

Article

Ileal Digestible and Metabolizable Energy of Corn, Wheat, and Barley in Growing Japanese Quail

Sousan Khanipour ¹, Mahmoud Ghazaghi ¹, Mohammad Reza Abdollahi ^{2,3}  and Mehran Mehri ^{1,*} 

¹ Department of Animal Sciences, Faculty of Agriculture, University of Zabol, Sistan 98661-5538, Iran; sousan.khanipour136@gmail.com (S.K.); ghazaghi207@yahoo.com (M.G.)

² Monogastric Research Centre, School of Agriculture and Environment, Massey University, Palmerston North 4442, New Zealand; m.abdollahi@massey.ac.nz

³ A2Z Poultry Feed DynamikZ, 69100 Lyon, France

* Correspondence: mehri@uoz.ac.ir; Tel.: +98-912-041-5519

Abstract: This study aimed to determine the ileal digestible energy (IDE), apparent metabolizable energy (AME), and nitrogen-corrected AME (AMEn) of three typical cereals for quail chicks with two age periods (day 15–21 and 22–28). The experimental diets comprised a corn–soybean meal reference diet (RD), and three test diets (TD) that were fed to quail chicks in a completely randomized design with five replicates per diet and 15 birds each. The TD comprised corn, wheat, and barley that partly replaced the RD at 300 g/kg (70% reference diet + 30% test ingredient). Age did not influence the IDE, AME, and AMEn values, while the effect of ingredient type was highly significant on the energy estimates ($p < 0.001$). The IDE values of corn, wheat, and barley were estimated as 2924, 3440, and 3184 kcal/kg, respectively. The AME values of corn, wheat, and barley were 3519, 2979, and 2710 kcal/kg, respectively. The estimated AMEn values of corn, wheat, and barley were 3483, 2903, and 2532 kcal/kg, respectively. These findings are crucial for optimizing diet formulations to support quail growth and performance effectively, as they provide valuable insights into the energy content of different cereals for quail production. Notably, the high IDE and AME values of wheat suggest its potential as a valuable energy source for quail diets. Understanding these values can aid in formulating diets that meet the energy requirements of quail chicks, leading to improved growth rates, feed efficiency, and overall productivity in quail production systems.



Citation: Khanipour, S.; Ghazaghi, M.; Abdollahi, M.R.; Mehri, M. Ileal Digestible and Metabolizable Energy of Corn, Wheat, and Barley in Growing Japanese Quail. *Poultry* **2024**, *3*, 190–199. <https://doi.org/10.3390/poultry3030015>

Academic Editor: Jianmin Yuan

Received: 19 April 2024

Revised: 5 June 2024

Accepted: 18 June 2024

Published: 24 June 2024

Corrected: 12 March 2025



Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Keywords: cereals; Japanese quail; metabolizable energy; substitution

1. Introduction

Commonly used in the poultry industry, the metabolizable energy (ME) system is employed to define poultry energy needs, incorporating apparent metabolizable energy (AME) and nitrogen-corrected AME (AMEn) [1]. The AME and AMEn values of poultry feed ingredients can be influenced by factors such as age, breed, and diet composition.

Studies have shown that the age of the chicken can impact the AME and AMEn of feed ingredients like soybean meal and canola meal [1,2]. Poultry breeds impact the AME and AMEn as well. Many published papers have evaluated numerous grains, like corn and wheat, and have evaluated using cockerel or broilers. However, Japanese quails possess a distinctive digestive physiology with a shorter digestive tract and higher gut pH compared to other poultry species, which makes a difference in AME values for starch in quails compared with broilers.

Japanese quails have unique nutritional requirements compared to other poultry species. They require higher protein levels, particularly during the early growth stages, to support their rapid growth and development [1]. The specific energy requirements of quail chicks can vary depending on factors such as age, sex, and production stage [2,3].

Determining AME values for Japanese quails is crucial due to their unique nutritional needs and digestive physiology. The current study aimed to determine the IDE, AME, and AMEn of corn, wheat, and barley for Japanese quail at two different age periods.

2. Materials and Methods

This study's experimental protocols were approved by the Research Animal Ethic Committee of the University of Zabol, in line with the "Animal Research: Reporting of In Vivo Experiments" (ARRIVE) guidelines [1].

2.1. Bird Management and Experimental Diets

The digestibility, metabolizability, and nitrogen retention of corn, wheat, and barley were studied in a feeding trial with growing Japanese quail at two age periods: 15–21 days and 22–28 days. The proximate and nutrient composition of the tested feed ingredients is shown in Table 1.

Table 1. Nutrient content of feed ingredients (g/kg; as received basis).

Feed	Corn	Wheat	Barley
Dry matter	905	922	902
Crude protein (N $\times$ 6.25)	79.6	101.0	110.0
Ether extract	37.0	22.0	26.0
Ash	12.0	18.0	22.0
Crude fiber	21.0	28.0	43.0
Gross energy (kcal/kg)	4025	4018	3952

Two groups of Japanese quail chicks, only one day old, were provided from the experimental farm of the University of Zabol. Afterward, they were placed in floor pens in controlled environments until they were assigned to the experimental groups. The experimental diets comprised a corn–soybean meal reference diet (RD), and three test diets (TDs) that were fed to quail chicks in a completely randomized design, resulting in statistical evaluation with a factorial arrangement of 3×2 with five replicates per treatment and 15 birds each. The reference diet was used only as part of the methodology. The temperature was kept at 35 °C on day 1 and then slowly decreased to 29, 26, and 23 °C by the end of weeks 2, 3, and 4. A lighting schedule of 18 h of light and 6 h of darkness was used during the trial. Central ceiling extraction fans and wall inlet ducts controlled ventilation. Birds were given a standard diet from day 0 to day 14 after hatching before being assigned to the experimental diets. A total of 300 quail chicks with a similar body weight (42.6 ± 4.62 g for 15 to 21 days) were present in each age period. The substitution method was used to estimate the IDE, AME, and AMEn of feed ingredients. In this method, a reference diet was formulated to meet or exceed the NRC [2] nutrient recommendations for growing Japanese quails (Table 2). Then, the test diets were formulated by replacing (*w/w*) 300 g/kg of the reference diet with one of the tested feed ingredients. Experimental diets and water were provided ad libitum to the birds.

2.2. Ileal Digestibility Measurements

The ileal digestibility of DM and CP was determined using the marker-assisted method, allowing for the estimation of IDE for each test ingredient. In order to serve as an indigestible marker, the experimental diets were supplemented with titanium dioxide (TiO₂) at a concentration of 5 g/kg. The birds ($n = 15$) were euthanized using CO₂ asphyxiation on days 21 and 28, and their ileal digesta was extracted by gently flushing distilled water into a container. The sample was then placed on ice, frozen at -20 °C, freeze-dried, and ground to a particle size of 0.1 mm.

2.3. Metabolizability Measurements

The total excreta collection procedure [3] was employed to assess the metabolizability of DM and CP and estimate the NR, AME, and AMEn of test ingredients. Diets were

administered for 7 days in each period, with the first 4 days for adaptation and the following 3 days for data collection [4]. The excreta collection was performed twice daily. The collected excreta were pooled within a replicate floor pen (any contamination was removed) and then oven-dried at 105 °C for 24 h ground (0.5-mm screen) and stored at −4 °C for further analysis.

Table 2. Composition of the reference diet.

Ingredients	Amount (g/kg)
Corn	340.0
Wheat	180.1
Soybean meal	386.6
Corn gluten meal	8.80
Soybean oil	24.4
Cornstarch	25.0
Limestone	14.2
DCP	6.20
NaCl	3.20
NaHCO ₃	0.20
DL-Methionine	3.70
L-Lysine.HCl	1.40
L-Threonine	1.10
Mineral premix ¹	2.50
Vitamin premix ²	2.50
Nutrient composition	
AME (Kcal/kg) ³	2900
CP (g/kg) ⁴	250
Ca (g/kg) ³	8.00
P _{available} (g/kg) ³	3.00
Na (g/kg) ³	1.60
Cl (g/kg) ³	2.60
K (g/kg) ³	9.60
DEB (mEq/kg) ⁵	270

¹ Mineral premix provided per kilogram of diet: Mn (from MnSO₄·H₂O), 65 mg; Zn (from ZnO), 55 mg; Fe (from FeSO₄·7H₂O), 50 mg; Cu (from CuSO₄·5H₂O), 8 mg; I [from Ca (IO₃)₂·H₂O], 1.8 mg; Se, 0.30 mg; Co (from Co₂O₃), 0.20 mg; Mo, 0.16 mg. ² Vitamin premix provided per kilogram of diet: vitamin A (from vitamin A acetate), 11,500 U; cholecalciferol, 2100 U; vitamin E (from dl-α-tocopheryl acetate), 22 U; vitamin B₁₂, 0.60 mg; riboflavin, 4.4 mg; nicotinamide, 40 mg; calcium pantothenate, 35 mg; menadione (from menadione dimethyl-pyrimidine), 1.50 mg; folic acid, 0.80 mg; thiamine, 3 mg; pyridoxine, 10 mg; biotin, 1 mg; choline chloride, 560 mg; ethoxyquin, 125 mg. ³ Calculated values. ⁴ Analyzed values. ⁵ DEB: dietary electrolyte balance represents dietary Na + K – Cl in mEq/kg of diet.

2.4. Chemical Analysis

The analysis of dry matter (DM) for the test ingredients, test diets, digesta, and collected excreta was conducted using standard procedures (method 930.15; AOAC, 2006). The ash content was examined using a standard procedure (method 942.05, AOAC, 2006). The standard procedure was used to determine crude fiber (method 978.10, AOAC, 2006). To determine the crude fat (method 2003.05), the Soxtec extraction procedure was employed. The crude protein (CP) was assessed using a standard method (method 990.03, [5]). Gross energy (GE) was measured using an adiabatic oxygen bomb calorimeter (Parr Instruments, Moline, IL, USA) that was calibrated with benzoic acid.

2.5. Calculations

All data were expressed on a DM basis. The substitution method was used to calculate the IDE (the excreta output was replaced with digesta output and GE of digesta), AME, and AMEn of feed ingredients, as described by Wu, et al. [4]:

$$\text{AME}_{\text{Diet}} (\text{kcal/kg}) = [(\text{FI} \times \text{GE}_{\text{Diet}}) - (\text{Excreta output} \times \text{GE}_{\text{Excreta}})]/\text{FI} \quad (1)$$

The AME of the tested feed ingredients was then calculated using the following formula:

$$\text{AME}_{\text{test ingredient}} (\text{MJ/kg}) = [\text{AME of test diet} - (\text{AME of reference diet} \times P_{\text{bd}})] / P_{\text{ti}} \quad (2)$$

where P_{bd} and P_{ti} represent the proportion of the reference diet and test ingredient in the test diet, respectively. Based on the composition of the reference diet, P_{bd} and P_{ti} were 0.6876 and 0.30, respectively.

Nitrogen retention, as a percentage of intake, was determined:

$$\text{N retention (\%)} = 100 \times [((\text{FI} \times N_{\text{Diet}}) - (\text{Excreta output} \times N_{\text{Excreta}})) / (\text{FI} \times N_{\text{Diet}})] \quad (3)$$

The AMEn was then calculated by correction for zero N retention by assuming 8.22 kcal/g N retained in the body, as described by [3].

The coefficient (C) of apparent ileal digestibility or total tract metabolizability of DM and CP in test diets was determined using the following formula [6]:

$$C = 1 - [(T_d / T_o) \times (E_o / E_d)], \quad (4)$$

where T_d represents the concentration of titanium dioxide in the diet; T_o signify the concentration of titanium dioxide in the output (excreta or digesta); E_o shows the nutrient concentration in the output (excreta or digesta); and E_d denotes the nutrient concentration in the diet. Thereafter, the ileal digestibility or metabolizability of DM and CP in test ingredients was calculated by a difference method, as described for the AME of test ingredients in Equation (3).

2.6. Statistical Analysis

Data were analyzed using the one-way ANOVA with SAS [7] in a completely randomized design with a factorial arrangement of 3×2 :

$$Y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \varepsilon_{ijk}$$

where Y_{ijk} represents the observed response variable for the i th level of the ingredient, the j th level of the age, and the k th replicate; μ is the overall mean; τ_i is the effect of the i th level of the ingredient; β_j is the effect of the j th level of the age; ε_{ijk} is the random error term. Pen was treated as the experimental unit, and test diets and age were the fixed effects included in the model. Treatment means were calculated using the LSMEANS statement adjusted for Tukey's test to separate the statistical differences among the treatments. Differences were reported as significant at $p < 0.05$. Before conducting ANOVA, we assessed the normality and homogeneity of variances in the data using Shapiro–Wilk and Levene's tests, respectively. The correlation between the AME:IDE ratio and CP content of the ingredients was assessed by the REG procedure of SAS [7].

3. Results

3.1. Ileal Digestibility and Total Tract Metabolizability

The ileal digestibility of DM (iDM) and CP (iCP) and the metabolizability of DM (mcDM) and CP (mcCP) are shown in Tables 3 and 4, respectively. Feed type significantly affects the ileal digestibility of iDM ($p < 0.001$), where the highest iDM was attributed to wheat (88.1%), followed by barley (84.6%) and corn (73.6%). The interaction of feed $\times$ age affects the ileal digestibility of CP ($p = 0.003$), where the iCP in corn (56.1 to 74.0%) and barley (69.0 to 84.0%) diets was increased with increasing age. The main effect or interactive effect of feed and age was not significant on the mcDM and mcCP (Table 4); however, the mcCP showed a decreasing trend with advancing age (85.1 to 79.7%; $p = 0.098$). The interaction of feed $\times$ age affects the NR, where the NR was decreased with advancing age in corn (86.2 to 74.7%) while it was increased with increasing age in barley (81.7 to 87.8%).

Table 3. Ileal digestibility coefficients of dry matter (iDM), crude protein (iCP), and ileal digestible energy (IDE) at two age groups (I: 15–21 d; II: 22–28 d) of growing Japanese quail ¹.

Ingredient	Age	iDM (%)	iCP (%)	IDE (kcal/kg)
Corn	I	72.5 ^b	56.1 ^c	2954
Wheat	I	89.4 ^a	65.3 ^b	3441
Barley	I	85.1 ^a	69.0 ^b	3194
Corn	II	74.8 ^b	64.0 ^b	2894
Wheat	II	86.7 ^a	63.7 ^b	3439
Barley	II	84.0 ^a	83.2 ^a	3260
SEM		2.41	1.99	79.2
Ingredient				
Corn		73.6	60.0 ^c	2924 ^c
Wheat		88.1	64.5 ^b	3440 ^a
Barley		84.6	76.1 ^a	3227 ^b
SEM		1.70	1.41	56.0
Age				
I		82.3	63.5 ^b	3196
II		81.8	70.3 ^a	3198
SEM		1.39	1.15	45.7
<i>p</i> -value				
Feed		<0.001	<0.001	<0.001
Age		0.801	<0.001	0.983
Feed × Age		0.575	0.003	0.733

Means in a column not sharing a common letter (a–c) are significantly different ($p < 0.05$). ¹ Each value is the mean of five replicate pens with 15 birds per pen.

Table 4. Metabolizability coefficients of dry matter (mcDM), crude protein (mcCP), nitrogen retention (NR), and apparent metabolizable energy (AME), apparent metabolizable energy corrected for zero nitrogen retention (AMEn), and difference in the AME and AMEn (Δ AME = AME – AMEn) at two age groups (I: 15–21 d; II: 22–28 d) of growing Japanese quail ¹.

Ingredient	Age	mcDM (%)	mcCP (%)	NR (%)	AME (kcal/kg)	AMEn (kcal/kg)	Δ AME (kcal)
Corn	I	83.7	82.5	86.2 ^a	3340	3300	39.6
Wheat	I	78.5	83.9	74.9 ^b	2899	2831	68.5
Barley	I	86.2	88.8	81.7 ^{ab}	2663	2506	158
Corn	II	81.4	80.3	74.7 ^b	3698	3665	33.3
Wheat	II	83.9	77.9	76.6 ^b	3058	2976	82.6
Barley	II	87.0	80.8	87.8 ^a	2757	2558	198
SEM		2.47	3.79	3.11	133	188	18.4
Ingredient							
Corn		82.6	81.4	80.5 ^{ab}	3519 ^a	3483 ^a	36.3 ^c
Wheat		81.2	80.9	75.8 ^b	2979 ^b	2903 ^b	75.5 ^b
Barley		86.6	84.8	84.7 ^a	2710 ^b	2532 ^c	178 ^a
SEM		1.74	2.68	2.20	93.8	98.5	13.0
Age							
I		82.8	85.1	80.9	2968	2879	88.6
II		84.1	79.7	79.7	3171	3066	105
SEM		1.43	2.19	1.79	76.6	80.4	10.6
<i>p</i> -value							
Feed		0.101	0.549	0.033	<0.001	<0.001	<0.001
Age		0.529	0.098	0.631	0.077	0.117	0.297
Feed × Age		0.313	0.737	0.029	0.592	0.530	0.465

Means in a column not sharing a common letter (a–c) are significantly different ($p < 0.05$). ¹ Each value is the mean of five replicate pens with 15 birds per pen.

3.2. The IDE, AME, and AMEn of Feed Ingredients

Although age did not influence the IDE, AME, and AMEn values, the ingredient type was highly significant in the energy estimates ($p < 0.001$). It should be noted that age showed an increasing trend on AME ($p = 0.077$), while a decreasing trend on AMEn ($p = 0.081$). The estimated IDE of corn, wheat, and barley in younger quails (15 to 21 d) were 2954, 3441, and 3194 kcal/kg, respectively, the corresponding values in older quails (22 to 28 d) were 2894, 3439, and 3260 kcal/kg, respectively (Table 3). According to the estimates (Table 4), the AME values of corn, wheat, and barley in younger quails (from 15 to 21 d) were 3340, 2899, and 2663 kcal/kg, respectively, while in older quails (from 22 to 28 d), the corresponding values were 3698, 3058, and 2757 kcal/kg, respectively. The AMEn values of corn, wheat, and barley in younger quails (from 15 to 21 d) were 3300, 2831, and 2506 kcal/kg, respectively, while in older quails (from 22 to 28 d), the corresponding values were 3665, 2976, and 2558 kcal/kg, respectively. Age significantly affects the Δ AME (AME – AMEn), where it increased from 88.6 to 105 kcal with advancing age. The AME: IDE ratio (y) negatively correlated with CP (x; %) content of the cereals:

$$y = 15.29 - 5.77x; R^2 = 0.721.$$

4. Discussion

The present study aimed to determine the IDE, AME, and AMEn values of three main cereals (i.e., corn, wheat, and barley), as the principal energy sources for Japanese quails. Unfortunately, no data on the AMEn values of the studied feed ingredients for Japanese quail chicks are available, so a comparison with the AMEn values of the feed ingredients for broiler chickens may be the only reference point available.

The findings of the present study highlight significant variations in AME and AMEn values across different feed ingredients and age groups, underscoring the complexity of nutrient utilization in poultry. For a more thorough understanding of the underlying biological or physiological mechanisms driving these observations, it is crucial to examine the impact of dietary components, such as non-starch polysaccharides (NSPs). Exploring the implications of these findings on practical feeding strategies or feed formulation is warranted. The effects of non-starch polysaccharides (NSPs) on the energy values of corn, wheat, and barley in Japanese quails are complex and influenced by various factors. Corn, wheat, and barley have different NSP contents, which can affect their digestibility and energy values. For example, corn has a lower NSP content compared to wheat and barley, which can make it more digestible [8,9]. The digestibility of NSPs in Japanese quails can vary depending on factors such as the type of NSP, the age of the bird, and the enzymes in the diet. It was found that the digestibility of NSPs in Japanese quails was influenced by the type of NSP and enzymes in the diet [10]. The age and sex of Japanese quails can also influence the effects of NSPs on energy values. For example, a study by Nóbrega et al. [9] found that the rate of passage in the gastrointestinal tract of Japanese quails was influenced by sex and apparent metabolizable energy (AMEn) content in the diet.

Although the lowest IDE value was observed for corn and the highest IDE was estimated for wheat, among the studied ingredients, the highest AME and AMEn were obtained for corn, which was under the lowest ileal digestibility of DM and CP in corn. One plausible reason may be that a lower ileal digestibility of DM and CP can lead to higher AME and AMEn values for corn by providing more available nutrients in the lower part of the intestine and resulting in higher AME or AMEn values than IDE. Our data showed that there was a negative correlation between the AME:IDE ratio and the CP content of the cereals, and each percent increase in CP resulted in a 5.77 unit decrease in the AME:IDE ratio. The negative correlation between the ratio of AME:IDE and the CP content of ingredients in poultry is related to the energy available for the bird's growth and maintenance. AME is the energy available for the bird's metabolism, while IDE is the energy that is not absorbed and is excreted, and CP is a source of energy but also a source of nitrogen for the bird's growth. When the CP content of ingredients is high, the

bird's metabolism is focused on the digestion and utilization of nitrogen, which can reduce the energy available for growth and maintenance. This is because the bird's metabolism requires energy to digest and absorb the nitrogen from the CP, which can reduce the energy available for other metabolic processes. Furthermore, the efficiency of AME for net energy (NE) in broilers is affected by the CP content of the diet. As the CP content decreases, the efficiency of AME for NE increases, which can also contribute to the negative correlation between the AME:IDE and CP content [11]. Another study by Wu et al. [12] found that the NE content was positively related to AME and ether extract, but negatively to crude protein. This suggests that, as the CP content of ingredients increases, the energy available for the bird's growth and maintenance decreases. This is supported by several studies, such as the one by Toghyani et al. [13], which found that the AMEn values of expeller-extracted canola meal (ECM) were negatively correlated with its composition and AME content for broiler chickens. The study also found that the IDE value was only 2.2% higher than the AME value, indicating that a significant portion of the energy in the ECM was not available for the bird's metabolism.

Although bird age is a determinant factor affecting the AMEn in growing birds [14], we could not find any significant improvement in the AMEn of the studied feed ingredients. In the study of Khalil et al. [14], the AMEn quadratically changed with the increasing age of broilers, while the behavior of AMEn in most cereals plateaued during the third and fourth week of age, which agreed with our findings. In the current study, the AMEn values of cereal grains did not differ between weeks 3 and 4, which was associated with equal NR in the two age groups, suggesting that the potential of the quail chicks to metabolize energy could not be different between the third and fourth week of age.

It has been shown that the penalty imposed by the N correction to the AME in cereals such as corn, wheat, and barley was 1.02, 2.56, and 6.71%, respectively. This lower AME penalization in cereal grains compared with protein-rich sources is expected, based on their lower protein content and N retention [15]. Apart from the higher N retention in younger chicks and less catabolism of the retained protein in the body compared to older birds [16], the protein metabolizability also decreased with advancing age in the present study, which could be justified by significant increases in feed intake in older chicks (Figure 1). Lopez and Leeson [16] showed that feed intake in broilers continues to increase. In contrast, the N retention declines as birds grow over time, and higher feed intake increases the passage rate while decreasing the retention time, leading to lower CP digestibility. However, different ages of poultry may have variable abilities to digest and metabolize feed components [17]. Some limiting factors, including the secretion and activities of digestive enzymes and the surface area for absorption in younger chicks, are overcome with advancing age, resulting in better nutrient utilization in older broilers [18,19]. However, this may not be valid in our case, possibly due to the close age difference between quail chicks in the present study.

In the current study, the AMEn values of corn in quail chicks were compared with those values determined in broiler chickens by Lopez and Leeson [20]. The AMEn of corn for quail chicks in the present study (ranging from 3210 to 3300 kcal/kg) was comparable to those reported for broiler chickens (ranging from 3162 to 3459 kcal/kg; Figure 2). The same was observed for the AMEn of wheat, where the estimated values of AMEn for quail chicks were comparable with those reported for broiler chickens (Figure 2). The reported AMEn of wheat for starting broiler chickens by Del Alamo, et al. [21] ranged from 2876 to 2982 kcal/kg, and Khalil et al. [22] estimated that the AMEn of wheat was 2576, which was close to our estimations. Comparing our estimates of the AMEn of barley also indicated that there was no difference between the AMEn of barley for broiler chickens and growing quail chicks (Figure 2). The AMEn of barley for broiler chickens ranged from 2369 kcal/kg [22] to 2654 kcal/kg [23], 2682 kcal/kg [24], and 2841 kcal/kg [25]. The AMEn of the corn, wheat, and barley in quail chicks did not differ from those values in broiler chickens, showing that both growing quail and broiler chickens may equally use these cereal grains for energy extraction. However, some morphological differences, such as the

length of the intestine and passage rate, likely affect the energy utilization of various classes of birds. For example, a longer intestine and subsequently slower passage rate in a laying hen intestine may result in higher energy utilization in layers compared to broilers [26].

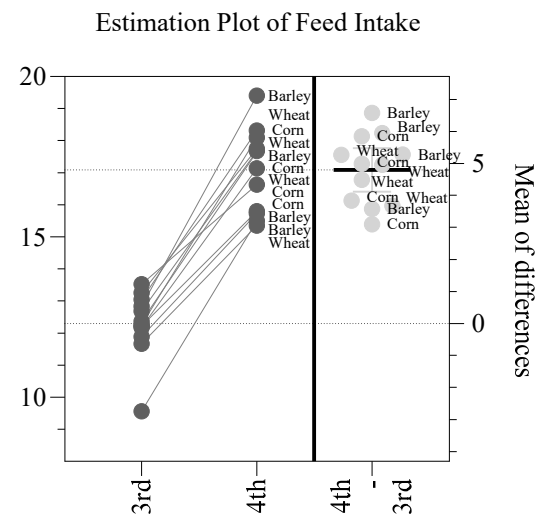


Figure 1. Comparison of the feed intake in quail chicks in the third (3rd) and fourth (4th) weeks of age.

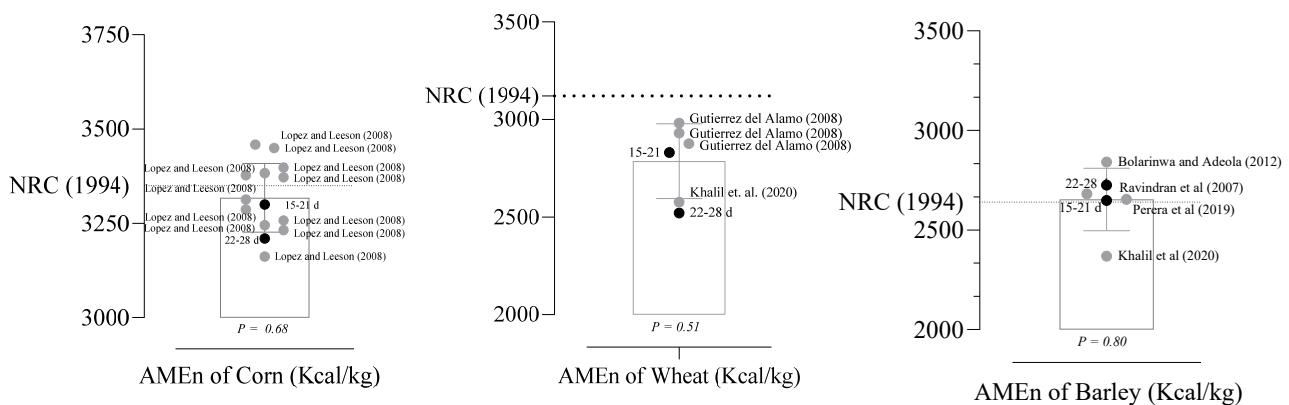


Figure 2. One sample *t*-test of the determined apparent metabolizable energy corrected for zero nitrogen (AMEn) of corn, wheat, and barley in quail chicks with the AMEn values reported in broiler chickens.

The present study reflects that the difference between AME and AMEn (Δ AME) was higher in older quails than in younger birds. In fact, the difference between AME and AMEn represents the energy that is retained in the body as nitrogen, which is a valuable nutrient for growth and development. The higher Δ AME means a higher penalty imposed on the AME by N correction, which shows that more energy is retained in the body as nitrogen. Khalil et al. [14] found that the AMEn of a corn–soy diet increased numerically by 98 kcal/kg from d 14 to 21, indicating a higher penalty imposed on the AME by N correction in older birds, which agreed with our results. However, Abdollahi et al. [15] stated that the N correction can also penalize the energy value of cereal grains, with the penalty ranging from 1.69% in maize to 2.46% in barley, which was close to our findings in the present study. These studies demonstrate that the Δ AME is an important indicator of the energy retained in the body as nitrogen and that a higher penalty imposed by N correction shows a higher retention of energy as nitrogen. The older birds retain more nitrogen compared to younger birds, which is consistent with the fact that older birds have a higher body weight and muscle mass compared to younger birds [15,16,27].

5. Conclusions

This study investigated the nutrient utilization of Japanese quail-fed cereal grains. Corn exhibited superior ME values than wheat and barley in growing quail chicks. Age-related changes were noted, particularly in protein metabolizability, which tended to decrease with advancing age, while nitrogen retention remained consistent across treatments and age groups. The AME values of corn, wheat, and barley were 3519, 2979, and 2710 kcal/kg, respectively. The estimated AMEn values of corn, wheat, and barley were 3255, 2676, and 2281 kcal/kg, respectively. Future research should focus on optimizing feed formulation for quail chicks, exploring alternative energy sources, and considering age-specific nutrient requirements to enhance quail performance and production efficiency. This study contributes valuable insights for the quail industry, guiding future research towards more effective diet strategies for improved profitability.

Author Contributions: Conceptualization, M.M. and M.G.; methodology, M.M. and M.G.; software, M.M.; validation, M.R.A.; formal analysis, M.M.; investigation, S.K.; resources, M.M.; data curation, M.M. and M.R.A.; writing—original draft preparation, M.M.; writing—review and editing, M.M. and M.G.; visualization, M.M.; supervision, M.M.; project administration, M.M.; funding acquisition, M.M.; All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Quails were managed according to the Guide for the Care and Use of Agricultural Animals in the University of Zabol guidelines. The University of Zabol Animal Care and Use Committee approved all experimental methods.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are not available due to privacy.

Conflicts of Interest: We have confirmed that no authors received funding from any company. Therefore, there are no potential conflicts of interest to declare.

References

1. Du Sert, N.P.; Ahluwalia, A.; Alam, S.; Avey, M.T.; Baker, M.; Browne, W.J.; Clark, A.; Cuthill, I.C.; Dirnagl, U.; Emerson, M. Reporting animal research: Explanation and elaboration for the ARRIVE guidelines 2.0. *PLoS Biol.* **2020**, *18*, e3000411.
2. NRC. *Nutrient Requirements for Poultry*, 9th ed.; National Academy Press: Washington, DC, USA, 1994.
3. Hill, F.; Anderson, D. Comparison of metabolizable energy and productive energy determinations with growing chicks. *J. Nutr.* **1958**, *64*, 587–603. [[CrossRef](#)]
4. Wu, S.-B.; Choct, M.; Pesti, G. Historical flaws in bioassays used to generate metabolizable energy values for poultry feed formulation: A critical review. *Poult. Sci.* **2020**, *99*, 385–406. [[CrossRef](#)] [[PubMed](#)]
5. AOAC. *Official Methods of Analysis*; AOAC International: Arlington, VA, USA, 2006.
6. Kong, C.; Adeola, O. Evaluation of amino acid and energy utilization in feedstuff for swine and poultry diets. *Asian-Australas. J. Anim. Sci.* **2014**, *27*, 917. [[CrossRef](#)]
7. SAS. *SAS/STAT 9.1 User's Guide*; SAS Institute Inc.: Cary, NC, USA, 2002.
8. Anwar, U.; Chishti, F.; Bilal, M.; Farooq, U.; Mustafa, R.; Zamir, S.; Hussain, M.; Hussain, M.; Ashraf, M.; Qamar, S. Inclusion of Stored Wheat in the Feed of Broilers Influences Intake, Growth Performance, Nutrient Digestibility, and Digesta Viscosity from 1–21 Days of Age. *Braz. J. Poult. Sci.* **2023**, *25*, eRBCA-2022-1736. [[CrossRef](#)]
9. Nóbrega, I.; Nogueira, H.; Lima, M.; Sakomura, N.; Peruzzi, N.; Artoni, S.; Suzuki, R.; Silva, E. Rate of feed passage in Japanese quail. *Animal* **2020**, *14*, s267–s274. [[CrossRef](#)]
10. Alagawany, M.; Elnesr, S.S.; Farag, M. The role of exogenous enzymes in promoting growth and improving nutrient digestibility in poultry. *Iran. J. Vet. Res.* **2018**, *19*, 157.
11. Tay-Zar, A.-C.; Wongphatcharachai, M.; Srichana, P.; Geraert, P.-A.; Noblet, J. Prediction of net energy of feeds for broiler chickens. *Anim. Nutr.* **2024**, *16*, 241–250. [[CrossRef](#)] [[PubMed](#)]
12. Wu, S.-B.; Swick, R.A.; Noblet, J.; Rodgers, N.; Cadogan, D.; Choct, M. Net energy prediction and energy efficiency of feed for broiler chickens. *Poult. Sci.* **2019**, *98*, 1222–1234. [[CrossRef](#)] [[PubMed](#)]
13. Toghyani, M.; Rodgers, N.; Barekatin, M.R.; Iji, P.; Swick, R.A. Apparent metabolizable energy value of expeller-extracted canola meal subjected to different processing conditions for growing broiler chickens. *Poult. Sci.* **2014**, *93*, 2227–2236. [[CrossRef](#)]
14. Khalil, M.; Abdollahi, M.; Zaefarian, F.; Chrystal, P.; Ravindran, V. Apparent metabolizable energy of cereal grains for broiler chickens is influenced by age. *Poult. Sci.* **2021**, *100*, 101288. [[CrossRef](#)] [[PubMed](#)]

15. Abdollahi, M.R.; Wiltafsky-Martin, M.; Ravindran, V. Application of apparent metabolizable energy versus nitrogen-corrected apparent metabolizable energy in poultry feed formulations: A continuing conundrum. *Animals* **2021**, *11*, 2174. [[CrossRef](#)] [[PubMed](#)]
16. Lopez, G.; Leeson, S. Relevance of nitrogen correction for assessment of metabolizable energy with broilers to forty-nine days of age. *Poult. Sci.* **2007**, *86*, 1696–1704. [[CrossRef](#)] [[PubMed](#)]
17. Adeola, O.; Anwar, M.; Abdollahi, M.; Ravindran, V. Age-related energy values of meat and bone meal for broiler chickens. *Poult. Sci.* **2018**, *97*, 2516–2524. [[CrossRef](#)]
18. Juanchich, A.; Urvoix, S.; Hennequet-Antier, C.; Narcy, A.; Mignon-Grasteau, S. Phenotypic timeline of gastrointestinal tract development in broilers divergently selected for digestive efficiency. *Poult. Sci.* **2021**, *100*, 1205–1212. [[CrossRef](#)] [[PubMed](#)]
19. Noy, Y.; Sklan, D. Nutrient use in chicks during the first week posthatch. *Poult. Sci.* **2002**, *81*, 391–399. [[CrossRef](#)] [[PubMed](#)]
20. Lopez, G.; Leeson, S. Assessment of the nitrogen correction factor in evaluating metabolizable energy of corn and soybean meal in diets for broilers. *Poult. Sci.* **2008**, *87*, 298–306. [[CrossRef](#)] [[PubMed](#)]
21. Del Alamo, A.G.; Verstegen, M.; Den Hartog, L.; De Ayala, P.P.; Villamide, M. Effect of wheat cultivar and enzyme addition to broiler chicken diets on nutrient digestibility, performance, and apparent metabolizable energy content. *Poult. Sci.* **2008**, *87*, 759–767. [[CrossRef](#)] [[PubMed](#)]
22. Khalil, M.; Abdollahi, M.; Zaefarian, F.; Ravindran, V. Measurement of ileal endogenous energy losses and true ileal digestible energy of cereal grains for broiler chickens. *Poult. Sci.* **2020**, *99*, 6809–6817. [[CrossRef](#)]
23. Perera, W.; Abdollahi, M.; Ravindran, V.; Zaefarian, F.; Wester, T.; Ravindran, G. Nutritional evaluation of two barley cultivars, without and with carbohydrase supplementation, for broilers: Metabolisable energy and standardised amino acid digestibility. *Br. Poult. Sci.* **2019**, *60*, 404–413. [[CrossRef](#)]
24. Ravindran, V.; Tilman, Z.; Morel, P.; Ravindran, G.; Coles, G. Influence of β -glucanase supplementation on the metabolisable energy and ileal nutrient digestibility of normal starch and waxy barleys for broiler chickens. *Anim. Feed Sci. Technol.* **2007**, *134*, 45–55. [[CrossRef](#)]
25. Bolarinwa, O.; Adeola, O. Energy value of wheat, barley, and wheat dried distillers grains with solubles for broiler chickens determined using the regression method. *Poult. Sci.* **2012**, *91*, 1928–1935. [[CrossRef](#)] [[PubMed](#)]
26. Sakomura, N.K. Modeling energy utilization in broiler breeders, laying hens and broilers. *Braz. J. Poult. Sci.* **2004**, *6*, 1–11. [[CrossRef](#)]
27. Temim, S.; Chagneau, A.-M.; Guillaumin, S.; Michel, J.; Peresson, R.; Geraert, P.-A.; Tesseraud, S. Effects of chronic heat exposure and protein intake on growth performance, nitrogen retention and muscle development in broiler chickens. *Reprod. Nutr. Dev.* **1999**, *39*, 145–156. [[CrossRef](#)] [[PubMed](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.