar body weight (BW) was killed by cervical dislocation at the beginning of the trial (day 14). At day 42, 10 representative birds per treatment were individually weighed and killed to calculate energy retained in body tissues. Carcasses were immediately frozen at −20 °C for subsequent analyses. Frozen carcass samples were cut into small pieces, ground twice, and stored in labelled plastic bags. Two 70-g subsamples were collected, placed in plastic containers, freeze-dried at −50 °C under a vacuum of 20 Pa for 72 h using a lyophiliser (Harvest Right, North Salt Lake, UT, USA), and analysed for dry matter, crude protein (CP) (N; 986.06) and ether extract (EE; 920.39) following standard AOAC (2000) procedures. Gross energy was determined according to the methodology of Silva et al. (2021) using a Parr 1261 adiabatic bomb calorimeter (Parr Instrument Co., Moline, IL, USA).

## Energy calculations

ER for each experimental group was calculated as the difference between total body energy at day 42 and day 14.

HP for each group was determined from the difference between MEI and ER:
$$HP = MEI - ER$$
Actual MEI was quantified from feed offered and refusals, multiplied by the dietary ME value. Heat production attributable to outdoor physical activity was estimated from the difference in ER between the free-range and indoor groups. Net energy for maintenance (NE$_m$) was calculated using the equation of Scott et al. (1982):
$$NE_m = 83 \times (BW)^{0.75}.$$
Metabolisable energy for maintenance (ME$_m$) was estimated using a utilisation efficiency of 0.82 (Scott et al., 1982). Energy retained as protein (ER$_p$) and fat (ER$_f$) were calculated according to Liu et al. (2017) as follows:

$ER_p$ = [total body protein content at day 42(g) − − total body protein content at day 14 (g)] × × 5.64 kcal/g$^{0.75}$,

$ER_f$ = [total body fat content at day 42 (g) − total body fat content at day 14 (g)] × 9.12 kcal/g$^{0.75}$.

## Statistical analysis

The data were analysed using a completely randomised design to compare treatment effects with the general linear model (GLM) procedure of SAS 9.4 software (SAS Institute Inc., Cary, NC, USA). Differences between treatment means were assessed using Duncan's multiple range test (Duncan, 1955), with significance set at $P \leq 0.05$. The following statistical model was used:
$$Y_{ij} = \mu + T_i + E_{ij},$$
where: $Y_{ij}$ – observation, $\mu$ – overall mean, $T_i$ – treatment effect and $E_{ij}$ – experimental random error.

# Results

## Behavioural patterns

Data in Table 2 demonstrate that broilers reared in free-range system displayed more natural and diverse behaviours compared to birds from the indoor system. Foraging and locomotion behaviours were markedly increased in free-range birds, reaching 8.84% and 4.77% at 6 weeks, respectively, compared to 0.82% and 1.14% for indoor birds, indicating more intense physical activity. In contrast, indoor broilers showed higher feeding activity (17.25% vs. 10.85%) and spent slightly more time resting by week 6, reflecting more sedentary

**Table 2.** Behavioural patterns of broilers reared in both indoor and free-range rearing systems

| Activities[*], % | 4 Week | | 6 Week | |
|---|---|---|---|---|
| | indoor | free-range | indoor | free-range |
| Feeding | 19.33 | 12.29 | 17.25 | 10.85 |
| Drinking | 6.41 | 5.03 | 5.74 | 4.59 |
| Foraging | 2.6 | 7.83 | 0.82 | 8.84 |
| Locomotion | 1.69 | 5.68 | 1.14 | 4.77 |
| Dust bathing | 3.74 | 3.4 | 2.03 | 1.46 |
| Resting | 66.23 | 65.77 | 73.02 | 69.49 |

[*] behavioural frequencies were calculated as proportions of the total observed activity

behavioural profile. Dust bathing occurred in both systems but declined slightly with age, suggesting reduced motivation or physical capacity in older birds. Resting remained the dominant activity in both systems.

## Growth performance

The effects of indoor and free-range rearing systems on broiler growth performance are presented in Table 3. No significant differences were observed between the two systems for final BW, BWG, FI, or FCR ($P > 0.05$).

**Table 3.** Performance traits of broilers at 42 days of age in both indoor and free-range rearing systems

| Items | Indoor | Free-range | SEM | $P$-value |
|---|---|---|---|---|
| Initial body weight, g | 486.50 | 485.38 | 0.681 | 0.262 |
| Final body weight, g | 3060.75 | 3065.25 | 38.483 | 0.935 |
| Body weight gain, g/bird/day | 91.93 | 92.14 | 1.378 | 0.919 |
| Feed intake, g/bird/day | 159.73 | 161.62 | 2.652 | 0.622 |
| Feed conversion ratio, g feed:g gain | 1.74 | 1.76 | 0.033 | 0.711 |

SEM – standard error of the mean; $P > 0.05$ – not statistically significant

## ME requirements

Data on ME and NE requirements for broilers reared in indoor and free-range system are presented in Table 4. The ME of the experimental diet, determined using a digestibility trial, was 3050 kcal/kg. Based on MEI and ER data, HP was calculated, including $ME_m$ and ME for outdoor activity; additionally, ER in body tissues (as protein or fat) was estimated. Although ME intake did not differ between the two groups ($P > 0.05$), free-range broilers retained significantly less energy in their bodies (approx. 9.5%) and had significantly higher HP (approx. 17.7%) than indoor birds. The additional ME requirement attributable to outdoor activity in free-range birds was 40.50 kcal/kg of $BW^{0.75}$/day, which was not expended by indoor birds. Free-range broilers retained significantly less energy

**Table 4.** Metabolizable and net energy requirements (kcal/kg $BW^{0.75}$ per day) for both indoor and free-range rearing systems

| Items | Indoor | Free-range | SEM | $P$-value |
|---|---|---|---|---|
| MEI | 488 | 498 | 9.423 | 0.470 |
| ER | 281.17[a] | 254.50[b] | 5.631 | 0.007 |
| HP | 206.83[b] | 243.50[a] | 11.148 | 0.041 |
| $NE_m$ | 167.83 | 163.83 | 2.029 | 0.147 |
| $ME_m$ | 204.33 | 199.00 | 2.420 | 0.150 |
| NE for pasture | 0.00[b] | 26.67[a] | 6.184 | 0.012 |
| ME for pasture | 0.00[b] | 40.50[a] | 9.426 | 0.013 |
| $ER_p$ | 175.70 | 171.90 | 3.447 | 0.454 |
| $ER_f$ | 105.30[a] | 82.22[b] | 2.114 | 0.001 |

MEI – metabolizable energy intake, ER – energy retained, HP – heat production, $NE_m$ – net energy for maintenance, $ME_m$ – metabolizable energy for maintenance, $ER_p$ – energy retained as protein, $ER_f$ – energy retained as fat, SEM – standard error of the mean; [ab] – means within a row with different superscripts are significantly different at $P < 0.05$

as fat (approx. 22%) than indoor birds, whereas energy retained as protein did not differ significantly between the groups (~173.8 kcal/kg of $BW^{0.75}$/day; $P > 0.05$).

## ME partition

Figure 1 shows ME distribution in different metabolic activities for broilers reared in indoor and free-range system. Free-range birds retained approximately 6.5% less energy than those reared in the indoor system. The $NE_m$ requirement was slightly lower in the free-range group, accounting for around 40% of total MEI compared with approximately 42% in indoor birds. Energy expended on outdoor activity in free-range broilers represented about 8% of daily MEI.

## Discussion

The observed feeding behaviour aligns with the findings of Campbell et al. (2025), who reported that indoor-reared broilers tended to spend more time around feed and water sources due to restricted space and limited environmental enrichment, resulting in prolonged feeding durations. However, the reduced feeding time observed in free-range birds does not necessarily indicate lower feed intake, as they may meet their nutritional needs over shorter feeding periods. Increased foraging and locomotion activities in free-range broilers reflect their greater opportunity to express natural behaviours in more complex environments. Supporting this, Bokkers and Koene (2003) and Fanatico et al. (2008) noted that outdoor access promoted walking, pecking, and ground-scratching, contributing to improved muscle
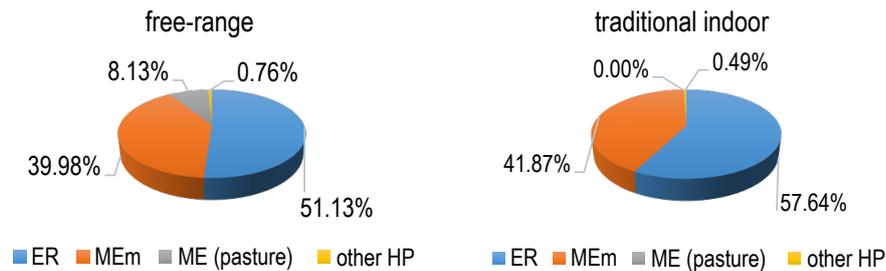
**Figure 1.** Distribution of ME intake as proportions for different metabolic activities by broilers in both traditional indoor and free-range rearing systems

ER – energy retained, ME – metabolizable energy, $ME_m$ – metabolizable energy for maintenance, HP – heat production

development and bone strength. Dust bathing, a comfort behaviour critical for feather maintenance and parasite control, was observed in both groups but declined with age, potentially due to increased body mass or environmental limitations. Slightly longer resting activity in the indoor group by week 6 could be linked to increased body weight, reduced environmental stimulation, or leg weakness due to limited exercise.

The lack of significant differences between treatments concerning performance traits suggested that broilers reared under free-range conditions could efficiently maintain their growth at levels comparable to indoor-reared birds, without increasing their feed intake, despite the additional exercise during outdoor access. Similar results were reported by Tong et al. (2015), who found that outdoor activity did not affect ($P > 0.05$) BW, daily gain, FI or FCR of broilers between 21 and 42 days of age. Other researchers also reported that free-range systems did not influence performance traits (Bartlett et al., 2015; Fanatico et al., 2016; Silva et al., 2021). However, Ponte et al. (2008) recorded higher BW in broilers with outdoor access, while other studies reported reduced growth performance in free-range birds compared to conventionally reared chickens (Skomorucha et al., 2008; Wang et al., 2009). These inconsistency may be attributed to differences in genetic strain, stocking density, level of outdoor activity, and uncontrolled environmental factors such as temperature, humidity, light intensity, and photoperiod (Wang et al., 2009). The broiler strain used in the present study did not display excessive physical activity, which is more typical of lighter breeds and tends to decrease with age (Sánchez-Casanova et al., 2019; 2022).

When calculating energy retained in body tissues, it is important to distinguish between protein ($ER_p$) and fat ($ER_f$) deposition. In the current study, although free-range broilers retained less total energy, their $ER_p$ was similar to that of indoor-reared birds, while $ER_f$ was lower, indicating more efficient protein deposition relative to fat under free-range conditions. On the other hand, the additional ER retained in broilers reared indoors was mainly present in the form of fat, resulting in higher carcass fatness compared to free-range birds (Połtowicz and Doktor, 2011). Therefore, similar growth performance was achieved in the free-range group despite lower fat deposition, which may be considered a desirable carcass trait in some countries due to health issues associated with excessive dietary fat in human diets.

The significant increment in HP in free-range broilers was due to the higher ME required for intensive physical activity during outdoor access, whereas this energy expenditure was absent in the indoor group. Similarly, Sakomura et al. (2011) reported that energy demand varies with rearing systems, noting that birds raised on the ground required 20% more energy than those kept in cages. Similarly, Brainer et al. (2016) and Sánchez-Casanova et al. (2022) observed that birds in free-range production systems engage in various energy-demanding behaviours such as walking, running, preening, scratching, sand bathing, and foraging, which collectively contributed to the higher energy expenditure in this production system.

$ME_m$ is traditionally defined as the energy needed to maintain a balanced metabolism (anabolism and catabolism), with energy retention close to zero (Chwalibog, 1991). For growing animals, a more precise definition is the amount of ME required to maintain body temperature, support normal activity and sustain the dynamic equilibrium of protein and fat turnover (Sakomura et al., 2011). The $ME_m$ values calculated in the current study (204.33 and 199 kcal/kg $BW^{0.75}$ for the free-range and indoor groups, respectively) were higher than 142 and 157.6 kcal/kg $BW^{0.75}$/day estimated by Liu et al. (2017) and Sakomura et al. (2003). This discrepancy is likely due to a lack of standardisation in the methodologies used to determine energy balance.

Additionally, other factors, including genotype, sex, age, behaviour, and environmental conditions, may also influence $ME_m$ demand (Brainer et al., 2016).

The traditional approach of representing energy utilisation in growing animals is based on dividing MEI into growth as RE in body tissues and HP, including $ME_m$ and any additional activity, such as the outdoor energy expenditure measured in free-range birds in the present study. Although MEI was similar between groups, free-range broilers had higher HP due to increased physical activity, leaving less energy available for retention in the body. This finding supports the principle outlined by Sakomura et al. (2011), which posits that energy deposition for growth occurs only after maintenance requirements have been fully met and a surplus energy is available for growth.

Van Milgen et al. (2001) have found using indirect calorimetry method that physical activity represent a substantial component of maintenance energy, accounting for 8–10%. Unlike indoor-reared broilers, free-range birds can redistribute ME based on their physiological priorities, including the energy expended on outdoor activity. Therefore, the energy requirement for physical activity is highly variable and dependent on the rearing system (Brainer et al., 2016).

$ME_m$ accounted for a large proportion of total MEI intake, representing approximately 40% and 42% for free-range and indoor systems, respectively, which was consistent with previously reported values of 42–44% (Lopez and Leeson, 2008).

Some limitations of the present study should be taken into consideration, including its restriction to a single-season and the absence of vegetation in the outdoor area. These factors may have influenced behaviour and energy partitioning. Therefore, future research conducted under varying climatic conditions, with vegetation cover, and longer rearing periods is recommended to validate and extend the present findings.

## Conclusions

Broilers reared under free-range and conventional indoor systems demonstrated comparable growth performance. However, the distribution of metabolizable energy (ME) differed between systems, reflecting variations in physical and metabolic activity. Free-range birds displayed more natural behaviours, suggesting welfare advantages, but required additional energy to support their outdoor activity (quantified at 40.50 kcal/kg body weight$^{0.75}$/day, equivalent to 8.13% of daily ME

intake). These results offer important guidance for nutritionists and producers in formulating diets that balance productivity with the specific energy requirements of welfare-oriented poultry production systems.

## Conflict of interest

The Authors declare that there is no conflict of interest.

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