Net protein requirements for maintenance and weight gain in male guinea pigs (*Cavia porcellus*) of the Peru breed

Requerimientos de proteína neta para mantenimiento y ganancia de peso en cuyes machos (*Cavia porcellus*) de la raza Perú

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Abstract

Net protein requirements for weight gain (NP_g) and maintenance (NP_m) in meat-producing guinea pigs are not yet established. The objective of this study was to estimate the requirements for NP_m and NP_g in male guinea pigs of the Peru breed using the comparative slaughter method. Sixty guinea pigs with an initial body weight (BW) of 393 ± 55 g were distributed in five groups of 12 animals. The animals were fed a pelleted diet. At the beginning of the experiment, a reference group with a BW 385.9 ± 44.5 g was slaughtered. Two groups were fed *ad libitum*, another group received 75% of the feed provided to the *ad libitum* groups, and a fifth group was kept at the maintenance level. One of the *ad libitum*-fed groups was slaughtered when its BW reached 846.6 ± 48 g. The other animals, distributed according to their feeding level, were slaughtered when the second *ad libitum*-fed group reached 1197 ± 84 g BW. The NP_m requirement was 3.97 g/kg/EBW$^{0.75}$ (empty body weight). And the requirement was NP_g 2.5 g/kg EBW$^{0.75}$. The protein use efficiency was 0.629.

Keywords
crude protein • retained protein • digestible protein • requirement protein

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Resumen

Los requerimientos de proteína neta para ganancia de peso (PN_g) y mantenimiento (PN_m) en cuyes de producción de carne aún no han sido establecidos. El objetivo fue estimar los requerimientos de PN_m y PN_g en cuyes machos de la raza Perú utilizando la metodología de sacrificio comparativo. Se utilizaron 60 cuyes con un peso vivo (PV) inicial de 393 ± 55 g, distribuidos en cinco grupos de 12 animales. Los animales se alimentaron con una dieta peletizada. Al inicio del experimento, se sacrificó un grupo de referencia con un PV 385,9 ± 44,5 g. Dos de los grupos fueron alimentados *ad libitum*, mientras que a otro grupo se le proporcionó el 75% en comparación con los que tenían acceso *ad libitum*, y un quinto grupo se mantuvo en el nivel de mantenimiento. Uno de los grupos que tuvo acceso *ad libitum* fue sacrificado cuando su PV alcanzó 846,6 ± 48 g. Los demás animales, distribuidos según su nivel de alimentación, fueron sacrificados cuando el otro grupo con acceso *ad libitum* alcanzó 1197 ± 84 g PV. El requerimiento de PN_m fue 3,97 g/kg/$PCV^{0,75}$ (peso corporal vacío) y PN_g 2,5 g/kg/$PCV^{0,75}$. La eficiencia de utilización de proteína fue 0,629.

Palabras clave

proteína cruda • proteína retenida • proteína digestible • requerimiento de proteína

Introduction

The guinea pig (*Cavia porcellus*) is an herbivorous, monogastric mammal native to Peru, Ecuador, Bolivia, and Colombia, where it is primarily raised for meat production (5). In these countries, the demand for guinea pig meat has increased due to its nutritional quality, palatability, and, above all, the population's consumption habits (10). Its production has spread to countries such as Brazil, Cameroon, the Democratic Republic of Congo, Tanzania, and Mexico (3, 26, 35). Guinea pig farming has contributed to improved family diets, food security, and overall economic conditions (10).

However, guinea pig production as a food source is relatively unknown worldwide (7). Guinea pigs have been used for scientific research (27) or as pets, and some of the available reference information on husbandry and diet is based on work under laboratory conditions (18 Since meat-producing guinea pigs have higher productive yields, these recommendations are not applicable (6, 8). Thus, the information available on nutritional requirements for maintenance and weight gain of this species is limited with little or no research available (19, 27). Protein requirements can be divided into maintenance and weight gain and are the fundamental components of muscle tissue, certain hormones, and all enzymes (23). Proteins and amino acids are indispensable nutrients for guinea pig performance. If guinea pigs do not receive adequate protein, they do not achieve the growth potential characteristic of their breed (32). In addition, the protein deposition of an animal is considered the most important determinant for weight gain, due to the high water content of protein-rich tissues (33).

Usually, rations for guinea pigs are formulated with the 18% crude protein (CP) recommended by the NRC (1995) for laboratory animals. In some cases, because the rabbit is a species with digestive anatomy and physiology similar to that of guinea pigs, comparisons have been made in terms of feeding and nutrient utilization efficiency at the digestive level (34, 36). So far, no studies report nutritional requirements discriminated in maintenance requirements and weight gain in guinea pigs for meat production (32). Based on the above aspects, this study aimed to determine the protein requirements for maintenance and weight gain in male guinea pigs of the Peru breed.

Material and methods

Animal ethics: The experiment was approved by the Ethics Committee for Animal Experimentation of the University of Antioquia (Act N°138 of 09 February 2021).

Housing and handling of animals

A total of 60 male guinea pigs of the Peru breed were used. All animals were given a 20-day acclimation period to adapt to handling and the experimental diet. During the entire experimental period, the animals were housed in individual metabolic cages 0.3 m long x 0.3 m wide x 0.25 m high, which were equipped with an automatic feeder and drinker The average temperature was 18°C, with a relative humidity of 80%, annual precipitation of 2304 mm, and an altitude of 2150 meters above sea level (masl). The experiment began when the animals were 35 days old and had an initial body weight (BW) of 393 ± 55 g. The animals were weighed every seven days to monitor daily weight gain (DWG) to the amount of feed to be fed.

Diet and dietary levels

Animal diet was balanced according to the NRC's (1995) report. Although this report suggests the inclusion of wheat (23.6%) and whole oats (25.2%); for reasons of availability, it was decided to replace them with rice and corn meal (table 1), respectively. The feed was provided in pellet form twice daily, at 7:00 and 15:00 h.

Table 1. Ingredients and percentage composition on a dry basis of the experimental diet.

Tabla 1. Ingredientes y composición porcentual en base seca de la dieta experimental.

Ingredient	Quantity %
Alfalfa hay	35.0
Soybean meal, expeller	12.0
Corn	44.3
Rice flour	3.0
Soybean oil	3.0
Dicalcium phosphate	0.5
Calcium carbonate	1.0
Salt	0.8
Mineral premixes and vitamins*	0.4
Dry matter	92.1
Crude protein	16.4
Ether extract	4.0
Ash	5.5
Neutral detergent fiber	22
Acid detergent fiber	16
Non-fiber carbohydrates[2]	50.5
Digestible energy (kcal kg^{-1}DM)	3705
Metabolizable energy (kcal kg^{-1}DM)	3520

*Minerals: cobalt 1.5; copper 6.6; manganese 39.7; zinc 19.8; iodine 1.1; iron 50; selenium 0.3 (mg kg^{-1}). Vitamins: vitamin A 6614; vitamin D3 2200 (IU kg^{-1}), vitamin E 22; vitamin K 5; thiamine 4.4; riboflavin 3.3; niacin 11; pantothenic acid 11; choline 529; pyridoxine 5; folic acid 4.8; biotin 2.2; ascorbic acid 250; methionine hydroxy analog 500(mgkg^{-1});vitaminB12 11 µg kg^{-1}. Antioxidant BHT0.1gkg^{-1};Salinomycin 20 mg kg^{-1}. Source NRC (1995). 2 CNF=100%-(Crude protein+Ether extract+Ash+Neutral detergent fiber).

*Minerales: cobalto 1,5; cobre 6,6; manganeso 39,7; zinc 19,8; yodo 1,1; hierro 50; selenio 0,3 (mg/kg). Vitaminas: vitamina A 6614; vitamina D3 2200 (UI/kg), vitamina E 22; vitamina K 5; tiamina 4,4; riboflavina 3,3; niacina 11; ácido pantoténico 11; colina 529; piridoxina 5; ácido fólico 4,8; biotina 2,2; ácido ascórbico 250; metionina hidroxi análogo 500 (mg/kg); vitamina B1211µg/kg.Antioxidante BHT 0,1 g/kg; Salinomicina 20 mg/kg. Fuente NRC (1995). [2] CNF= 100%-(Proteína bruta+Extracto Etéreo+Cenizas+Fibra detergente neutra).

The diet was provided at three levels: *ad libitum* feeding (24 animals), where feed rejected (orts) accounted for 20% of the offered amount; restricted feeding (12 animals), with intake set at 75% of the ad libitum level; and maintenance feeding (12 animals), based on an intake of 150-160 kcal DE kg^{-1} $BW^{0.75}$, which is 30-40% higher than the 115.2 kcal DE kg^{-1} $BW^{0.75}$ reported by Matin *et al.* (1975) for laboratory guinea pigs. The DE was considered 95% of ME, following Xiccato and Trocino (2020); the EM was calculated using the diet composition values (table 1). Then, the diet energy density was estimated at 3705 kcal DE kg^{-1}. The described feeding levels are necessary to establish energy requirements, using linear regression, according to comparative slaughter method (22).

Digestibility test

To determine the retained protein (RP) and crude protein (CP) losses associated with the digestive process, an apparent digestibility test was performed 28 days after the start of the experiment at three feeding levels (*ad libitum*, restricted, maintenance) with six animals each. The test lasted six days. Dry matter intake (DMI) was calculated as the difference between the amount of feed offered and the amount rejected by the animals. Each day, the rejected feed per animal was weighed and stored at -15°C, thus obtaining an individual composite sample for subsequent chemical analysis. Fecal dry matter production was determined by the total fecal collection procedure. Each day, in the morning and the afternoon, the feces were removed from the collection tray, stored individually, and frozen at -15°C.

Urine collection

Simultaneously with the digestibility test, total urine collection was performed. Urine was stored in containers containing 5 ml of sulfuric acid (5% H_2SO_4) to avoid nitrogen (N) losses in the form of ammonium and was stored at -15°C. Urinary weight and volume were recorded daily. At the end of the six days, urine samples were pooled to obtain a composite sample per animal for subsequent chemical analysis.

Slaughter of animals

The 60 guinea pigs were divided into five groups of twelve animals each and were slaughtered in three periods. The first group was slaughtered at the beginning of the experiment with a BW of 385.9 ± 44.5 g. This group was designated as the reference group, allowing for the estimation of the initial composition of the 48 animals culled later, facilitating the comparison of the final body composition with the initial composition. Twenty-eight days after the experiment began, a second group of 12 animals fed *ad libitum* with a BW of 846.6 ± 48 g was culled, marking this point as the intermediate slaughter. Finally, the remaining 36 animals, 12 per feeding level (*ad libitum*, restricted, and maintenance), were culled at 90 days, when one of the *ad libitum*-fed groups reached a BW of 1189.7 ± 105 g. Before slaughter, the animals were subjected to an 18-hour fasting, after which they were weighed to determine the shrunk body weight (SBW). For slaughter, a Dick KTBG captive bolt pistol (Friedr Dick GmbH & Co. Deizisau, Germany) was used. The procedure followed the method described by Limon *et al.* (2016). Immediately after the stunning, the jugular veins were bilaterally severed and blood was collected. Animals were depilated by exposing to water heated to 90°C for 10 seconds. Then, after weighting, gastrointestinal contents were removed. Empty body weights (EBW) were determined by the difference between the SBW and the weight of the gastrointestinal contents. Hair, blood, and body plus organs (BO) were stored separately at -15°C for later chemical analysis.

Chemical analysis

The BO was ground in a mill model ML C012 (capacity 150 kg h^{-1}, power 850W, voltage 110). In the offered and orts, feces, BO, hair, and blood were analyzed for DM (AOAC 2007; Method 39.1.02), ether extract (AOAC 2007; Method 39.1.05), CP (AOAC 2007; Method 39.1.19), ash (AOAC 2007; Method 39.1.09) and gross energy (GE) (LECO AC600 calorimetric pump, MI, USA). Only DM, CP, and GE were analyzed in the urine samples. The results for the body plus organs, hair, and blood were summed to obtain the body's chemical composition at each slaughter.

Crud protein balance

Each animal's CP intake (CPI) was determined by the difference between the amount of CP offered and rejected. Digestible protein intake (DPI) was obtained by comparing CPI and CP losses through feces. In the protein balance, RP was estimated by the difference between CPI and losses through urine and feces. In the comparative slaughter trial, the RP was obtained by the difference between the body RP at the time of slaughter and the beginning of the study, based on the body composition of the reference animals. Crud protein balance results were expressed in g/kg/$EBW^{0.75}$. The EBW value corresponded to the mean weight, obtained as (initial EBW + final EBW/2).

Net protein requirements for weight gain (NP_g) and maintenance (NP_m)

The NP_g (g/kg $EBW^{0.75}$/day) corresponded to the average RP in animals fed *ad libitum* throughout the entire experimental period. From the regression parameters: $log y = a + b * log x$, where: $y = log_{10}$ of total CP content and $x = log_{10}$ of EBW. The net protein requirement per kg EBW was calculated by the derivative of the above equation, according to the following model (2): $y` = b * 10^{a} * x^{(b-1)}$, where: $y`$ = NP_g required to gain one kg of EBW (g/kg/EWG/day) and x = EBW (kg). The equations were constructed with the information from the 24 animals fed *ad libitum* and the 12 animals from the restricted feeding level. The NP_m requirement was estimated using linear regression equations between retained nitrogen (RN, g/kg $EBW^{0.75}$/day) in the EBW of the animals during the experimental period (y) as a function of nitrogen intake (NI, g/kg $EBW^{0.75}$/day) from the diet (x). To estimate the dietary CP requirement for maintenance (CP_m), the intersection with the X-axis was multiplied by a factor of 6.25. Endogenous and metabolic losses were estimated based on the negative intersection with the Y-axis, while the slope of the line was considered as the efficiency of nitrogen utilization from the feed (16). The digestible protein requirements for maintenance (DP_m) and digestible protein for weight gain (DP_g) were estimated by the ratio of the CP digestibility coefficient. The conversion of the EBW requirement into a BW requirement was carried out using the factor derived from the BW/EBW ratio.

Statistical analysis

The results of the metabolism trial were analyzed using a completely randomized design through analysis of variance, considering the feeding level (maintenance, restricted, and *ad libitum*) as a fixed effect with six animals per group. Means were compared using Tukey's test, with statistical differences considered significant at $p < 0.05$. In the linear regression analyses conducted with the data obtained from the comparative slaughter trial, the significance ($p < 0.05$) of the slope and intercept in each model was verified. Data processing was performed using the R statistical package (29).

Results

Protein balance and body composition

Table 2 (page XXX) presents the CP balance data for the three feeding levels: maintenance, restricted, and *ad libitum*. DMI and CPI were significantly higher in animals fed ad libitum ($p < 0.05$). Protein digestibility was significantly lower in animals fed *ad libitum (*$p<0.05$). The percentage of RP estimated in the digestibility test decreased as CPI increased ($p<0.05$). CP in feces differed with feeding level ($p<0.05$). When the percentage of CPI in urine was compared to DPI and CPI, no differences were present.

Comparative slaughter trial

Table 3 (page XXX) shows weight and body composition at slaughter for three feeding levels and a reference group of animals slaughtered at the beginning of the experiment. The average BW of the restricted-fed animals represented about 80% of the BW of the *ad libitum* animals. The EBW/BW ratio, fat, and BW increased with feeding level ($p<0.05$), while water content decreased($p<0.05$). CP and ash were stable, with values close to 20, and 5%, respectively.

Table 4 (page XXX) presents the results of comparative slaughter at the different feeding levels (*ad libitum*, restricted, maintenance). DWG was proportional to feeding level. a*d libitum-fed* animals were found to have higher DWG and to be more efficient in RP at an average weight of 846.6 g, at 28 experimental days. The average RP of animals fed *ad libitum* and slaughtered at 90 days was considered the requirement NP_g (2.5 g/kg $BW^{0.75}$/day).

Table 2. Protein partitioning in *ad libitum*, restricted, and maintenance-fed guinea pigs.
Tabla 2. Partición de proteína en cuyes alimentados *ad libitum*, restringidos y de mantenimiento.

Items	Maintenance	Restricted	*ad libitum*
Experimental days	28	28	28
BW (g)	481.8^{b} ± 60	611^{a} ± 81	698^{a} ± 34
DMI (g/day)	23.19^{b} ± 2.3	37.21^{a} ± 5	42.9^{a} ± 3.5
Crude protein intake and excretion (g/d)			
CPI	3.8^{b} ± 0.3	6.09^{a} ± 0.8	6.90^{a} ± 0.6
Fecal CP	0.59^{c} ± 0.08	1.1^{b} ± 0.18	1.7^{a} ± 0.22
DPI	3.21^{b} ± 0.3	4.99^{a} ± 0.7	5.21^{a} ± 0.5
CP urine	0.04^{a} ± 0.0	0.06^{a} ± 0.01	0.09^{a} ± 0.08
RP	3.17^{b} ± 0.3	4.93^{a} ± 0.7	5.11^{a} ± 0.5
Protein utilization efficiency (%)			
DP	84.5^{a} ± 1.3	81.9^{a} ± 2.3	75.4^{b} ± 2.5
RP/CPI	83.5^{a} ± 1.3	80.9^{a} ± 2.6	74.1^{b} ± 2.1
RP/DPI	98.8^{a} ± 0.3	98.8^{a} ± 0.4	98.2^{a} ± 1.3
CP feces/CPI	15.5^{b} ± 1.4	18.1^{b} ± 2.4	24.5^{a} ± 2.6
CP urine/CPI	0.95^{a} ± 0.2	0.95^{a} ± 0.3	1.3^{a} ± 1.0
CP urine/DPI	1.1^{a} ± 0.3	1.2^{a} ± 0.4	1.7^{a} ± 1.3

BW = body weight; DMI = dry matter intake; CP = crude protein; DPI = digestible protein intake; CPI=crudeproteinintake; RP = retained protein; EBW = empty body weight; DP = digestible protein. a,b,c. Averages within the same row with different letters differ ($p < 0.05$).

PVC = peso vivo corporal; CMS = consumo de materia seca; PC = Proteína cruda; CPD = consumo de proteína digestible; CPC = Consumo de proteína cruda; PR = Proteína retenida; PCV = peso corporal vacío; PD = proteína digestible, [a,b,c] Promedios dentro de la misma fila con letras diferentes difieren (p < 0,05).

Table 3. Body composition at slaughter with three feeding levels in guinea pigs.
Tabla 3. Composición corporal al sacrificio bajo tres niveles de alimentación en cuyes.

Items	Feeding level				
	Reference group	Maintenance	Restricted	*ad libitum*	
Experimental days	-	90	90	28	90
BW (g)	385.9^{c} ± 45	495.3^{c} ± 80	949.1^{b} ± 185	846.6^{b} ± 48	1189.7^{a} ± 105
EBW (g)	317.1^{c} ± 39	410.2^{c} ± 86.7	862.5^{b} ± 198.9	784.8^{b} ± 44.8	1128.4^{a} ± 103.6
EBW/BW	0.82^{c} ± 0.04	0.82^{c} ± 0.05	0.90^{b} ± 0.04	0.92^{ab} ± 0.01	0.94^{a} ± 0.01
$EBW^{0.75}$ (kg)	0.42^{c} ± 0.04	0.51^{c} ± 0.07	0.89^{b} ± 0.15	0.83^{b} ± 0.03	1.09^{a} ± 0.07
Chemical composition of EBW (%)					
Water	71.7^{a} ± 1.5	70.7^{a} ± 1.7	65.0^{b} ± 2.3	66.0^{b} ± 0.7	59.0^{c} ± 1
Fat	1.6^{c} ± 0.2	3.5^{c} ± 1.3	10.0^{b} ± 3.4	10.2^{b} ± 0.9	16.2^{a} ± 1.3
Crud protein	20.3^{a} ± 1.5	20.3^{a} ± 1.1	20.0^{a} ± 1.1	19.8^{a} ± 1	20.8^{a} ± 1.3
Ash	5.4^{a} ± 0.7	5.2^{a} ± 0.6	5.2^{a} ± 0.5	4.9^{a} ± 0.2	5.0^{a} ± 0.8
GE (kcal/kg EBW)	1332^{c} ± 135	1404^{c} ± 154	2143^{b} ± 291	2090^{b} ± 97	2625^{a} ± 174

BW = body weight; EBW = empty body weight; $BW^{0.75}$=metabolic empty body weight; GE = gross energy, [a,b,c] Averages within the same row with different letters differ ($p < 0.05$).

PVC = peso vivo corporal; PCV = peso corporal vacío; $PCV^{0.75}$ = peso corporal vacíometabólico; EB = energía bruta, [a,b,c] Promedios dentro de la misma fila con letras diferentes difieren (p < 0,05).

Table 4. Daily weight gain, protein intake, and crud protein balance in guinea pigs across three feeding levels: results from a comparative slaughter study.

Tabla 4. Ganancia diaria de peso, consumo y balance de proteína cruda en cuyes bajo tres niveles de alimentación: resultados del estudio de sacrificio comparativo.

BW = body weight; DMI = dry matter intake; EBW=emptybodyweight; DWG = daily weight gain; CPI = crude protein intake; RP = retained protein.

PVC = peso vivo corporal; CMS = consumo de materia seca; PCV = peso corporal vacío; GPD = ganancia de peso diaria; CPC = consumo de proteína cruda; PR = proteína retenida, [a,b,c] Promedios dentro de la misma fila con letras diferentes difieren (p < 0,05).

Items	Feeding level			
	Maintenance	Restricted	*ad libitum*	
BW (g)	495.3^{c} ± 80	949.1^{b} ± 185	846.6^{b} ± 48	1189.7^{a} ± 105
Experimental days	90	90	28	90
DMI (g/day)	21.7^{c} ± 3.1	37.4^{b} ± 6.4	49.6^{a} ± 2.8	48.8^{a} ± 4.1
DWG (g/day)	1.1^{d} ± 0.4	5.9^{c} ± 1.5	13.2^{a} ± 1.9	9.3^{b} ± 1.0
CPI (g/day)	3.5^{c} ± 0.5	6.1^{b} ± 1	8.0^{a} ± 0.4	7.8^{a} ± 0.6
CPI (g/kg $EBW^{0.75}$/day)	7.5^{d} ± 0.3	9.1^{c} ± 0.3	12.0^{a} ± 0.6	10.3^{b} ± 0.5
RP (g/day)	0.19^{b} ± 0.1	1.2^{c} ± 0.4	2.7^{a} ± 0.4	1.9^{b} ± 0.3
RP (g/kg $EBW^{0.75}$/day)	0.4^{d} ± 0.2	1.8^{c} ± 0.3	4.1^{a} ± 0.5	2.5^{b} ± 0.4
RP/CPI (%)	5.4^{c} ± 3.7	19.9^{b} ± 3.8	33.8^{a} ± 4.4	23.7^{b} ± 3.2
$EBW^{0.75}$ average (g)	468.6^{c} ± 59	667.5^{b} ± 96	663.5^{b} ± 25	760.7^{a} ± 37

Net protein requirement for weight gain and maintenance

Table 5 shows the equations used to estimate the NP_g requirement and the EBW. The equations exhibited a good fit with determination coefficients exceeding 0.93 (R^2).

Table 5. Equations for estimating empty body weight and net protein requirement for weightgain in guinea pigs.

Tabla 5. Ecuaciones para estimar el peso corporal vacío y el requerimiento de proteína neta para la ganancia de peso en cuyes.

EBW (kg) = empty body weight; BW (kg) = body weight; NP = net protein.

PCV (kg) = peso corporal vacío;PVC(kg)=pesovivo corporal; PN = proteína neta.

Equation	R^2	Equation of NP requirements for gain (g/kg)
Log10 Protein = 2.315 ± 0.004 + 1.0681 ± 0.049*Log_{10}EBW	0.932	221* $EBW^{0.0681}$
EBW = -0.093 ± 0.023 + 1.0231 ± 0.023*BW	0.982	

With the equation to estimate the NP_g requirement and the equation to estimate the BW (table 5). The NP_g requirements for different BW (900, 1000, 1100, and 1200 g) were expressed in different DWG (5, 10, 15, and 20 g) (table 6, page XXX).

Figure 1 (page XXX) shows the relationship between NI and RN, both variables expressed in $g.kg^{-1}$ $EBW^{0.75}$ d^{-1}. The regression was constructed with animal data at the three feeding levels (*ad libitum*, restricted, and maintenance).

From the equation in figure 1 (page XXX), NI was estimated when the RN was zero, corresponding to the N requirement for maintenance (1.01 g). This requirement was expressed in CP_m when multiplied by the factor 6.25 (6.32 g/kg/$EBW^{0.75}$/day). On the other hand, the regression intercept corresponded to endogenous and metabolic N losses (0.6359 g/kg $EBW^{0.75}$/day) and its slope represented the N utilization efficiency (0.629). Based on this efficiency, the NP_m requirement was determined to be 3.97 (g/kg/$EBW^{0.75}$/day). With the protein digestibility coefficient found in the digestibility test at the maintenance level (84.5 %), the DP_m was estimated at 5.34 g/kg $EBW^{0.75}$/day.

Table 6. Net protein requirements for weight gain in guinea pigs.
Tabla 6. Requerimientos de proteína neta para la ganancia de peso en cuyes.

BW = body weight; EBW = empty body weight; EWG = empty body weight gain.

PVC = peso vivo corporal; PCV = peso corporal vacío; GPC = ganancia de peso corporal vacío.

BW(g)	EBW (g)	Protein EWG (g/kg)	Net protein requirement (g/day) at different BW gains (g)			
			5	10	15	20
900	828	217.8	1.00	2.00	3.01	4.01
1000	930	219.5	1.02	2.04	3.06	4.08
1100	1033	220.1	1.04	2.08	3.11	4.15
1200	1135	222.5	1.05	2.10	3.16	4.21

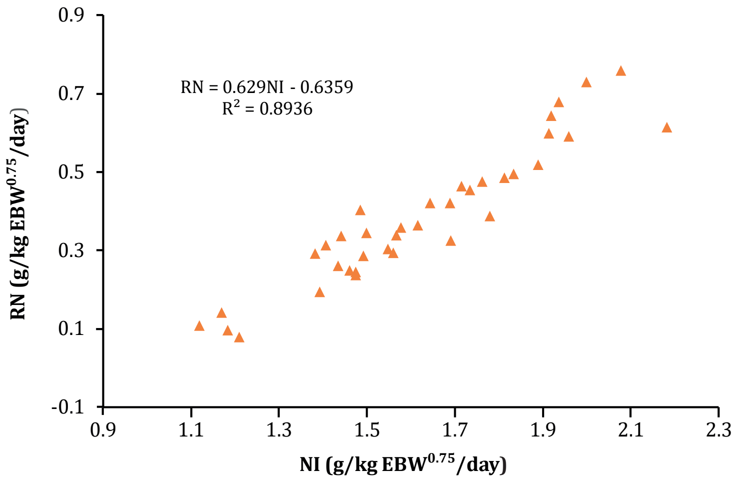

Figura 1. Relación entre el consumo de nitrógeno (CN g/kg PCV$^{0.75}$/día) y nitrógeno retenido (NR g/kg PCV$^{0.75}$/día).

Figure 1. Relationship between nitrogen intake (NI g/kg EBW$^{0.75}$/day) and nitrogen retained (RN g/kg EBW$^{0.75}$/day).

Table 7 presents the requirements of NP_m, NP_g, total NP, DP_m, DP_g, total DP, and total CP, for different BW gains (5, 10, 15, and 20 g/day) for animals of 900, 1000, 1100, and 1200 g of BW. Protein maintenance and gain increased as BW is higher and DWG increases.

Table 7. Protein requirements (g/day): net (NP), digestible (DP), and crude (CP), for maintenance ($_m$), gain ($_g$), and total for guinea pigs.
Table 7. Protein requirements (g/day): net (NP), digestible (DP), and crude (CP), for maintenance ($_m$), gain ($_g$), and total for guinea pigs.

BW = body weight; DWG = daily weight gain; * value calculated with the average protein digestibility coefficient of 80%; † value calculated with the protein utilization efficiency coefficient of 62.9%.

PVC = peso vivo corporal; GPC = ganancia de peso corporal vacío; * valor calculado con el coeficiente de digestibilidad promedio de la proteína del 80%; † valor calculado con el coeficiente de eficiencia de uso de la proteína del 62.9%.

BW, g	DWG, g/day	NP_m	NP_g	NP_{total}	$^*DP_m$	$^*DP_g$	$^*DP_{total}$	$^†CP_{total}$
900	5	3.45	1.00	4.45	4.39	1.27	5.66	7.08
	10	3.45	2.00	5.45	4.39	2.55	6.94	8.67
	15	3.45	3.01	6.45	4.39	3.82	8.21	10.26
	20	3.45	4.01	7.46	4.39	5.10	9.48	11.85
1000	5	3.76	1.02	4.79	4.79	1.30	6.09	7.61
	10	3.76	2.04	5.81	4.79	2.60	7.38	9.23
	15	3.76	3.06	6.83	4.79	3.90	8.68	10.85
	20	3.76	4.08	7.85	4.79	5.19	9.98	12.48

BW = body weight; DWG = daily weight gain; * value calculated with the average protein digestibility coefficient of 80%; † value calculated with the protein utilization efficiency coefficient of 62.9%.

PVC = peso vivo corporal; GPC = ganancia de peso corporal vacío; * valor calculado con el coeficiente de digestibilidad promedio de la proteína del 80%; † valor calculado con el coeficiente de eficiencia de uso de la proteína del 62.9%.

1100	5	4.07	1.04	5.11	5.18	1.32	6.50	8.12
	10	4.07	2.08	6.15	5.18	2.64	7.82	9.77
	15	4.07	3.11	7.18	5.18	3.96	9.14	11.42
	20	4.07	4.15	8.22	5.18	5.28	10.45	13.07
1200	5	4.37	1.05	5.42	5.56	1.34	6.90	8.62
	10	4.37	2.10	6.47	5.56	2.68	8.23	10.29
	15	4.37	3.16	7.53	5.56	4.01	9.57	11.97
	20	4.37	4.21	8.58	5.56	5.35	10.91	13.64

Discussion

Protein balance

Since CP losses in the feces increased with the feeding level ($p<0.05$) due to a higher intake, DP decreased. When comparing *ad libitum* and maintenance levels, an average variation of 9.1 percentage units in DP was observed ($p<0.05$). A lower DMI at the maintenance level may have prolonged the retention time of the feed in the gastrointestinal tract, which extends the period of exposure of the feed to digestive enzymes, thus facilitating feed absorption (17), which was finally reflected in higher protein digestibility. In general, a high protein digestibility was observed, 75.4% in *ad libitum* and 84.5% in the maintenance group. Similar findings have been recorded in the DP (77.02 to 86.56%) of wholesoybean meal in guinea pigs of the Peru breed (11). According to Chauca (1997), the guinea pig demonstrates a remarkable efficiency in the digestion of CP present in energyand protein foods compared to other monogastric species, thanks to its digestive physiology, which involves a first stage of enzymatic digestion in the stomach followed by a microbial phase in the cecum and colon. In a study with male guinea pigs, 63 feeds classified into fivecategories were evaluated (1, dry forages; 2, green forages; 3, agro-industrial and kitchen waste; 4, energy meals; 5, protein meals of animal and vegetable origin), an average DP of 73.53% was found (7). The higher digestibility observed in our study could be attributed to the quality of the feed used (table 1, page XXX).

Crude protein losses in urine for guinea pigs with balanced feed intake have been estimated at 2.8 g/day (25), which value differs considerably from the value of 0.09 g/day found in this study, with a diet containing 16.4% CP (table 1, page XXX). This difference can be attributed to the higher CP content in the diet (18.3 %) and higher DMI (49.49 g/day) reported by Bastianelli and Sauvant (1997). In rabbits, Lv *et al.* (2009) found that RP does not improve with increasing CP levels from 12 to 20% in the diet, which is ultimately reflected in higher CP excretion in feces and urine and low efficiency as CP supply increases. Because CP in urine and feces were lower at the maintenance level, RP (RP/CPI%) was higher, suggesting that animals use protein more efficiently under limited feeding conditions. Moon (1988) reports higher metabolic efficiency in guinea pigs under fasting conditions than other rodents.

Net weight gain protein

The NP_g requirement was 2.5 g/kg $EBW^{0.75}$/day. The higher DWG of 13.2 g/day observed in the *ad libitum* animals of intermediate slaughter (846.6 g of BW), was related to the higher protein deposition (2.7 g/day) found in this same group of animals (table 4, page XXX), this is due to the high content of water and protein in the tissues, which largely determines the DWG in an animal (4). This was also evidenced by the higher efficiency in the RP (33.8%) at 28 days of performance compared to the efficiency in the *ad libitum* animals at the final slaughter (23.7%). This is because as the guinea pig reaches the adult stage, it accumulates more fat than protein. According to De Figueiredo *et al.* (2020), the fat content of guinea pig meat is inversely proportional to the water and protein content. This was demonstrated by the body composition of reference animals versus *ad libitum* slaughter animals, in which fat content increased from 1.6 to 10.2 and 16.2 % as water content decreased from 71.7 to 66.0 and 59.0% for the reference animals and the two *ad libitum* groups, respectively (table 3, page XXX). Similar body composition trends are reported at three months of age (water 75%, protein 19%, and fat 2.64%) versus the body composition of guinea pigs at 18 months of age (water 72.6%, protein 19.6% and fat 5.7%) (31). NP_g requirements showed low variation, with values between 21.8 to 22.3 g/100 g for 828 to 1135 g of EBW, respectively (table 6, page XXX). Studies reveal that protein in guinea pigs for meatproduction is very stable and even between the lines and age of the animal; Peru breed 19.34% (18), Inka and Andean 20.36 and 19.26% CP respectively (31). It has been shown that guinea pigs respond efficiently with rations of 20% CP and that higher levels have no beneficial effect on growth (37).

Net maintenance protein and use efficiency

Endogenous and metabolic losses of N were estimated at 0.6359 g/kg $EBW^{0.75}$. In rabbits with a BW between 2.1 to 2.8 kg and diets with a CP between 12 to 20 %, an endogenous N value of 0.485 g/kg $BW^{0.75}$ has been reported (23), 23.7% higher than that found in this study. In contrast, in rabbits (New Zealand White x Californian)with a BW of 3.79 kg and a daily intake of 44.4 g DM/kg $BW^{0.75}$ from a protein-free diet, the endogenous N was 0.2539 g/kg $BW^{0.75}$ (15). Although thereare no reports on endogenous N losses in guinea pigs, the higher value found in comparison with rabbits suggests that N recycling and protein turnover may be more efficient in rabbits than in guineapigs in the conditions of this study. In guinea pigs, being smaller animals, the amount of endogenous N is related to protein turnover, which could result in higher metabolic rates and thus higher endogenous N values (30), explaining in part the higher losses compared to rabbits.

With the CP utilization efficiency of 0.629 (figure 1, page XXX), an NP_m requirement of 3.97 g/kg $BW^{0.75}$ was estimated. This value was found to be lower than that reported for growing wool-type rabbits (4.87 g/kg $BW^{0.75}$) (21) and higher than the requirements in growing rabbits (NP_m 3.03 g/kg $BW^{0.75}$) (23). Despite the absence of data on NP_m requirements in guinea pigs, the physiological, digestive, and nutritional similarity between rabbits and guinea pigs (36) suggests that the data obtained here are biologically consistent. From the relationship between NI and RN, protein use efficiency values of 0.585 and 0.6781are reported for growing and finishing rabbits, respectively (23). Xiccato and Trocino (2020) reported a value of 0.56 for rabbits in general. These values agree with the 0.629 found in this study (figure 1, page XXX). The efficiency observed for guinea pigs and that reported for rabbits is relatively high compared to other species such aslambs (0.29) (16) and beef cattle (0.34) (12). Thiscould indicate that most of the amino acids absorbed from the guinea pig diet, were availablefor protein synthesis, rather than being used for other metabolic processes, such as gluconeogenesis (14).

On the other hand, based on the protein digestibility coefficient of 84.5% obtained with themaintenance feeding level (table 2, page XXX), the amount of DP_m was determined to be 5.34 g/kg $EBW^{0.75}$. When comparing this result with the DP_m requirements for rabbits in the growingand finishing stages, which were 2.14 and 2.11 g/kg $BW^{0.75}$ respectively (23), notable differences exceeding 50% are observed. Parigi-Bini *et al.* (1992) report a DP_m requirement of 3.8 g/kg $BW^{0.75}$ for meat production rabbits, the latter value being the closest to the 5.34 found in this study, but still higher by 24%. The higher DP_m requirementsin guinea pigs can be attributed to the fact that small herbivorous mammals such as guinea pigs according to Sakaguchi (2003) have a higher energy and protein demand per unit of body mass than larger herbivorous animals such as rabbits. However, it should be noted thatthis value can be directly affected by protein digestibility.

Conclusions

The requirements of NP_m and NP_g in male guinea pigs of the Peru breed were 3.97 (g/kg $EBW^{0.75}$) and 2.5 (g/kg $EBW^{0.75}$), respectively. These values exceed some of those proposed for rabbits, but they align with the concept that small animals have higher requirements in terms of metabolic weight.

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