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Kinetic parameters of in situ degradability of crop residues in alpacas (*Vicugna pacos*)

Parámetros cinéticos de la degradabilidad in situ de residuos de cosecha en alpacas (*Vicugna pacos*)

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Abstract

The aim of this study was to determine the kinetic parameters of the *in-situ* degradability of dry matter (DM), crude protein (CP) and neutral detergent fibre (NDF) of crop residues (CR) of barley (*Hordeum vulgare* L), oats (*Avena sativa* L), peas (*Pisum sativum* L), quinoa (*Chenopodium quinoa* W) and beans (*Vicia faba* L) from the Huancavelica area, Peru. Two fistulated alpacas in the first stomach compartment were used. For the statistical analysis, the blocks were represented by the alpacas, the treatments by the CR and the subplots by the incubation times. Grounded CRs (5 g) were placed in nylon bags and incubated for 0, 12, 24, 48 and 72h, and the analysis of DM, CP and NDF was conducted. The parameters of degradability were estimated by non-linear regression D(t) = a+b(1-exp(-c*t)), the potential degradability was determined by D(p) = a+b, and effective degradability by D(e) = a+(b*c)/(c+k). Oats and quinoa had the highest DM percentages. CP content ranged from 2% for barley to 14.1% for beans. The NDF content was 34.94 % for beans, reaching 90.19 % for barley. There was an interaction effect of CR and incubation time on the degradability of the DM, CP and NDF. The degradability of these nutrients was influenced by the crop residues. The highest D(p) of the DM was for the pea (82.96%), followed by oats (79.26 %) and beans (75.47 %). The D(e) of the NDF was higher for beans of 37.96, 33.33 and 31.13 % in the passage rates of 3, 5 and 7 %/h, respectively. The high non-degradable fraction of the NDF (40.20 %) of the quinoa is highlighted and, therefore, the low D(p) of the DM (49.13%). The content of NDF and its kinetic characteristics exert a marked effect on the digestion of the CR under study.

Resumen

El presente trabajo tuvo como objetivo determinar los parámetros cinéticos de la degradabilidad in situ de la materia seca (MS), proteína cruda (PC) y fibra detergente neutro (FDN) de los residuos de cosecha (RC) de cebada (*Hordeum vulgare* L), avena (*Avena sativa* L), arveja (*Pisum sativum L*), quinua (*Chenopodium quinoa* W) y habas (*Vicia faba L*) de la zona de Huancavelica, Perú. Se utilizaron dos alpacas con fístula en el primer compartimento estomacal. Para el análisis estadístico, los bloques fueron representados por las alpacas, los tratamientos por los RC y las subparcelas por los tiempos de incubación. Los RC molidos (5 g) fueron colocados en bolsitas de nylon e incubados por 0, 12, 24, 48 y 72 h, y se analizó la MS, PC y FDN. Los parámetros de degradabilidad fueron estimados por regresión no lineal D(t)=a+b(1-exp(-c*t)), la degradabilidad potencial fue determinada mediante D(p)=a+b, y degradabilidad efectiva mediante D(e)=a+(b*c) /(c+k). La avena y la quinua presentaron los mayores porcentajes de MS. El contenido de PC varió de 2 % para la cebada a 14.1 % para las habas. El contenido de FDN fue de 34.94 % para las habas, llegando a 90.19 % para la cebada. Hubo efecto de la interacción de RC y tiempo en la degradabilidad de la MS, PC y FDN. Las degradabilidades de estos nutrientes fueron influenciadas por los residuos de cosecha. La mayor D(p) de la MS fue para la arveja (82.96 %), seguidos por la avena (79.26 %) y habas (75.47 %). La D(e) de la FDN fue mayor para habas de 37.96, 33.33 y 31.13 % en las tasas de pasaje de 3,

Palabras clave:

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cebada,
degradación in situ,
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valor nutritivo.

5 y 7 %/h, respectivamente. Se destaca la elevada fracción no degradable de la FDN (40.20 %) de la quinua y, por tanto, la baja D(p) de la MS (49.13 %). El contenido de FDN y sus características cinéticas ejercen acentuado efecto sobre la digestión de los RC en estudio.

Introduction

In extensive livestock production systems in the highlands of Peru, animals feed on low-quality, unimproved pastures, which translates into low animal productivity. However, some studies have shown that crop residues and agribusiness by-products can be used to supplement grazing animals and that the nutritional value of the residues can be improved through proven treatment procedures[1,2].

The nutritional value (NV) of a food is essentially determined by its energy and protein value, the former is closely related to the chemical composition and digestibility of organic matter[3]. Mathematically, it can be expressed: NV = dry matter intake (DM) x% nutrient x% nutrient digestibility[4]. Therefore, the NV of foods can allow the adaptation of diets that optimize product performance, which reduce production costs, as well as the reduction of energy losses, nitrogen compounds (N) associated with digestion, and metabolism of the nutrients[5]. On the other hand, the NV of coarse foods is affected by the forage species, plant age, time of year, soil fertility, mode of use[5-7], finding a great variability in its chemical-bromatological composition, in the degradation rate of its components.

The reduction of the NV with the development of the plant is a function of the decrease in the protein and phosphorus contents or by the increase of the stem/leaf ratio[5], giving rise to an elevation of the components of the cell wall, nutritionally called fiber neutral detergent (NDF). From a nutritional point of view, carbohydrates can be classified into non-fibrous carbohydrates (NFC) or cellular content plus pectin, fibrous carbohydrates (FC or NDF). The former present rapid, complete, and constant nutritional availability among foods (98-100 %)[8], while the FC (cellulose and hemicellulose), which constitute the plant cell wall, generally present slow and incomplete digestion, occupy space in the gastrointestinal tract[9,10]. This fraction is responsible for the variation in the digestion and consumption of food, especially of tropical forage species.

For the adequacy of diets for ruminants, information is required on the proportions of feed fractions and digestion rates[11] in order to synchronize the availability of energy and nitrogen in the rumen, maximize microbial efficiency, feed digestion, and the reduction of losses resulting from ruminal fermentation[6,12].

In vivo, in vitro, or in situ methods are used for food evaluation. This last technique has been used to estimate food degradation, due to its easy execution, speed, precision, and lower cost compared to in vivo techniques[6,13,14].

Understanding the chemical and nutritional characteristics of crop residues would help design optimal utilization strategies on farms and at the national

level. In Peru, the information available on the chemical composition and nutritional value of crop residues is scarce. Therefore, the objective of this study was to determine the kinetic parameters of the degradability of dry matter, crude protein, and neutral detergent fiber of the harvest residues of oats, barley, peas, quinoa, and beans in the first stomach compartment of the plant. alpaca.

Materials and methods

The experiment was developed in the Laboratory of Animal Nutrition and Food Evaluation of the National University of Huancavelica (NUH), located in the district, province, and region of Huancavelica, Peru, at 3680 masl[15].

For the in situ degradability study, two 2-year-old male Huacaya alpacas (*Vicugna pacos*) were used, dewormed, fistulated in the first stomach compartment, with an average body weight of 45 kg. The alpacas received 300 g/day of chopped green forage oats and 150 g of harvest residue mixture (HR) for 15 days. The following days they were fed with a mixture of HR and forage oats (hay) (60:40), at 8 and 16 h. The animals remained confined throughout the experimental period, in individual pens, constructed of metal with polyethylene shades and wooden floors.

HR were collected from barley (*Hordeum vulgare* L), oats (*Avena sativa* L), peas (*Pisum sativum* L), quinoa (*Chenopodium quinoa* Willd), and broad beans (*Vicia faba* L) from the provinces of Acobamba and Tayacaja, Huancavelica, in June 2018. The waste consisted of the material that was left after the seeds or pods had been removed by the owners. The residues were cut and chopped into fractions between 2 and 5 cm, using a MAQUIAGRO brand forage chopper to later be taken to the laboratory for its chemical-bromatological analysis, and for the study of in situ degradability according to the methodology of Ørskov & McDonald[16].

For the chemical-bromatological analysis, six subsamples of each treatment (10 % of the HR) were collected, they were mixed, obtaining a sample per treatment of 100 g. for degradability tests. The material for laboratory analysis and incubation was ground in a Retsch mill, leaving 2 mm diameter particles.

The dry matter (DM)[17], crude protein (CP), and NDF[18] determinations were made according to Silva & Queiroz[19]. Proportional samples of each repetition and by individual treatment were mixed to obtain a composite sample of each residue. These samples were destined for incubation in the first compartment of the stomach of each alpaca.

For incubation, 5 x 10 cm nylon bags with a pore opening of 50 µm20-22 were used, which were placed in an oven at 60 ºC for 12 h, and then weighed. 5 g of air-dry sample, closed with rubber bands, were placed in each bag. Duplicate samples were used for each incubation time per animal. The sacks were placed in a bucket with water for 12 min prior to placing the sacks in the first compartment of the alpacas' stomach.

Incubation periods of 12, 24, 48, and 72 h were used. The time 0 sacks were placed in the bucket with water and subsequently washed with running water, but they were not incubated. All the sacks were placed together in the first compartment of the stomach of the fistulated alpacas and were removed according to the established incubation times. Once removed, they were thoroughly washed in running water to remove material particles adhering to the external surface. The material was placed in a 222-liter capacity

MMM-Venticell stove with forced ventilation at 60 ºC for 24 h and was subsequently weighed with the help of a precision balance 0.01 g capacity of 1620 g Ohaus brand.

It was used subdivided plots conducted in a completely randomized block design, the two alpacas represented the blocks, the HR the treatments (plots), and the six incubation times of the residues the subplots. The analysis was performed according to the statistical model: Yijk = μ + Bi + Rj + εij + Tk + R x Tjk + εijk, where Yijk = the observation relative to HR (j) in combination with time (k) in the Block I); μ = the general mean, Bi = effect of block i (animal), Rj = effect of level j of factor R (HR), εij = experimental error of the plot, Tk = effect of level k of factor T (time), R x Tjk = effect of the interaction of factor R with factor T, εijk = experimental error relative to the sub-plot. The in situ degradability data of the DM, CP, and NDF of the HR were determined by the difference between the weight of the incubated samples and the weight of the DM, CP, and NDF residues after the incubation time, and expressed in percentages 23.

The information regarding the in-sack degradability of the HR of agricultural crops evaluated was subjected to analysis of variance by the GLM procedure of the statistical program SAS v. 9.2 for Windows®24, considering the animal, the harvest residues, and the incubation time.

The weight loss observed in DM, CP, and NDF at each incubation time was considered as potential degradability. With the Solver application of Microsoft Excel, the corresponding degradation rates were calculated, using the mathematical model[14,25,26]: D (t) = a + b (1-exp (-c * t)), where D (t) = amount of food that disappears from the sacks at incubation time t, a = rapidly degradable fraction (%), b = slowly degradable fraction (%), c = digestion of fraction b at the constant fractional rate (h- 1), and t = time (hours)[27-30].

The effective degradability (De) of the DM, PC, and NDF of the CR in the first compartment of the stomach of the alpaca was calculated using the equation by Carvalho et al.[13]: De = a + (b * c/c + k), where: De = effective degradability, k = is the estimated rate of passage of the particles, and a, b and c are the same components of the previous equation[13].

Results

Regarding the chemical-bromatological composition of the CR of agricultural crops (table 1), it was oats and quinoa that presented the highest DM percentages.

Regarding CP content, broad bean and barley residues were those that presented the highest and lowest crude protein content (14.10 vs. 2.15%, table 1), notable differences between a legume and a grass.

Table 1 Dry matter (DM), crude protein (CP) and neutral detergent fiber (NDF) levels obtained in barley, oats, peas, quinoa and broad bean harvest residues

Harvest residue	DM (%)	CP (% MS)	NDF (% DM)
Peas	93.33	10.41	68.05
Oats	96.74	7.87	62.92
Barley	88.80	2.15	90.19
Beans	93.04	14.10	34.94
Quinoa	96.51	3.92	89.92

Table 2 Summary of the analysis of variance of the degradability of dry matter (DM), crude protein (CP) and neutral detergent fiber (NDF) of the harvest residues of five agricultural crops in the first compartment of the stomach of the alpaca, in animal function and incubation time

Variation source	LG	Mean squares		
		DM	CP	NFD
Animal	1	ns	ns	ns
RC (R)	4	***	***	***
Error (a)	4			
Plot	9			
Time (T)	4	***	***	***
R x T	16	***	***	***
(Treatments)	25			
Time/pea residue	4	***	***	***
Time/oat residue	4	***	***	***
Time/barley residue	4	***	***	***
Time/bean residue	4	***	***	***
Time/quinoa residue	4	***	***	***
Residue/time 0	4	***	***	***
Residue/time 12	4	***	***	***
Residue/time 24	4	***	***	***
Residue/time 48	4	***	***	***
Residue/time 72	4	***	***	***
Error (b)	20			
Error total	49			
VC (%)		4.34	2.56	6.62

*** p <0.001; ns: not significant.

The decrease in DM ranged from 4.96 to 44.56% and from 25.50 to 79.28% for barley and broad bean, respectively, between the incubation period of 0 and 72 h. DM degradability at 72 h of incubation was 43.71, 64.39, and 68.57% for quinoa, oats, and peas, respectively (table 3).

The estimates of the coefficients a, b, and c of the equations adjusted for the potential degradabilities, according to the first-order asymptotic model of the MS, PC, and FDN are presented in table 4.

However, these residues showed higher coefficients (b) (part insoluble, but potentially degradable) in relation to the residues of broad beans and quinoa, probably due to their higher fiber content. In the case of the degradation rates of the potentially degradable fraction (c), the residues showed similar behaviors (1.79, 1.91, 1.55, and 2.28% / h), except for the bean residue which was higher (7.21% / h).

The degradability of PC (table 3) ranged from 63.94 to 91.41% for barley and oats, respectively, at 72 h of incubation.

In the soluble fraction (a) of the NDF, differences were observed between the CRs, with beans the highest fraction (24.92%) and oats the lowest fraction (3.67%) (table 4). The pea and quinoa residues presented similar coefficients (a) (16.29 vs. 13.73%). The highest potential degradability values of DM were observed in pea residues (82.96%), while the lowest potential degradability was registered for quinoa residues (49.13%, table 5), with a non-degradable fraction (i) of 50.87% DM (table 4).

Table 3 Average percentages of the disappearance of dry matter (DM), crude protein (CP) and neutral detergent fiber (NDF) of the harvest residues of agricultural crops of barley, oats, peas, quinoa and beans, depending on at incubation time

Harvest residues	Incubation time (h)				
	0	12	24	48	72
Dry matter disappearance (DM)					
Peas	25.64	31.06	52.26	53.44	68.57
Oats	14.33	28.92	40.36	50.60	64.39
Barley	4.96	21.73	23.56	30.13	44.56
Beans	25.50	57.53	64.39	70.05	79.28
Quinoa	18.72	22.44	34.73	36.81	43.71
Crude protein disappearance (CP)					
Peas	47.10	59.91	76.48	80.38	90.80
Oats	33.65	56.42	71.3	83.24	91.41
Barley	11.53	30.54	38.14	49.49	63.94
Beans	33.21	65.65	75.00	81.59	89.64
Quinoa	36.01	46.66	63.84	70.32	78.27
Disappearance of neutral detergent fiber (NDF)					
Peas	15.65	23.99	35.20	36.74	56.86
Oats	8.55	10.34	11.66	25.74	45.91
Barley	4.59	20.76	20.97	27.25	41.85
Beans	24.61	29.85	37.76	41.98	53.39
Quinoa	14.77	16.24	28.82	32.35	40.53

Table 4 Degradability of dry matter (DM), crude protein (CP) and neutral detergent fiber (NDF) of crop residues incubated in the first compartment of the alpaca's stomach, as a function of incubation time and the respective coefficients of determination (R^2)

Harvest residues	Parameter				R^2
	A	B	c	i	
Dry matter degradability (DM)					
Peas	24.77	58.19	1.79	17.04	0.92
Oats	15.11	64.15	1.91	20.74	0.99
Barley	7.79	51.21	1.55	41.00	0.93
Beans	26.17	49.31	7.21	24.53	0.97
Quinoa	17.99	31.14	2.28	50.87	0.94
Crude protein degradability (CP)					
Peas	46.79	46.63	3.33	6.58	0.96
Oats	33.81	60.32	3.90	5.87	0.99
Barley	13.26	62.41	2.11	24.33	0.98
Beans	33.76	53.06	6.85	13.18	0.98
Quinoa	35.19	47.86	3.07	16.95	0.98
Neutral detergent fiber degradability (NDF)					
Peas	16.29	83.71	0.81	0.00	0.92
Oats	3.67	96.32	0.65	0.00	0.89
Barley	7.87	61.27	1.02	30.86	0.90
Beans	24.92	75.07	0.63	0.00	0.97
Quinoa	13.73	46.07	1.18	40.20	0.94

A: water soluble fraction (%), B: potentially degradable water insoluble fraction (%), c: Kd = degradation fraction rate (h-1) (% / hour),
R^2: coefficient of determination; i: non-degradable fraction (%)

Degradation potentials of the DM of the pea and broad bean residues of 82.96 and 75.47 % were observed, the disappearance of the DM at 12 h of 36.00 vs 54.72 %, and maximum disappearance of degradation at 72 h of 66.88 and 75.20 %, respectively. -mind. These differences in the degradation of DM in

the first behavior of the alpaca's stomach may be an important factor influencing animal consumption.

Table 5 shows the values of the effective degradability of DM, CP, and NDF of agricultural crop residues. The effective degradability's of DM at the passage rates of 3, 5, and 7 %/h were higher for the broad bean residues in relation to the other residues.

The potential degradability values of CP were higher than 80 %, except for barley (75.67 %) (table 5). These figures indicate a good potential for microbial nitrogen production, despite the low CP contents, especially from barley and quinoa residues (table 3).

Except for barley, more than 60 % of CP degradability occurred after 12 h of incubation. At 72 h of incubation, pea, oat, broad bean, and quinoa residues showed CP degradability of 89.20, 90.50, 86.44, and 77.79 %, respectively. In this incubation time in barley, 62.04 % degradability of PC was observed.

Table 5 Potential and effective or actual degradability of dry matter (DM), crude protein (CP) and neutral detergent fiber (NDF) of the harvest residues of five agricultural products

Harvest residues	Potential degradability[1]	Effective degradability		
		Passage rate (%/h) [a]		
		3	5	7
		Dry material (%)		
Peas	82.96	46.49	40.04	36.60
Oats	79.26	40.04	32.83	28.85
Barley	59.00	25.26	19.92	17.09
Beans	75.47	60.99	55.29	51.19
Quinoa	49.13	31.46	27.75	25.66
		Crude protein (%)		
Peas	93.42	71.35	65.45	61.84
Oats	94.13	67.92	60.26	55.40
Barley	75.67	39.05	31.80	27.73
Beans	86.82	70.66	64.43	60.00
Quinoa	83.05	50.39	53.39	49.77
		Neutral detergent fiber (%)		
Peas	100	34.17	28.02	25.02
Oats	100	20.95	14.85	11.93
Barley	69.14	23.44	18.27	15.68
Beans	100	37.96	33.33	31.13
Quinoa	59.80	26.80	22.57	26.41

[a] Passage rates (K) of 3, 5 and 7 (% / hour) are assumed 31 1 Rapidly degradable fraction or fraction soluble in water (a, %) + slowly degradable fraction, or potentially degradable water insoluble fraction (b, %)

The potential degradability values of PC were higher than 80%, except for barley (75.67 %) (table 5). These figures indicate a good potential for microbial nitrogen production, despite the low CP contents, especially from barley and quinoa residues (table 3).

Except for barley, more than 60% of CP degradability occurred after 12 h of incubation. At 72 h of incubation, pea, oat, broad bean, and quinoa residues showed CP degradability of 89.20, 90.50, 86.44, and 77.79 %, respectively. In this incubation time in barley, 62.04 % degradability of CP was observed.

The effective degradability's of CP in the passage rates of 3, 5, and 7 % / h were higher for pea residues (71.35, 65.45, and 61.84 %/h, respectively), in relation to the other residues under study (table 5). Observing values of effective degradability of CP, it can be inferred that the residues of oats, barley, broad beans, and quinoa presented low values of (a) and (b)

high and (c) low, with the exception of the residue of broad beans (c : 6.85).

The bean residue had the highest soluble fraction (a) (24.92 %), while oats had the lowest value (3.67 %). For the part insoluble in water, but potentially degradable b, it was observed that the oat residue showed the highest fraction (96.32 %) and quinoa the lowest (46.07 %). In the case of degradation rate c, all the wastes presented very low rates.

The disappearance curve of the NDF shows that the CRs differ in terms of the rate of disappearance. Up to 48 h of incubation in the first compartment of the alpaca's stomach, the NDF degradation values remained close to 45 % in the pea and broad bean residues. From this time on, the observed values continued to be higher for these residues (53.44 vs 52.31). In contrast, in the residues of oats, barley, and quinoa the degradation values (up to 72 h) were 29.69, 31.64, and 33.75 %, respectively.

The effective degradability of the NDF differed among the residues and presented a maximum amplitude of 17.01, 18.48, and 19.20 % in the passage rates of 3, 5, and 7 %/h, respectively. Harvest residues of oats, peas, and broad beans had CP contents higher than 7 %, mean NDF contents higher than 60 %, except for the bean residue (34.94 %). Barley and quinoa between 2 and 4 % of CP, and around 90 % of NDF.

The pea, oat, and broad bean residues presented potential degradability coefficients of DM higher than 75 %. The potential degradability of the PC of the residues was observed values higher than 75 %.

The values of the indigestible fraction of NDF were above 30 % for barley and quinoa residues. Barley presented values higher than 20 and 40 % of the indigestible fraction of CP and DM. Therefore, they must be observed and considered in the adaptation of diets in alpacas.

The effective degradability of CP and NDF was similar among the residues at the passage rates of 3, 5, and 7 %/h.

Discussion

The data observed on the DM content of the barley was lower in relation to the other residues, and could also be a characteristic of the residue. The value of 88.75 % of DM of barley is close to the figure of 91.7 % obtained by Gallar-do[32]. However, it is close to the 91.01 % DM value reported by Haile[33].

Gallardo[32], obtained CP content in beans and barley of 16.3 and 3.7 %, respectively. On the other hand, the bean residue had the lowest fiber content (34.94 %) compared to the other residues (table 1), a value that agrees with the 33.3 % of NDF[32], while the residue with the highest fiber content was the barley (90.19 %). Haile et al.[33], reported CP values (6.71 %) of barley higher than those found in the present study. However, they obtained 73.8 % of NDF, which is lower than our results.

The small variations that exist in the chemical composition of the different HR carried out in this study in relation to other investigations can be attributed to the differences in varieties, the proportion of botanical fractions, cultivation conditions (geographical and seasonal variations, climatic conditions, and characteristics of the soil), degree of foreign matter and impurities such as soil contamination, different measurement methods, and laboratory procedures[34,35].

The values of the water-soluble fraction (a) of pea and broad beans residues (table 4) were relatively high for DM. Vieira et al.[36] indicated values of 33, 22, and 29 % of fraction (a), for the fruit peels of three varieties of passion fruit. Considering that fraction (a) represents the portion of the forage that is readily available for the microorganisms of the first stomach of the alpaca, the barley and oat residues presented lower values (7.79 and 15.11 %, respectively) for DM.

Vieira et al.[36] reported degradation rates (c) that varied between 9 and 10 % / h for the ruminal degradability of the fruit peels of passion fruit varieties. For napier and cameron elephant grass hay and rice straw, Vieira et al.[36] indicated degradation rates of 4.0, 3.7, and 2.7 %, respectively. Pires et al.[37] workings with fattening straw containing 40 % moisture when evaluating the degradability of DM, verified for fractions (a), (b), and (c) values of 20.23, 60.82, and 1.95 %, respectively. These results show great variation for the values of the soluble and insoluble fractions and the rate of degradation of forages. Also, in barley, Haile et al.[33] indicated values of 15.1, 25.3, and 0.04 % for the fractions of a, b and c, respectively. The differences between the values presented in the other studies and those obtained in the present one could probably be attributed to the use of different crop varieties evaluated in the studies.

According to the NRC[38], the degradation rate of the potentially degradable fraction of the protein ranges from 2 to 8 %/h. Despite the variations in fractions (a) and (b), the CP degradation rates in %/h (fraction c) remained constant (3.33, 3.90, 3.07 %/h) in pea residues, oats and quinoa, similar behavior of DM, whose fractions (c) were 1.79, 1.91 and 2.28 %/h, respectively. The fraction of PC soluble in water (a) in the pea residue presented a high value (46.79 %), comparable with the 54.0% reported by Vieira et al.36. In the barley residue, the lowest fraction of the water-soluble PC was verified (table 1).

The fraction (a) of oats in the study by Vieira et al.[36] with fruit peels from three varieties of passion fruit was between 2 and 5 %. In the NDF, the highest value of (a) was observed for beans (24.92 %), whose NDF content (34.94 %) was lower in relation to the other residues under study (table 1). In the case of values (b), the variation was between 46.07 and 96.32 % for the residues of quinoa and oats, respectively, while Vieira et al.[36] reported 48 % for the peels of the red variety of passion fruit, a similar value that of quinoa in the present study. Nilsen et al.[39] for NDF in barley reported values of 41.6, 50.6, and 0.060 % for the fractions of a, b and c, respectively, while for quinoa they obtained values of the fractions a, b, and c of 50.2, 39.6, and 0.078 %, respectively. These differences could be attributed to differences in leaf and stem ratio, animal and diet effects, particle size, incubation characteristics, rumen conditions, and microbial contamination[40].

The potential degradability of the DM of pea was similar to that obtained by Carvalho et al.[13] for *Pennisetum purpureum* Schum silages. Although the DM degradation potentials of quinoa and oat residues differ (49.13 vs 79.26 %), until the first 12 h, the DM disappearance values in the first performance (C1) at the rumen level of the alpaca were similar (25.46 vs 28.24 %). According to the non-linear equation pro-

posed by Ørskov & Mcdonald[16], the maximum degradation potentials of the DM of the quinoa and oat residues at 72 h of incubation were 43.12 and 63.02 %, respectively.

Rodríguez et al.[41] suggest that the high proportion of carbohydrates in the cell wall and the lignin content of the forage are the main causes of the lower degradability. Thus, the high NDF contents of barley and quinoa, around 90 %, are probably responsible for this form of behavior in the observed degradability. The high non-degradable fraction of the CP of barley may be related to a possible higher content of nitrogen insoluble in acid detergent (NIAD), related to the higher lignin content and NDF of the barley[42].

Vieira et al.[36] observed high values of the effective degradability of CP (68.89 to 80.83 %/h) in the peels of the fruit of passion fruit varieties, at a passage rate of 4.8 %. Sarti et al.[42], on the other hand, also observed CP effective degradability values of 66.8, 58.2, and 54.3 % in *P. purpureum* Schum silages at the passage rates of 2, 5, and 8 %/h, respectively.

According to Rodríguez et al.[41], values of 100 or of (c) less than 0.01 indicate the inadequacy of the model to the observed points or atypical responses (experimental error), giving rise to estimates of effective degradability that must be treated with due restriction. The non-degradable fraction (i) was higher for barley and quinoa residues (30.86 vs 40.20 %), showing that they have lower fiber quality.

The potential degradability of the NDF of the barley residue was higher than that of the quinoa (69.14 vs 59.80), which may be related to the high NDF contents. As in this study, Carvalho et al.[13] suggest that high crystalline cellulose and lignin contents of the cotton hull promote the slow disappearance of NDF in situ tests.

The degradation rates (fraction c) in all the residues were very low between 0.006 and 0.011 %/h (table 4). According to Carvalho et al.[13], for the forages to be considered of quality, their NDF degradation rates must be between 2 and 6 %/h, so that none of the residues understudy could be considered of quality. On the other hand, the potential degradabilities of NDF for pea, oat, and broad bean residues were 100 %, values that could be considered as erratic values. For the NDF content at a passage rate of 5 %, there is no similarity with the results of Vieira et al.[36] where the highest degradability was 45.83 % and the lowest was 34.61 % for the peels of the passion fruit of the mixture of equal parts of the yellow and red varieties, at a rate of passage of 4.8 %/h.

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Conflicts of interest

The authors declare that there is no conflict of interest.

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Ethical considerations

The animal welfare requirements have been met for the execution of the said study.

Authors' contribution to the article

Contreras Paco José Luis was dedicated to carrying out the laboratory analysis and author of the study with harvest residues, *Condori Yauri Cesar Javier* carried out the collection of samples and the execution of biological tests, *Poma Yaranga Javier* carried out the collection of samples and the execution of the biological tests, *Cordero Fernández Alfonso Gregorio* contributed in the statistical data processing, *De la Cruz Rojas Yhan Carlos* prepared the preliminary drafting of the manuscript.

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